CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This technical support document (TSD) is a stand-alone report that provides the technical analyses and results supporting the development of the final rule for residential refrigeration products.

1.2 SUMMARY OF NATIONAL BENEFITS (ANNUALIZED)

The benefits and costs of today's proposed standards can be expressed in terms of annualized values over the 30-year analysis period (2014–2043). Estimates of annualized values are shown in Table 1.2.1 The annualized monetary values are the sum of (1) the annualized national economic value, expressed in 2009$, of the benefits from operating products that meet the proposed standards (consisting primarily of operating cost savings from using less energy, minus increases in equipment purchase costs, which is another way of representing consumer NPV), and (2) the monetary value of the benefits of emission reductions, including CO_2 emission reductions.[a] The value of the CO_2 reductions, otherwise known as the Social Cost of Carbon (SCC), is calculated using a range of values per metric ton of CO_2 developed by a recent interagency process. The derivation of the SCC values is discussed in appendix 16-A of this TSD.

Although combining the values of operating savings and CO_2 reductions provides a useful perspective, two issues should be considered. First, the national operating savings are domestic U.S. consumer monetary savings that occur as a result of market transactions while the value of CO_2 reductions is based on a global value. Second, the assessments of operating cost savings and CO_2 savings are performed with different methods that use quite different time frames for analysis. The national operating cost savings is measured for the lifetime of refrigeration products shipped in 2014–2043. The SCC values, on the other hand, reflect the present value of future climate-related impacts resulting from the emission of one ton of carbon dioxide in each year. These impacts go well beyond 2100.

[a] DOE used a two-step calculation process to convert the time-series of costs and benefits into annualized values. First, DOE calculated a present value in 2011, the year used for discounting the NPV of total consumer costs and savings, for the time-series of costs and benefits using discount rates of three and seven percent for all costs and benefits except for the value of CO_2 reductions. For the latter, DOE used a range of discount rates, as shown in Table 1.2.1. From the present value, DOE then calculated the fixed annual payment over a 30-year period, starting in 2011, that yields the same present value. The fixed annual payment is the annualized value. Although DOE calculated annualized values, this does not imply that the time-series of cost and benefits from which the annualized values were determined would be a steady stream of payments.

Table 1.2.1 Annualized Benefits and Costs of Proposed Standards for Refrigeration Products Shipped in 2014-2043

	Discount Rate	Primary Estimate*	Low Net Benefits Estimate*	High Net Benefits Estimate*
		Monetized (million 2009$/year)		
Benefits				
Operating Cost Savings	7%	2275	1996	2560
	3%	3160	2720	3596
CO_2 Reduction at $4.9/t**	5%	162	162	162
CO_2 Reduction at $22.1/t**	3%	515	515	515
CO_2 Reduction at $36.3/t**	2.5%	772	772	772
CO_2 Reduction at $67.1/t**	3%	1567	1567	1567
NO_X Reduction at $2,519/ton**	7%	21	21	21
	3%	28	28	28
Total (Operating Cost Savings, CO_2 Reduction and NO_x Reduction)†	7% plus CO_2 range	2457 to 3863	2178 to 3584	2742 to 4148
	7%	2810	2531	3095
	3%	3703	3263	4139
	3% plus CO_2 range	3350 to 4755	2910 to 4315	3786 to 5192
Costs				
Incremental Product Costs	7%	1167 to 1569	1480	1232
	3%	1081 to 1526	1430	1147
Net Benefits				
Total†	7% plus CO_2 range	888 to 2696	698 to 2103	1511 to 2916
	7%	1241 to 1643	1051	1863
	3%	2176 to 2622	1832	2993
	3% plus CO_2 range	1823 to 3674	1479 to 2885	2640 to 4045

* The Primary, Low Benefits, and High Benefits Estimates utilize forecasts of energy prices and housing starts from the AEO2010 Reference case, Low Estimate, and High Estimate, respectively. In addition, incremental product costs reflect a medium decline rate for product prices in the Primary Estimate, a low decline rate for product prices in the Low Benefits Estimate, and a high decline rate for product prices in the High Benefits Estimate. The derivation of trends for product prices is explained in section IV.G.3. In the Primary estimate, the range of results for incremental product costs reflects the range of product price forecasts.

** The CO_2 values represent global monetized values (in 2009$) of the social cost of CO_2 emissions in 2010 under several scenarios. The values of $4.9, $22.1, and $36.3 per metric ton (t) are the averages of SCC distributions calculated using 5%, 3%, and 2.5% discount rates, respectively. The value of $67.1/t represents the 95^{th} percentile of the SCC distribution calculated using a 3% discount rate. The value for NO_X (in 2009$) is the average of the low and high values used in DOE's analysis.

† Total benefits for both the 3-percent and 7-percent cases are derived using the SCC value calculated at a 3-percent discount rate, which is $22.1/ton in 2010 (in 2007$). In the rows labeled as "7% plus CO_2 range" and "3% plus CO_2 range," the operating cost and NO_X benefits are calculated using the labeled discount rate, and those values are added to the full range of CO_2 values.

1.3 OVERVIEW OF STANDARDS FOR RESIDENTIAL REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS

The Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163 (42 United States Code (U.S.C.) 6291–6309), established an energy conservation program for major household appliances. The National Energy Conservation Policy Act of 1978 (NECPA), Pub. L. 95-619, amended EPCA to add Part C[b] of Title III (42 U.S.C. 6311–6317), which established an energy conservation program for certain industrial equipment. Additional amendments to EPCA give DOE the authority to regulate the energy efficiency of several products, including residential refrigerators, refrigerator-freezers, and freezers—the products that are the focus of this document. The amendments to EPCA in the National Appliance Energy Conservation Act of 1987 (NAECA), Pub. L. 100-12, established energy conservation standards for refrigerators, refrigerator-freezers, and freezers, as well as requirements for determining whether these standards should be amended. (42 U.S.C. 6295(b))

NAECA first established performance standards for residential refrigerators, refrigerator-freezers, and freezers, and further required that DOE conduct two cycles of rulemakings to determine if more stringent standards are justified.[c] (42 U.S.C. 6295(b)) On November 17, 1989, DOE published a final rule in the *Federal Register* updating the performance standards; the new standards became effective on January 1, 1993. 54 FR 47916. Subsequent to this final rule, DOE determined that new standards for some of the product classes were based on incomplete data and incorrect analysis. As a result, DOE published a correction that amended the new standards for three product classes: (1) refrigerators and refrigerator-freezers with manual defrost, (2) refrigerator-freezers—automatic defrost with bottom-mounted freezer but without through-the-door (TTD) ice service, and (3) chest freezers and all other freezers. 55 FR 42845 (Oct. 24, 1990). DOE updated the performance standards once again for refrigerators, refrigerator-freezers, and freezers by publishing a final rule in the *Federal Register* on April 28, 1997. 62 FR 23102. The new standards became effective on July 1, 2001. By completing a second standards

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[b] Part C has been redesignated Part A-1

[c] Definition of "refrigerators", "refrigerator-freezers", and "freezers" is provided in chapter 3 of the TSD.

rulemaking, DOE had fulfilled its legislative requirement to conduct two cycles of standards rulemakings.

Stakeholders submitted a petition in 2004 requesting that DOE conduct another rulemaking to amend the standards for residential refrigerator-freezers. In April 2005, DOE granted the petition and conducted a limited set of analyses to assess the potential energy savings and economic benefit of new standards. DOE issued a report in October 2005 detailing the analyses.[1] The analysis examined the technological and economic feasibility of new standards set at Energy Star levels effective in 2005 for the two most popular product classes of refrigerators: top-mount refrigerator-freezers without TTD features and side-mount refrigerator-freezers with TTD features. DOE confined its updated analysis to these two classes because they accounted for a majority of current product shipments. Depending on assumptions about the impact that standards would have on market efficiency, DOE estimated that amended standards at the 2005 Energy Star levels would yield between 2.4 to 3.4 quads,[d] with an associated economic impact to the Nation ranging from a burden or cost of $1.2 billion to a benefit or savings of $3.3 billion.[e]

DOE published draft data sheets containing energy-savings potentials for refrigerator-freezers in October 2005 as part of its fiscal year 2006 schedule-setting process. These data sheets summarized the following in table format: (1) the potential energy savings from regulatory action in cumulative quads from 2010 to 2035, (2) the potential economic benefits or burdens, (3) the potential environmental or energy security benefits, (4) the status of required changes to test procedures, (5) other regulatory actions, (6) recommendations by interested parties, (7) evidence of market-driven or voluntary efficiency improvements, (8) regulatory issues, and (9) the 2005 priority. The data sheets for refrigerators and refrigerator-freezers were based on the October 2005 draft technical report analyzing potential new amended energy conservation standards for residential refrigerator-freezers described above. This report and the associated data sheets provided input to the setting of priorities for rulemakings activities. Other products were given a higher priority, and limited rulemaking work on refrigerators and freezers was carried out in the following years prior to the enactment of the Energy Independence and Security Act of 2007 (EISA).

EISA, signed into law on December 19, 2007, requires that DOE publish a final rule no later than December 31, 2010, to determine whether to amend the standards in effect for refrigerators, refrigerator-freezers, and freezers manufactured on or after January 1, 2014. As a result, DOE embarked on a standards rulemaking for these products to comply with the requirements of EISA.

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[d] A quad represents a quadrillion Btu (or 10^{15} Btu).

[e] Economic impact based on a discount rate of 7 percent real.

1.4 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

Under EPCA, when DOE is studying new or amended standards, it must consider, to the greatest extent practicable, the following seven factors (42 U.S.C. 6295 (o)(2)(B)(i)):

1) the economic impact of the standard on the manufacturers and consumers of the affected products;

2) the savings in operating costs throughout the estimated average life of the product compared to any increases in the initial cost or maintenance expense;

3) the total projected amount of energy savings likely to result directly from the imposition of the standard;

4) any lessening of the utility or the performance of the products likely to result from the imposition of the standard;

5) the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from the imposition of the standard;

6) the need for national energy conservation; and

7) other factors the Secretary considers relevant.

Other statutory requirements are set forth in 42 U.S.C. 6295 (o)(1)–(2)(A), (2)(B)(ii)–(iii), and (3)–(4) and 42 U.S.C. 6316(e).

DOE considers stakeholder participation to be a very important part of the process for setting energy conservation standards. Through formal public notifications (i.e., Federal Register notices), DOE actively encourages the participation and interaction of all stakeholders during the comment period in each stage of the rulemaking. Beginning with the Framework Document and during subsequent comment periods, interactions among stakeholders provide a balanced discussion of the information that is required for the standards rulemaking.

Before DOE determines whether or not to adopt a proposed energy conservation standard, it must first solicit comments on the proposed standard. (42 U.S.C. 6313(a)(6)(B)(i)) Any new or amended standard must be designed to achieve significant additional conservation of energy and be technologically feasible and economically justified. (42 U.S.C. 6313(a)(6)(A)) To determine whether economic justification exists, DOE must review comments on the proposal and determine that the benefits of the proposed standard exceed its burdens to the greatest extent practicable, weighing the seven factors listed above. (42 U.S.C. 6295 (o)(2)(B)(i))

After the publication of the framework document, the energy conservation standards rulemaking process involves three additional, formal public notices, which DOE publishes in the Federal Register. The first of the rulemaking notices is a NOPM, which is designed to publicly vet the models and tools used in the preliminary rulemaking and to facilitate public participation before the NOPR stage. The second notice is the NOPR, which presents a discussion of comments received in response to the NOPM and the preliminary analyses and analytical tools; analyses of the impacts of potential amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts of amended energy conservation standards; and the proposed energy conservation standards for each product. The third notice is the final rule, which presents a discussion of the comments received in response to the NOPR; the revised analyses; DOE's weighting of these impacts; the amended energy conservation standards DOE is adopting for each product; and the effective dates of the amended energy conservation standards.

In September 2008, DOE published a notice of public meeting and availability of the framework document. 73 FR 54089 (September 18, 2008). The framework document, *Rulemaking Framework for Residential Refrigerators, Refrigerator-Freezers, and Freezers*, describes the procedural and analytical approaches DOE anticipated using to evaluate the establishment of amended energy conservation standards for these products. This document is available at: http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/refrigerator_freezer_framework.pdf.

Subsequently, DOE held a public meeting on September 29, 2008, to discuss procedural and analytical approaches to the rulemaking. In addition, DOE used the public meeting to inform and facilitate involvement of interested parties in the rulemaking process. The analytical framework presented at the public meeting described the different analyses, such as the engineering analysis and the consumer economic analyses (i.e., the life-cycle cost (LCC) and payback period (PBB) analyses), the methods proposed for conducting them, and the relationships among the various analyses.

During the September 2008 public meeting, interested parties commented about numerous issues relating to each one of the analyses listed in Table 1.4.1. Comments from interested parties submitted during the framework document comment period elaborated on the issues raised during the public meeting. DOE attempted to address these issues during its preliminary analyses and summarized the comments and DOE's responses in chapter 2 of the preliminary TSD.

Table 1.4.1 Analyses Under the Process Rule

Preliminary Analyses	NOPR	Final Rule
Market and technology assessment	Revised preliminary analyses	Revised analyses
Screening analysis	Consumer sub-group analysis	
Engineering analysis	Manufacturer impact analysis	
Energy use analysis	Utility impact analysis	
Markups analysis	Environmental assessment	
Life-cycle cost and payback period analysis	Employment impact analysis	
Shipments analysis	Regulatory impact analysis	
National impact analysis		
Preliminary manufacturer impact analysis		

As part of the information gathering and sharing process, DOE organized and held interviews with manufacturers of the residential refrigerators, refrigerator-freezers, and freezers considered in this rulemaking as part of the engineering analysis. DOE selected companies that represented production of all types of products, ranging from small to large manufacturers, and included the Association of Home Appliance Manufacturers (AHAM) member companies. DOE had four objectives for these interviews: (1) solicit manufacturer feedback on the draft inputs to the engineering analysis; (2) solicit feedback on topics related to the preliminary manufacturer impact analysis; (3) provide an opportunity, early in the rulemaking process, to express manufacturers' concerns to DOE; and (4) foster cooperation between manufacturers and DOE.

DOE incorporated the information gathered during the engineering interviews with manufacturers into its engineering analysis (Chapter 5) and the preliminary manufacturer impact analysis (Chapter 12). Following the publication of the preliminary analyses and the preliminary public meeting, DOE held additional meetings with manufacturers as part of the consultative process for the manufacturer impact analysis conducted during the NOPR phase of the rulemaking.

DOE developed spreadsheets for the engineering, LCC, PBP, and national impact analyses for each product. For each product, DOE developed an LCC spreadsheet that calculates the LCC and PBP at various energy efficiency levels. DOE also developed a national impact analysis spreadsheet that calculates the national energy savings (NES) and national net present values (NPVs) at various energy efficiency levels. This spreadsheet includes a model that forecasts the impacts of amended energy conservation standards at various levels on product shipments. All of these spreadsheets are available on the DOE website for refrigerators and freezers (http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers.html).

1.5 STRUCTURE OF THE DOCUMENT

This Final Rule TSD outlines the analytical approaches used in this rulemaking. The TSD consists of seventeen chapters and nineteen appendices.

Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to this rulemaking, and outlines the structure of the document.
Chapter 2	Analytical Framework: describes the rulemaking process.
Chapter 3	Market and Technology Assessment: characterizes the market for the considered products and the technologies available for increasing equipment efficiency.
Chapter 4	Screening Analysis: identifies all the design options that improve efficiency of the considered products, and determines which technology options are viable for consideration in the engineering analysis.
Chapter 5	Engineering Analysis: discusses the methods used for developing the relationship between increased manufacturer price and increased efficiency.
Chapter 6	Markups for Equipment Price Determination: discusses the methods used for establishing markups for converting manufacturer prices to customer equipment prices.
Chapter 7	Energy Use Analysis: discusses the process used for generating energy-use estimates for the considered products as a function of efficiency levels.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: discusses the effects of standards on individual customers and users of the equipment and compares the LCC and PBP of equipment with and without higher efficiency standards.
Chapter 9	Shipments Analysis: estimates shipments of the refrigeration products over the 30-year analysis period (2014-2043), which is used in performing the national impact analysis (NIA).
Chapter 10	National Impact Analysis: assesses the national energy savings, and the national net present value of total consumer costs and savings, expected to result from specific, potential energy conservation standards for refrigeration products.

Chapter 11	Consumer Subgroup Analysis: discusses the effects of standards on different subgroups of consumers.
Chapter 12	Manufacturer Impact Analysis: discusses the effects of standards on the finances and profitability of product manufacturers.
Chapter 13	Employment Impact Analysis: discusses the effects of standards on national employment.
Chapter 14	Utility Impact Analysis: discusses selected effects of standards on electric and gas utilities.
Chapter 15	Environmental Assessment: discusses the effects of standards on emission of carbon dioxide, nitrogen oxides (NO_x), and mercury.
Chapter 16	Monetization of Emission Reductions Benefits
Chapter 17	Regulatory Impact Analysis: discusses the impact of non-regulatory alternatives to efficiency standards.
Appendix 4-A	Investigation of VIP Supply
Appendix 5-A	Engineering Data
Appendix 5-B	ERA Model Development and WinERA User Manual
Appendix 7-A	Literature Survey of Energy Consumption by Residential Refrigerator-Freezers
Appendix 7-B	Data for Estimating Distribution of Refrigerator and Freezer Size in the RECS Sample
Appendix 8-A	User Instructions for LCC and PBP Spreadsheets
Appendix 8-B	Uncertainty and Variability
Appendix 8-C	Consumer Retail Prices for Baseline Residential Refrigerator-Freezers and Freezers
Appendix 8-D	Household Discount Rate Distributions
Appendix 8-E	Estimation of Equipment Price Trends
Appendix 9-A	Relative Price Elasticity of Demand for Appliances

Appendix 10-A User Instructions for Shipments and NIA Spreadsheets

Appendix 10-B National Equipment and Operating Costs

Appendix 10-C National Net Present Value Using Alternative Price Trend Sensitivities

Appendix 12-A Manufacturer Impact Analysis Interview Guides

Appendix 12-B Government Regulatory Impact Model Overview

Appendix 12-C Federal Production Tax Credits

Appendix 16-A Social Cost of Carbon

Appendix 17-A RIA Supporting Materials

REFERENCES

1 U.S. Department of Energy. *Technical Report: Analysis of Amended Energy Conservation Standards for Residential Refrigerator-Freezers*. October 2005. <http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrigerator_report_1.pdf >

CHAPTER 2. ANALYTICAL FRAMEWORK

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CHAPTER 2. ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

Section 6295(o)(2)(A) of 42 United States Code (U.S.C.) requires the U.S. Department of Energy (DOE) to set forth energy conservation standards that are technologically feasible and economically justified, and would achieve the maximum improvement in energy efficiency. This chapter provides a description of the general analytical framework that DOE uses in developing such standards. The analytical framework is a description of the methodology, the analytical tools, and relationships among the various analyses that are part of this rulemaking. For example, the methodology that addresses the statutory requirement for economic justification includes analyses of life-cycle cost (LCC), economic impact on manufacturers and users, national benefits, impacts, if any, on utility companies, and impacts, if any, from lessening competition among manufacturers.

Figure 2.1.1 summarizes the stages and analytical components of the rulemaking process. The focus of this figure is the center column, which lists the analyses that DOE conducts. The figure shows how the analyses fit into the rulemaking process, and how they relate to each other. Key inputs are the types of data and information that the analyses require. Some key inputs exist in public databases; DOE collects other inputs from stakeholders or persons with special knowledge. Key outputs are analytical results that feed directly into the standards-setting process. Arrows connecting analyses show types of information that feed from one analysis to another.

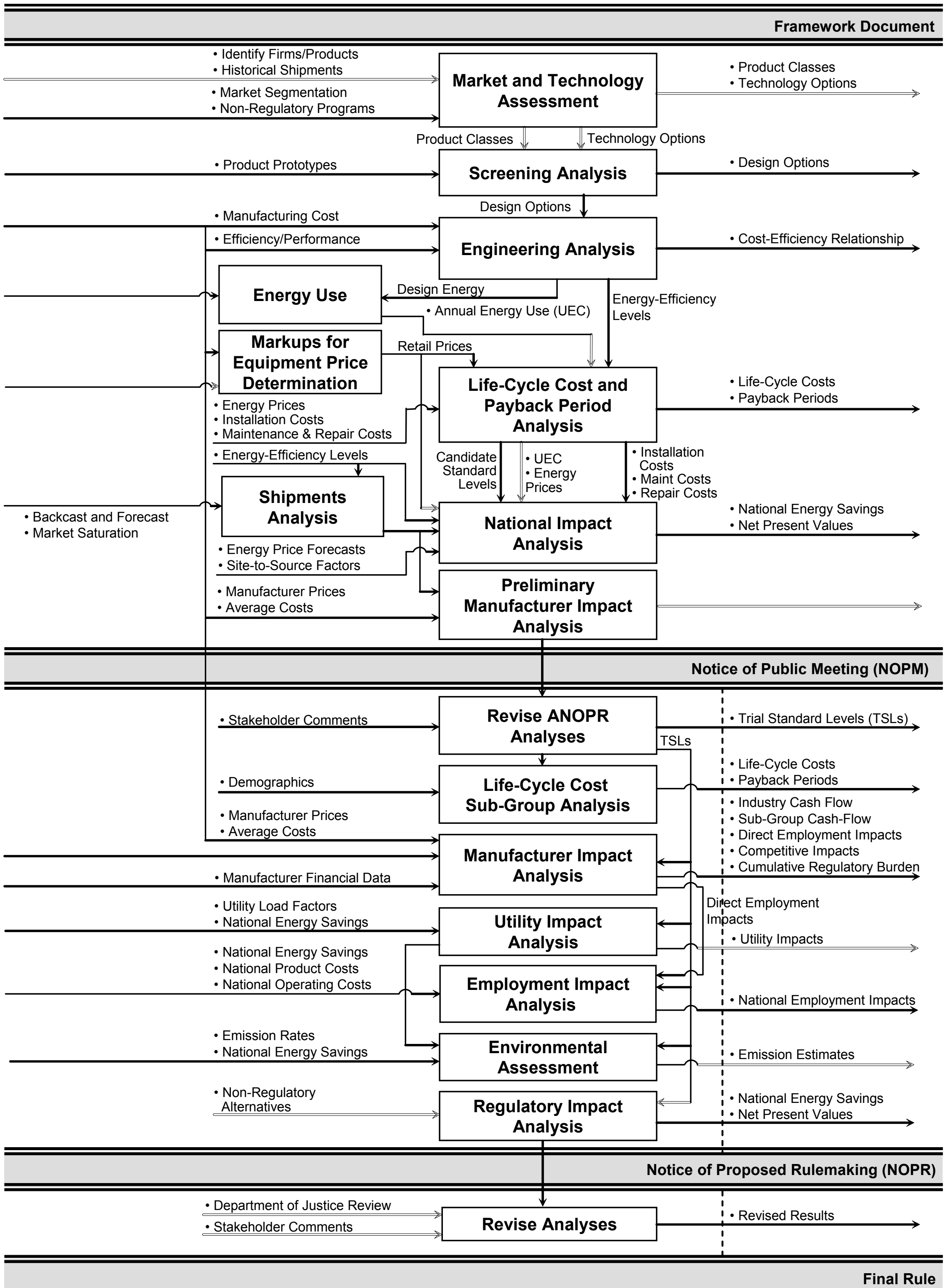

Figure 2.1.1 Flow Diagram of Analyses for the Energy Conservation Standards Rulemaking Analysis Process

The analyses performed prior to the notice of proposed rulemaking (NOPR) stage as part of the preliminary analyses and described in the preliminary technical support document (TSD) are listed below. These analyses were revised for the NOPR based in part on comments received, and reported in the NOPR TSD. The analyses were revised once again for the final rule based on comments received in response to the NOPR.

- A market and technology assessment to characterize the relevant product markets and existing technology options, including prototype designs.

- A screening analysis to review each technology option and determine if it is technologically feasible; is practical to manufacture, install, and service; would adversely affect product utility or product availability; or would have adverse impacts on health and safety.

- An engineering analysis to develop cost-efficiency relationships that show the manufacturer's cost of achieving increased efficiency.

- An energy use analysis to determine the annual energy use in the field of the considered products as a function of efficiency level.

- An LCC and payback period (PBP) analysis to calculate, at the consumer level, the relationship between savings in operating costs compared to any increase in the installed cost for products at higher efficiency levels.

- A shipments analysis to forecast product shipments, which then are used to calculate the national impacts of standards and future manufacturer cash flows.

- A national impact analysis (NIA) to assess the impacts at the national level of potential energy conservation standards for each of the considered products, as measured by the net present value (NPV) of total consumer economic impacts and the national energy savings (NES).

- A preliminary manufacturer impact analysis to assess the potential impacts of energy conservation standards on manufacturers, such as impacts on capital conversion expenditures, marketing costs, shipments, and research and development costs.

The additional analyses DOE performed for the NOPR stage of the rulemaking analysis include those listed below. DOE further revised the analyses for the final rule based on comments received in response to the NOPR.

- A consumer subgroup analysis to evaluate impacts of standards on particular consumer sub-populations, such as low-income households.

- A manufacturer impact analysis to estimate the financial impact of standards on manufacturers and to calculate impacts on competition, employment, and manufacturing capacity.

- An employment impact analysis to assess the indirect impacts of amended energy conservation standards on national employment.

- A utility impact analysis to estimate the effects of amended energy conservation standards on installed electricity generation capacity and electricity generation.

- An environmental impact analysis to provide estimates of the effects of amended energy conservation standards on emissions of carbon dioxide (CO_2), nitrogen oxides (NOx), and mercury (Hg).

- A regulatory impact analysis to assess alternatives to amended energy conservation standards that could achieve substantially the same regulatory goal.

2.2 BACKGROUND

DOE developed this analytical framework and documented it in the Rulemaking Framework Document for Refrigerators, Refrigerator-Freezers, and Freezers (September 18, 2008). DOE presented the analytical approach to interested parties during a public meeting held on September 29, 2008. The framework document is available at http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers.html. At the meeting and during the related comment period, DOE received many comments that helped it identify and resolve issues involved in this rulemaking.

DOE then gathered additional information and performed preliminary analyses to help develop the potential energy conservation standards for refrigeration products. This process culminated in DOE's announcement of a preliminary analysis public meeting to discuss and receive comments on the following matters: The product classes DOE analyzed; the analytical framework, models, and tools that DOE was using to evaluate standards; the results of the preliminary analyses performed by DOE; and potential standard levels that DOE could consider. 74 FR 58915 (November 16, 2009). DOE also invited written comments on these subjects and announced the availability on its website of a preliminary technical support document (preliminary TSD) it had prepared to inform interested parties and enable them to provide comments. Id. (The preliminary TSD is available at http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/ref_frz_prenopr_prelim_tsd.pdf)

The preliminary analysis public meeting announced in the November 2009 notice took place on December 10, 2009. At this meeting, DOE presented the methodologies and results of the analyses set forth in the preliminary TSD. DOE also discussed plans for conducting the NOPR analyses. The comments received since publication of the November 2009 notice, including those received at the preliminary analysis public meeting, contributed to DOE's proposed resolution of the issues in this rulemaking and the analysis conducted in support of the NOPR.

The NOPR public meeting was announced in September 2010 and took place on October 14, 2010. At this meeting, DOE presented revised methodologies and results of the analyses described in the NOPR TSD. Comments received during the NOPR comment period were used to produce revised results presented in the final rule.

The following sections provide a general description of the different analytical components of the rulemaking analytical plan. DOE has used the most reliable data available at the time of each analysis in this rulemaking. DOE has also considered submissions of additional data from interested parties during the rulemaking process.

2.3 MARKET AND TECHNOLOGY ASSESSMENT

When initiating a standards rulemaking, DOE develops information on the present and past industry structure and market characteristics for the equipment concerned. This activity assesses the industry and equipment both quantitatively and qualitatively based on publicly available information and encompasses the following: (1) manufacturer market share and characteristics, (2) existing regulatory and non-regulatory equipment efficiency improvement initiatives, and (3) trends in product characteristics and retail markets. This information serves as resource material throughout the rulemaking.

DOE reviewed existing literature and interviewed manufacturers to get an overall picture of the residential refrigeration product industry serving the United States market. Industry publications and trade journals, government agencies, and trade organizations provided the bulk of the information, including: (1) manufacturers and their approximate market shares, (2) shipments by capacity and equipment class, (3) equipment information, and (4) industry trends. The appropriate sections of the final rule describe the analysis and resulting information leading up to the proposed trial standard level while the supporting documentation is provided in the different chapters of the TSD.

The market and technology assessment also addresses applicable test procedures. DOE initiated a test procedure rulemaking for refrigeration products and published a test procedure NOPR on May 27, 2010. 75 FR 29824. The test procedure final rule was published on tktktk. [FR citation]. The test procedure rulemaking is discussed briefly in Chapter 3 of the final rule TSD.

2.3.1 Product Classes

DOE categorizes covered products into separate product classes and formulates a separate energy conservation standard for each product class. The criteria for separation into different classes are type of energy used, capacity, and other performance-related features such as those that provide utility to the consumer or others deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295(q) and 6316(a))

DOE is proposing several new product classes for refrigeration products as part of this rulemaking. The new product classes include product classes made effective through the Office of Hearing and Appeal's exception relief process, and based on performance and utility differences associated with all-refrigerators, products with automatic icemakers, and built-in products. This is described briefly in Chapter 3 of the final rule TSD, and in greater detail in the final rule.

2.3.2 Technology Assessment

As part of the market and technology assessment, DOE developed a list of technologies for consideration for improving the efficiency of residential refrigeration products. DOE typically uses information about existing and past technology options and prototype designs to determine which technologies manufacturers use to attain higher performance levels. In consultation with interested parties, DOE develops a list of technologies for consideration. Initially, these technologies encompass all those DOE believes are technologically feasible.

DOE developed its list of technologically feasible design options for refrigeration products from trade publications, technical papers, the TSD for the previous refrigeration product rulemaking, and through consultation with manufacturers of components and systems. Since many options for improving product efficiency are available in existing products, product literature and direct examination provided additional information. Chapter 3 of the final rule TSD includes the detailed list of all technology options identified.

2.4 SCREENING ANALYSIS

After DOE identified the technologies in the technology assessment that could potentially improve the energy efficiency of residential refrigeration products, DOE conducted the screening analysis. The purpose of the screening analysis is to evaluate the technologies to determine which options to consider further and which options to screen out. DOE consults with industry, technical experts, and other interested parties in developing a list of technologies for consideration. DOE then applies the screening criteria to determine which technologies are unsuitable for further consideration in this rulemaking. Chapter 4 of the final rule TSD, the screening analysis, contains details on the criteria that DOE uses.

The screening analysis examines whether various technologies (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; and (4) have adverse impacts on health and safety. In consultation with interested parties, DOE reviews the list to determine if the technologies described in chapter 3 of the final rule TSD are practicable to manufacture, install, and service; would adversely affect product utility or availability; or would have adverse impacts on health and safety. In the engineering analysis, DOE further considers the efficiency enhancement options (i.e., technologies) that it did not screen out in the screening analysis.

2.5 ENGINEERING ANALYSIS

The engineering analysis (chapter 5) establishes the relationship between the manufacturing production cost and the efficiency for each residential refrigeration product. This relationship serves as the basis for cost/benefit calculations in terms of individual consumers, manufacturers, and the Nation. Chapter 5 discusses product classes DOE analyzed, the representative baseline units, the efficiency levels analyzed, the methodology DOE used to develop the manufacturing production costs, and the cost-efficiency curves.

In the engineering analysis, DOE evaluates a range of product efficiency levels and their associated manufacturing costs. The purpose of the analysis is to estimate the incremental manufacturer selling prices (MSPs) for a product that would result from increasing efficiency levels above the level of the baseline model in each product class. The engineering analysis considers technologies not eliminated in the screening analysis. The LCC analysis uses the cost-efficiency relationships developed in the engineering analysis.

The proposed changes to the test procedure will result in changes in the measured energy use of most refrigeration products, and also in the adjusted volume of these products. The adjusted volume measurement directly impacts the energy conservation standards, since the standards are expressed in terms of this parameter. Chapter 5 of the final rule TSD describes conversion of the energy standard equations for baseline-efficiency products from representation based on the current test procedure to the proposed new test procedure. The chapter also presents calculations showing the adjustment of the energy use equation slope for three product classes.

DOE typically structures its engineering analysis around one of three methodologies: (1) the design-option approach, which calculates the incremental costs of adding specific design options to a baseline model; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels without regard to the particular design options used to achieve such increases; and/or (3) the reverse-engineering or cost-assessment approach, which involves a "bottom-up" manufacturing cost assessment based on a detailed bill of materials derived from teardowns of the product being analyzed.

For the NOPR analysis, which was retained for the final rule, DOE used a combination of all three of these approaches. DOE developed a manufacturing cost model for refrigeration products based on reverse engineering of purchased products. DOE determined the potential for efficiency improvement of design options and groups of design options using energy modeling. DOE estimated costs for these efficiency improvements based on the manufacturing cost model, information from component vendors, and information obtained through discussions with manufacturers. However, DOE based the cost-efficiency curves developed for the downstream analyses on specific efficiency levels representing percent energy use reductions in 5 percent increments. Chapter 5 of the final rule TSD describes the methodology that DOE used to perform the efficiency level analysis and derive the cost-efficiency relationship.

2.6 MARKUPS TO DETERMINE PRODUCT PRICE

DOE used markups to convert the manufacturer selling prices estimated in the engineering analysis to customer prices, which then were used in the life-cycle cost (LCC) and payback period (PBP) and manufacturer impact analyses. DOE calculates separate markups for baseline products (baseline markups) and for more efficient products (incremental markups). The incremental markup relates the change in the manufacturer sales price of higher-efficiency models (the incremental cost increase) to the change in the retailer or distributor sales price.

To develop markups, DOE identifies how the products are distributed from the manufacturer to the customer. After establishing appropriate distribution channels, DOE relied on economic data from the U.S. Census Bureau and other sources to define how prices are marked up as the products pass from the manufacturer to the customer. See Chapter 6 for details on the development of markups.

2.7 ENERGY USE ANALYSIS

The energy use analysis, which assesses the energy savings potential from higher efficiency levels, provides the basis for the energy savings values used in the LCC and subsequent analyses. The goal of the energy use analysis is to generate a range of energy use values that reflects actual product use in American homes. The analysis uses information on use of actual products in the field to estimate the energy that would be used by new products at various efficiency levels.

Studies show that measurements of field energy use often vary considerably from the rated usage as determined by the DOE test procedure. To determine the field energy use by products that would meet possible energy efficiency standards, DOE developed "usage adjustment factors' (UAFs) that relate estimated field energy consumption for each sample household to the estimated test energy use. DOE developed such UAFs for standard-size units.

In its preliminary analysis, DOE treated the field energy consumption reported for households in the Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS) as the actual consumption of the refrigeration product(s) in that household. RECS is a national sample survey of housing units that collects statistical information on the consumption of and expenditures for energy in housing units along with data on energy-related characteristics of the housing units and occupants. DOE used RECS to estimate the field energy usage of standard-sized refrigerator-freezers and freezers on a representative sample of housing units using these products.

For the NOPR, DOE developed a new approach to derive UAFs for the RECS sample households. This approach involved collection of field metered electricity use data for residential refrigeration products. DOE was able to obtain data from seven studies, including about 100 data points that DOE collected itself. From identifying information about each unit, its test energy consumption was estimated and the UAF was calculated as the ratio of metered energy use to test energy use. For each product category, DOE performed regressions on numerous variables of potential interest in order to construct a function that predicts the UAF based on household and climate variables. Within each of the product categories modeled, DOE used the appropriate set of regression coefficients, along with values for the relevant variables specific to each household, to generate UAF estimates for each RECS household. For compact refrigeration products, a UAF of 1 was used. This approach was retained for the final rule.

Chapter 7 of this TSD provides more detail about DOE's approach for characterizing energy use of refrigeration products.

2.8 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

New or amended energy conservation standards affect products' operating expenses—usually decreasing them—and consumer prices for the products—usually increasing them. DOE analyzed the net effect of amended standards on consumers by evaluating the net LCC. To evaluate the net LCC, DOE used the cost-efficiency relationship derived in the engineering analysis, along with the energy costs derived from the energy use characterization. Inputs to the LCC calculation include the installed cost of a product to the consumer (consumer purchase price plus installation cost), operating expenses (energy expenses and maintenance costs), the lifetime of the unit, and a discount rate.

Because the installed cost of a product typically increases while operating cost typically decreases in response to new standards, there is a time in the life of products having higher-than-baseline efficiency when the net operating-cost benefit (in dollars) since the time of purchase is equal to the incremental first cost of purchasing the higher-efficiency product. The length of time required for products to reach this cost-equivalence point is known as the payback period (PBP).

Recognizing that several inputs to the determination of consumer LCC and PBP are either variable or uncertain, DOE conducted the LCC and PBP analysis by modeling both the uncertainty and variability in the inputs using Monte Carlo simulation and probability distributions. DOE developed LCC and PBP spreadsheet models incorporating both Monte Carlo simulation and probability distributions by using Microsoft Excel spreadsheets combined with Crystal Ball (a commercially available add-in program).

Using information in RECS, DOE developed samples of individual households that use the considered standard-size refrigeration products. By developing household samples, DOE was able to perform the LCC and PBP calculations for each household to account for the variability in energy consumption and electricity price associated with each household. As noted above, DOE did not develop a household sample for compact refrigerators and freezers since a large number of such products are used in lodging, dormitories and other commercial establishments. DOE identified several other input values for estimating the LCC, including: retail prices; discount rates; and product lifetimes. DOE characterized these values with probability distributions.

DOE developed discount rates separately for residential consumers and commercial consumers. Because some compact refrigerators and freezers are used in commercial applications, DOE developed commercial discount rates and for those commercial consumers that purchase compact refrigerators and freezers. DOE developed discount rates from estimates of the interest rate, or finance cost, applied to purchases of residential and commercial products. Following accepted principles of financial theory, the finance cost of raising funds to purchase such products can be interpreted as: (1) the financial cost of any debt incurred to purchase products, principally interest charges on debt; or (2) the opportunity cost of any equity used to purchase products, principally interest earnings on household equity.

2.9 SHIPMENTS ANALYSIS

Forecasts of product shipments are needed to calculate the national impacts of standards on energy use, NPV, and future manufacturer cash flows. DOE developed shipment forecasts based on an analysis of key market drivers for each considered product. In DOE's shipments model, shipments of products are driven by new construction as well as stock replacements.

The shipments models take an accounting approach, tracking market shares of each product class and the vintage of units in the existing stock. Stock accounting uses product shipments as inputs to estimate the age distribution of in-service product stocks for all years. The age distribution of in-service product stocks is a key input to calculations of both the NES and NPV, because operating costs for any year depend on the age distribution of the stock.

Chapter 9 of the TSD provides additional details on the shipments analysis.

2.10 NATIONAL IMPACT ANALYSIS

The national impact analysis assesses the aggregate impacts at the national level of potential energy conservation standards for each of the considered products, as measured by the net present value (NPV) of total consumer economic impacts and the national energy savings (NES). DOE determined both the NPV and NES for the efficiency levels considered for the product classes analyzed. To make the analysis more accessible and transparent to all interested parties, DOE prepared a Microsoft Excel spreadsheet model to forecast NES and the national consumer economic costs and savings resulting from new standards. The spreadsheet model uses as inputs typical values (as opposed to probability distributions). To assess the effect of input uncertainty on NES and NPV results, DOE conducted sensitivity analyses by running scenarios on specific input variables, which are described in chapter 10.

Several of the inputs for determining NES and NPV depend on the product efficiency. DOE developed efficiency trends for the base case and standards cases. These trends specify the average annual historical and forecasted shipments-weighted product efficiencies. In developing the energy efficiencies forecasted over time for each of the standards cases, DOE used a "roll-up + ENERGY STAR" scenario to establish the distribution of efficiencies for the year that revised standards are assumed to become effective (i.e., 2014) and subsequent years. In this scenario, product efficiencies in the base case that did not meet the standard level under consideration would roll-up to meet the new standard level in 2014. DOE assumed that new criteria would be established for ENERGY STAR refrigeration products, and that such products would gradually gain a larger market share. The details of the approach are described in Chapter 10.

2.10.1 National Energy Savings Analysis

The inputs for determining the national energy savings (NES) for each product analyzed are: (1) annual energy consumption per unit; (2) shipments; (3) product stock; (4) national energy consumption; and (5) site-to-source conversion factors. DOE calculated the national energy consumption by multiplying the number of units, or stock, of each product (by vintage, or age) by the unit energy consumption (also by vintage). DOE calculated annual NES based on the difference in national energy consumption for the base case (without new efficiency standards) and for each considered efficiency level. DOE estimated energy consumption and savings based on site energy, and converted the electricity consumption and savings to source (primary) energy. Cumulative energy savings are the sum of the NES for each year.

2.10.2 Net Present Value Analysis

The inputs for determining net present value (NPV) of consumer benefits are: (1) total annual installed cost; (2) total annual savings in operating costs; (3) a discount factor; (4) present value of costs; and (5) present value of savings. DOE calculated net savings each year as the difference between the base case and each standards case in total savings in operating costs and total increases in installed costs. DOE calculated savings over the life of each product, accounting for differences in yearly energy rates. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3% and 7% to discount future costs and savings to present values.

DOE calculated increases in total installed costs as the difference in total installed cost between the base case and standards case (*i.e.*, once the standards take effect). Because the more efficient products bought in the standards case usually cost more than products bought in the base case, cost increases appear as negative values in the NPV.

DOE expressed savings in operating costs as decreases associated with the lower energy consumption of products bought in the standards case compared to the base efficiency case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year.

Chapter 10 of this TSD provides additional details regarding the national impacts analysis.

2.11 CONSUMER SUBGROUP ANALYSIS

The consumer subgroup analysis evaluates economic impacts on selected groups of consumers who might be adversely affected by a change in the national energy conservation standards for the considered products. DOE evaluates impacts on particular subgroups of consumers primarily by analyzing the LCC impacts and PBP for those particular consumers using the LCC spreadsheet model.

For the NOPR, DOE evaluated impacts of standards on low-income and fixed-income (i.e., senior) consumers. This approach was retained for the final rule.

2.12 MANUFACTURER IMPACT ANALYSIS

DOE performed a manufacturer impact analysis (MIA) to estimate the financial impact of amended energy conservation standards on manufacturers of residential refrigeration products, and to calculate the impact of such standards on employment and manufacturing capacity. The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA relies on the government regulatory impact model (GRIM), an industry-cash-flow model customized for this rulemaking. The GRIM inputs are information regarding the industry cost structure, shipments, and revenues. This includes information from many of the analyses described above, such as manufacturing costs and prices from the engineering analysis and shipments forecasts. The key GRIM output is the industry net present value (INPV). Different sets of assumptions (scenarios) will produce different results. The qualitative part of the MIA addresses factors such as product characteristics, characteristics of particular firms, and market and product trends, and includes assessment of the impacts of standards on subgroups of manufacturers. The complete MIA is described in chapter 12 of the final rule TSD.

DOE conducted each MIA in this rulemaking in three phases. In Phase I, DOE created an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepared an industry cash-flow model and an interview questionnaire to guide subsequent discussions. In Phase III, DOE interviewed manufacturers, and assessed the impacts of standards both quantitatively and qualitatively. DOE assessed industry and subgroup cash flow and NPV using the GRIM. DOE then assessed impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions.

2.13 EMPLOYMENT IMPACT ANALYSIS

The imposition of standards can affect employment both directly and indirectly. Direct employment impacts are changes, produced by new standards, in the number of employees at plants that produce the covered products. DOE evaluated direct employment impacts in the manufacturer impact analysis. Indirect employment impacts that occur because of the imposition of standards may result from consumers shifting expenditures between goods (the substitution effect) and from changes in income and overall expenditure levels (the income effect). DOE utilizes Pacific Northwest National Laboratory's ImSET model to investigate the combined direct and indirect employment impacts. The ImSET model, which was developed for DOE's Office of Planning, Budget, and Analysis, estimates the employment and income effects energy-saving technologies produced in buildings, industry, and transportation. In comparison with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments.

2.14 UTILITY IMPACT ANALYSIS

The utility impact analysis estimates the effects of amended energy conservation standards on installed electricity generation capacity and electricity generation. For this analysis, DOE adapted NEMS, which is a large multi-sectoral, partial-equilibrium model of the U.S. energy sector that the EIA has developed throughout the past decade, primarily for preparing EIA's AEO. In previous rulemakings, a variant of NEMS (currently termed NEMS-BT, BT referring to DOE's Building Technologies Program), was developed to better address the specific impacts of an energy conservation standard. NEMS, which is available in the public domain, produces a widely recognized baseline energy forecast for the United States through the year 2030. The typical NEMS outputs include forecasts of electricity sales, prices, and electric generating capacity. DOE conducts the utility impact analysis as a scenario that departs from the latest AEO reference case. In other words, the energy savings impacts from amended energy conservation standards are modeled using NEMS-BT to generate forecasts that deviate from the AEO reference case.

As part of the utility impact analysis, DOE analyzed the potential impact on electricity prices resulting from amended standards on refrigeration products and the associated benefits for all electricity users in all sectors of the economy.

2.15 ENVIRONMENTAL IMPACT ANALYSIS

The intent of the environmental assessment is to quantify and consider the environmental effects of amended energy conservation standards for the products covered in this rulemaking. The primary environmental effects of these standards would be reduced power plant emissions resulting from reduced consumption of electricity. DOE will assess these environmental effects by using NEMS-BT to provide key inputs to its analysis. The portion of the environmental assessment that will be produced by NEMS-BT considers carbon dioxide (CO_2), nitrogen oxides (NO_X), and mercury (Hg). The environmental assessment also considers impacts on SO_2 emissions.

2.15.1 Carbon Dioxide

In the absence of any Federal emissions control regulation of power plant emissions of CO_2, a DOE standard is likely to result in reductions of these emissions. The CO_2 emission reductions likely to result from a standard will be estimated using NEMS-BT and national energy savings estimates drawn from the NIA spreadsheet model. The net benefit of the standard is the difference between emissions estimated by NEMS-BT at each standard level considered and the *AEO* Reference Case. NEMS-BT tracks CO_2 emissions using a detailed module that provides results with broad coverage of all sectors and inclusion of interactive effects.

2.15.2 Sulfur Dioxide

DOE has preliminarily determined that SO_2 emissions from affected Electric Generating Units (EGUs) are subject to nationwide and regional emissions cap and trading programs that are likely to eliminate the standards' impact on SO_2 emissions. The costs of meeting such emission cap requirements are reflected in the electricity prices and forecasts used in DOE's analysis of the standards. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for all affected EGUs. SO_2 emissions from 28 eastern States and the District of Columbia (DC) are also limited under the Clean Air Interstate Rule (CAIR, published in the Federal Register on May 12, 2005. 70 FR 25162 (May 12, 2005)), which creates an allowance-based trading program that will gradually replace the Title IV program in those States and DC. (The recent legal history surrounding CAIR is discussed below.) The attainment of the emissions caps is flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emission allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. However, if the standard resulted in a permanent increase in the quantity of unused emission allowances, there would be an overall reduction in SO_2 emissions from the standards. While there remains some uncertainty about the ultimate effects of efficiency standards on SO_2 emissions covered by the existing cap and trade system, the NEMS-BT modeling system that DOE plans to use to forecast emissions reductions currently indicates that no physical reductions in power sector emissions would occur for SO_2.

2.15.3 Nitrogen Oxides

NEMS-BT also has an algorithm for estimating NO_X emissions from power generation. The impact of these emissions, however, will be affected by the CAIR, which the Environmental Protection Agency (EPA) issued on May 12, 2005. CAIR will permanently cap emissions of NO_X in 28 eastern states and the District of Columbia. 70 FR 25162 (May 12, 2005).

Much like SO_2 emissions, a cap on NO_X emissions means that amended energy conservation standards may have little or no physical effect on these emissions in the 28 eastern States and the DC covered by CAIR. Although CAIR has been remanded to the EPA by the DC Circuit, it will remain in effect until it is replaced by a rule consistent with the Court's July 11, 2008, opinion in North Carolina v. EPA. 531 F.3d 896 (DC Cir. 2008); see also North Carolina v. EPA, 550 F.3d 1176 (DC Cir. 2008). Because all States covered by CAIR opted to reduce NO_X emissions through participation in cap-and-trade programs for electric generating units, emissions from these sources are capped across the CAIR region.

DOE uses NEMS-BT to estimate the emissions reductions from possible standards in the 22 States where emissions are not capped.

2.15.4 Mercury

Similar to emissions of SO_2 and NO_X, future emissions of Hg would have been subject to emissions caps. In May 2005, EPA issued the Clean Air Mercury Rule (CAMR). 70 FR 28606 (May 18, 2005). CAMR would have permanently capped emissions of mercury for new and existing coal-fired power plants in all States by 2010. However, on February 8, 2008, the DC Circuit issued its decision in New Jersey v. Environmental Protection Agency, in which the DC Circuit, among other actions, vacated the CAMR. 517 F.3d 574 (DC Cir. 2008). EPA has decided to develop emissions standards for power plants under the Clean Air Act (Section 112), consistent with the DC Circuit's opinion on the CAMR. See http://www.epa.gov/air/mercuryrule/pdfs/certpetition_withdrawal.pdf. Pending EPA's forthcoming revisions to the rule, DOE is excluding the CAMR from its Environmental Analysis. In the absence of CAMR, a DOE standard would likely reduce Hg emissions and DOE plans to use NEMS-BT to estimate these emission reductions. However, DOE continues to review the impact of rules that reduce energy consumption on Hg emissions, and may revise its assessment of Hg emission reductions in future rulemakings.

2.15.5 Particulate Matter

DOE acknowledges that particulate matter (PM) impacts are of concern due to human exposures that can impact health. However, impacts of PM emissions reduction are much more difficult to estimate than other emissions reductions due to the complex interactions between PM, other power plant emissions, meteorology, and atmospheric chemistry that impact human exposure to particulates. Human exposure to PM usually occurs at a significant distance from the power plants that are emitting particulates and particulate precursors. When power plant emissions travel this distance, they undergo highly complex atmospheric chemical reactions. Although the EPA does keep inventories of direct PM emissions of power plants, in its source attribution reviews, the EPA does not separate direct PM emissions from power plants from the sulfate particulates indirectly produced through complex atmospheric chemical reactions. The great majority of PM emissions from power plants are of these secondary particles (secondary sulfates). Thus, it is not useful to examine how the amended standard impacts direct PM emissions independent of indirect PM production and atmospheric dynamics. Therefore, DOE is not planning to assess the impact of these standards on particulate emissions. Further, even the cumulative impact of PM emissions from power plants and indirect emissions of pollutants from other sources is unlikely to be significant.

2.15.6 Monetization of Emissions Reductions

For those emissions for which real national emission reductions are anticipated (CO_2, Hg, and NO_X for 22 states), only ranges of estimated economic values based on environmental damage studies of varying quality and applicability are available. Therefore, DOE intends to report estimates of monetary benefits derived using these values and consider these benefits in weighing the costs and benefits of each of the standard levels considered.

In order to estimate the monetary value of benefits resulting from reduced emissions of CO_2 emissions, it is DOE's intent to use in its analysis the most current Social Cost of Carbon (SCC) values developed and/or agreed to by interagency reviews. The SCC is intended to be a monetary measure of the incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

At the time of this notice, the most recent interagency estimates of the potential global benefits resulting from reduced CO_2 emissions in 2010 were $4.7, $21.4, $35.1, and $64.9 per metric ton in 2007 dollars. These values are then adjusted to 2009$ using the appropriate standard GDP deflator values. For emissions reductions that occur in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE will give preference to consideration of the global benefits of reducing CO2 emissions. See appendix 15A of this TSD for the full range of annual SCC estimates from 2010 to 2050. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of CO_2 and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also estimates the potential monetary benefit of reduced NO_X emissions resulting from the standard levels it considers. For NO_X emissions, available estimates suggest a very wide range of monetary values for NO_X emissions, ranging from $370 per ton to $3,800 per ton of NO_X from stationary sources, measured in 2001$ (equivalent to a range of $447 to $4,591 per ton in 2009$). Refer to the OMB, Office of Information and Regulatory Affairs, "2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities," for additional information. In accordance with U.S. Office of Management and Budget (OMB) guidance, DOE will conduct two calculations of the monetary benefits derived using each of the economic values used for $NO_{X,}$ one using a real discount rate of 3 percent and another using a real discount rate of 7 percent.[a]

DOE does not plan to monetize estimates of Hg in this rulemaking. DOE is aware of multiple agency efforts to determine the appropriate range of values used in evaluating the potential economic benefits of reduced Hg emissions. DOE has decided to await further guidance regarding consistent valuation and reporting of Hg emissions before it once again monetizes Hg in its rulemakings.

2.16 REGULATORY IMPACT ANALYSIS

In the NOPR and also the final rule, DOE prepared a regulatory impact analysis (RIA) pursuant to Executive Order 12866, Regulatory Planning and Review, 58 FR 51735, October 4, 1993, which is subject to review by the Office of Information and Regulatory Affairs at the Office of Management and Budget. The RIA addresses the potential for non-regulatory approaches to supplant or augment energy conservation standards in order to improve the energy efficiency or reduce the energy consumption of the products covered under this rulemaking.

DOE recognizes that voluntary or other non-regulatory efforts by manufacturers, utilities, and other interested parties can substantially affect energy efficiency or reduce energy consumption. DOE bases its assessment on the actual impacts of any such initiatives to date, but also considers information presented by interested parties regarding the impacts existing initiatives might have in the future.

[a] OMB, Circular A-4: Regulatory Analysis (Sept. 17, 2003).

CHAPTER 3: MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This report provides a profile of the residential refrigerator and freezer product industries in the United States. The U.S. Department of Energy (DOE) developed the market and technology assessment presented in this chapter primarily from publicly available information. This assessment identifies the major manufacturers and their product characteristics, which form the basis for the engineering and the life-cycle cost (LCC) analyses. Present and past industry structure and industry financial information help DOE in the process of conducting the manufacturer impact analysis.

3.1.1 Product Definitions

3.1.1.1 Refrigerators, Refrigerator-Freezers, and Freezers

The Code of Federal Regulations (CFR) establishes the product definitions for refrigerators, refrigerator-freezers, and freezers as follows:[1]

- The term *Refrigerator* means an electric refrigerator and the term *Refrigerator-freezer* means an electric refrigerator-freezer.

- *Electric refrigerator* means a cabinet designed for the refrigerated storage of food at temperatures above 32 degrees Fahrenheit (°F) and below 39 °F, configured for general refrigerated food storage, and having a source of refrigeration requiring single phase, alternating current electric energy input only. An electric refrigerator may include a compartment for freezing and storage of food at temperatures below 32 °F, but does not provide a separate low temperature compartment designed for the freezing and storage of food at temperatures below 8 °F.

- *Electric refrigerator-freezer* means a cabinet which consists of two or more compartments with at least one of the compartments designed for the refrigerated storage of food at temperatures above 32 °F. and with at least one of the compartments designed for the freezing and storage of food at temperatures below 8 °F. which may be adjusted by the user to a temperature of 0 °F. or below. The source of refrigeration requires single phase, alternating current electric energy input only.

- *Compact refrigerator, refrigerator-freezer, and freezer* means any refrigerator, refrigerator-freezer or freezer with total volume less than 7.75 ft^3 (220 L) and 36 inches (0.91 meters) or less in height.

- *Freezer* means a cabinet designed as a unit for the freezing and storage of food at temperatures of 0 °F or below, and having a source of refrigeration requiring single phase, alternating current electric energy input only.

DOE has changed some of these definitions, as described in the refrigeration product test procedure final/interim final rule (75 FR 78810 (December 16, 2010)).

3.1.1.2 Wine Coolers

DOE amended the definition of "electric refrigerator", effective December 19, 2001, to include a maximum temperature of the fresh food storage compartment, and to exclude certain appliances whose physical configuration makes them unsuitable for general storage of perishable foods.[2] Because wine coolers maintain storage temperature above 39 ºF, they are exempted from existing refrigerator product classifications and are not required to meet minimum efficiency standards. DOE is considering conducting a separate rulemaking to establish coverage of wine coolers and related products (i.e. combination wine storage-freezers and wine storage-refrigerators), and to set energy standards for them.

3.2 MARKET ASSESSMENT

3.2.1 Product Classes

3.2.1.1 Product Classes Listed in the CFR

The CFR establishes the product classes for refrigerators, refrigerator-freezers, and freezers.[3] As per the CFR, there are 18 product classes. The product classes are based on the following characteristics: type of unit (refrigerator, refrigerator-freezer, or freezer), size of the cabinet (standard or compact), type of defrost system (manual, partial, or automatic), presence or absence of through-the-door (TTD) ice service, and placement of the fresh food and freezer compartments for refrigerator-freezers.

3.2.1.2 Product Classes Modifications

Table 3.2.1 below shows the product classes addressed in this rulemaking, including 25 new product classes. The additional product classes address the following:

- Product classes made effective through the Office of Hearing and Appeal's exception relief process.
- All-refrigerators.
- Products with automatic icemakers.
- Built-in products.

Table 3.2.1 Product Classes for Refrigerators, Refrigerator-Freezers, and Freezers

No.	Product Class
Classes listed in the CFR	
1	Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
2	Refrigerator-freezers—partial automatic defrost
3	Refrigerator-freezers—automatic defrost with top-mounted freezer without an automatic icemaker.
4	Refrigerator-freezers—automatic defrost with side-mounted freezer without an icemaker
5	Refrigerator-freezers—automatic defrost with bottom-mounted freezer without an icemaker
6	Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service
7	Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service
8	Upright freezers with manual defrost
9	Upright freezers with automatic defrost without an automatic icemaker
10	Chest freezers and all other freezers except compact freezers
11	Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost
12	Compact refrigerator-freezers—partial automatic defrost
13	Compact refrigerator-freezers—automatic defrost with top-mounted freezer without an automatic icemaker
14	Compact refrigerator-freezers—automatic defrost with side-mounted freezer without an automatic icemaker
15	Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer without an automatic icemaker
16	Compact upright freezers with manual defrost
17	Compact upright freezers with automatic defrost
18	Compact chest freezers
Product Classes Established During this Rulemaking	
1A	All-refrigerators—manual defrost
3A	All-refrigerators—automatic defrost
5A	Refrigerator-freezers—automatic defrost with bottom-mounted freezer with TTD ice service
10A	Chest freezers with automatic defrost
11A	Compact all-refrigerators—manual defrost
13A	Compact all-refrigerators—automatic defrost
3-BI	Built-in refrigerator-freezer—automatic defrost with top-mounted freezer without an automatic icemaker
3I	Refrigerator-freezers—automatic defrost with top-mounted freezer with an automatic icemaker without through-the-door ice service
3I-BI	Built-in refrigerator-freezers—automatic defrost with top-mounted freezer with an automatic icemaker without through-the-door ice service
3A-BI	Built-in all-refrigerators—automatic defrost
4I	Refrigerator-freezers—automatic defrost with side-mounted freezer with an automatic icemaker without through-the-door ice service
4-BI	Built-in refrigerator-freezers—automatic defrost with side-mounted freezer without an

No.	Product Class
	automatic icemaker
4I-BI	Built-in refrigerator-freezers—automatic defrost with side-mounted freezer with an automatic icemaker without through-the-door ice service
5I	Refrigerator-freezers—automatic defrost with bottom-mounted freezer with an automatic icemaker without through-the-door ice service
5-BI	Built-in refrigerator-freezers—automatic defrost with bottom-mounted freezer without an automatic icemaker
5I-BI	Built-in refrigerator-freezers—automatic defrost with bottom-mounted freezer with an automatic icemaker without through-the-door ice service
5A-BI	Built-in refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service
7-BI	Built-in refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service
9-BI	Built-in upright freezers with automatic defrost without an automatic icemaker
9I	Upright freezers with automatic defrost with an automatic icemaker
9I-BI	Built-in upright freezers with automatic defrost with an automatic icemaker
13I	Compact refrigerator-freezers—automatic defrost with top-mounted freezer with an automatic icemaker
14I	Compact refrigerator-freezers—automatic defrost with side-mounted freezer with an automatic icemaker
15I	Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer with an automatic icemaker

Two of these new product classes, currently called product class 5A, automatic defrost refrigerator-freezers with bottom-mounted freezer with TTD ice service, and product class 10A, chest freezers with automatic defrost, were identified in the framework document as product classes 19 and 20. DOE has established these two new product classes pursuant to its decision order to grant exemptions to standards for these specific product categories. DOE has adopted the product class designations for these products which were previously adopted by Canada in order to maintain international consistency.

DOE's Office of Hearings and Appeals granted five exceptions for refrigerator-freezer products with bottom-mounted freezer and TTD ice service, to Maytag Corporation (Maytag), LG Electronics, Inc. (LG), Samsung Electronics, Electrolux Home Products, and BSH Home Appliances Corporation (BSH). DOE granted Maytag its exception on August 11, 2005 (case number TEE-0022), LG's exception on November 9, 2005 (case number TEE-0025), Samsung's exception on July 26, 2007 (case number TEE-0047), Electrolux's exception on December, 2008 (case number TEE-0056), and BSH's exception on April 23, 2010 (case number TEE-0070). Before these rulings, there was no appropriately-defined category for this type of product, since the minimum standard for product class 5 (refrigerator-freezers with automatic defrost with bottom-mounted freezer without TTD ice service)[a] was established to cover only products without TTD ice-service at the time of its development. The actual energy consumption of this new product (i.e., with TTD ice-service) is higher than that of product class 5 due to the added heat loss through the door to the fresh-food space, the reduced temperatures of the space reserved in the fresh food compartment for ice storage, which is maintained at lower temperatures than the rest of the fresh food compartment, and the energy consumed by the fan used to cool the space used for ice production and storage.

DOE's Office of Hearings and Appeals granted an exception to Electrolux Home Products (Electrolux) for a specific brand of chest freezer with automatic defrost (case number TEE-0012). The Association of Home Appliance Manufacturers (AHAM) filed a letter supporting this exemption and recommended that DOE use the direct final rule process to establish a new class of chest freezers that would correspond to the minimum efficiency standard for automatic defrost chest freezers. The minimum standard for product class 10 (chest freezers and all other freezers) was established to cover products without automatic defrost at the time of its development. The actual energy consumption of the new product (i.e., with automatic defrost) is higher than that of product class 10 due to the added energy consumption associated with the automatic defrost system.

Five of the additional new product classes are all-refrigerator products. All-refrigerators are defined as "an electric refrigerator which does not include a compartment for the freezing and long time storage of food at temperatures below 32 °F. (0.0 °C.). It may include a compartment of 0.50 cubic feet capacity (14.2 liters) or less for the freezing and storage of ice." (10 CFR part 430, subpart B, appendix A1, section 1.4) DOE has for the 2014 standard separated all-refrigerators from their previous product classes, which currently also include refrigerators other than all-refrigerators (i.e. with freezer compartments larger than 0.5 cubic feet in size) and refrigerator-freezers. The test procedure changes described in section 3.2.2 will result in significantly higher energy use for refrigerators with freezer compartments larger than 0.5 cubic feet and refrigerator-freezers and somewhat less energy use for all-refrigerators. Hence, as explained in the energy standard rulemaking NOPR (see 75 FR 59470, 59488 (September 27, 2010)), separating these product classes is justified under the provisions of EPCA addressing product classes (see 42 U.S.C. 6295(q)).

DOE established eleven of the additional new product classes to distinguish products with automatic icemakers from those that do not have automatic icemakers. The incorporation of icemaking energy use into the test procedure for products with automatic icemakers requires this step.

Eleven of the additional new product classes are built-in products. Built-in products represent a small percentage of total refrigeration product shipments, in the range 1 to 2 percent.

[a] Product class structure, including identification numbers and descriptions, have been changed during this rulemaking. The new structure takes effect in 2014 with the new energy conservation standards. The TSD may refer to product classes using their current numbers and descriptors, or the new numbers and descriptors, which take effect in 2014, depending on the context. In this case, the text discusses past status of product class 5, so its current descriptor is used.

These products are designed to be integrated seamlessly into the kitchen cabinetry. Achieving this functionality requires design features that limit the potential to improve efficiency. DOE has concluded that creating separate product classes for these products is justifiable under EPCA's requirements for separate product classes (42 U.S.C. 6295(q)).

3.2.2 Product Test Procedures

The CFR establishes the test procedures for refrigerators, refrigerator-freezers, and freezers. (10 CFR Part 430, Subpart B, Appendices A1 and B1) DOE initiated a test procedure rulemaking in late 2008 to address test procedure issues identified at the framework workshop associated with this energy conservation standard rulemaking and to address recent test procedure waivers. A test procedure NOPR was published May 27, 2010. 75 FR 29824.

DOE published a combined final rule/interim final rule in the test procedure rulemaking to provide stakeholders with more time to evaluate the impact of the test procedure amendments. 75 FR 78810 (December 16, 2010).

The test procedure interim final rule implemented the following test procedure amendments to apply coincident with the new energy conservation standard (January 1, 2014):

1. Modification of product definitions to clarify the status of wine storage related products.
2. Modified procedures for test sample preparation, including explicit requirements for waivers if the product's energy use cannot properly be measured by the test procedure.
3. Addition of the anti-circumvention language initially introduced in AHAM HRF-1-2007, section 1.2.
4. Clarification of procedures for establishing product clearances to walls during testing.
5. Special requirements in case non-standard compartment temperature sensor locations are used during testing.
6. Clarification of how to set the median temperature settings for electronic control products.
7. Clarification that the dual-standardized-temperature approach that manufacturers use for setting temperatures during testing is part of the DOE procedure.
8. Elimination of extrapolation-based determination of energy use in cases where products fail to bring compartment temperatures down to their standardized temperatures with temperature controls set in their coldest positions. Such test samples will be considered to have failed the test.
9. Modified test procedures for convertible compartments and special compartments.
10. Establishment of a temperature-averaging procedure for auxiliary compartments.
11. Modified definition for anti-sweat heater so that the definition applies to heaters preventing interior as well as exterior condensation.
12. Clarification that averaging of tests with the anti-sweat heater switch turned on and off applies to energy use measurements as well as annual energy cost measurements.
13. Incorporation of test procedures for products with variable anti-sweat heating control, currently addressed in waivers
14. Modification of the long-time and variable defrost test method to capture precooling and temperature recovery energy use.
15. Establishing test procedures measure all defrost energy use for products with multiple defrost cycle types.

16. Update the AHAM standard reference from AHAM HRF-1-1979 to HRF-1-2008.
17. New compartment temperatures.
18. New volume calculation methods.
19. Elimination of the optional Part 3 of the variable defrost test.
20. Corrections and other test procedure language changes.
21. Rounding to the nearest kilowatt-hour per year for both the energy use measurement and the energy standard.
22. Incorporation of a fixed-value placeholder representing icemaking energy use for products with automatic icemakers.

The expected measurement changes for these test procedure changes are associated primarily with the compartment temperature changes and the change in the volume calculation method. Chapter 5 discusses these measurement changes in greater detail, in section 5.4.2.

3.2.3 Manufacturer Information

This section provides information on domestic manufacturers of residential refrigerators, refrigerator-freezers, and freezers, including their brand names and products sold in the United States (section 3.2.3.1), estimated market shares (section 0), industry mergers and acquisitions (section 3.2.3.3), and product distribution channels (section 3.2.3.4). The section also discusses manufacturer trade groups (section 3.2.3.5) and manufacturers of compressors (section 3.2.3.6), as this is one of the most important components of residential refrigeration products.

3.2.3.1 Refrigerator, Refrigerator-Freezer, and Freezer Manufacturers

Table 3.2.2 lists refrigerator, refrigerator-freezer, and freezer manufacturers selling products in the United States. The second column indicates whether the manufacturer is a member of AHAM, and the third column indicates whether the manufacturer produces products that are ENERGY STAR compliant. Manufacturers that are a member of AHAM are listed first in the table and generally have the largest U.S. market shares. There are also several smaller manufacturers supplying products to the U.S. Those smaller manufacturers that produce ENERGY STAR-compliant products are listed directly after AHAM member manufacturers.

Table 3.2.2 Refrigerator, Refrigerator-Freezer, and Freezer Manufacturers

Manufacturer Name	AHAM Member	E* Products	Std Refrig-Freezer	Freezer	Com-pact	Built-In	Custom Door/Inter.	Under Counter	Luxury Unit°°	Other″
Aga Foodservice Group*	Y	-	-	-	-	-	-	-	-	-
Marvel Industries	-	-	Y	Y	-	Y	-	Y	Y (BI,SS,SI)	Y
Northland Corp.	-	-	-	Y	-	-	Y	-	Y (BI,SS,CDD,SI)	-
Bosch Home Appliances Corp.	Y	Y	Y	Y	-	-	Y	-	Y (CDD,SS)	-
Electrolux Home Products**	Y	Y	-	-	-	Y	Y	Y	Y (CDD,SS,BI)	-
Frigidaire	-	Y	Y	Y	-	-	-	-	-	-
Fisher & Paykel Appliances Inc.	Y	-	Y	-	-	-	-	-	Y (SS)	-
GE Appliances***	Y	Y	Y	Y	Y	-	-	-	Y (SS,SI)	-
Hotpoint	-	Y	Y	Y	Y	-	-	-	-	-
Monogram	-	Y	Y	Y	-	Y	-	-	Y (BI,SS,SI)	Y
Haier Group	Y	Y	Y	-	Y	-	-	-	Y (CB,SS,SI)	Y
LG Electronics	Y	Y	Y	-	-	-	-	-	Y (TD,SI, SS)	Y
Liebherr	Y	Y	Y	-	-	Y	-	-	Y (BI,SS)	
Samsung Electronics America	Y	Y	Y	-	-	-	-	-	-	-
Sanyo North America Corp.	Y	Y	Y	Y	Y	-	-	Y	-	Y
Sub-Zero Freezer Company	Y	Y	-	Y	-	Y	Y	Y	Y (BI,CDD)	Y
U-Line Corporation	Y	Y	-	Y	Y	-	-	Y	-	Y
Viking Range Corporation	Y	Y	-	Y	-	Y	Y	-	Y (BI,CDD,SS)	-
Whirlpool[††]	Y	Y	Y	-	-	-	-	-	-	-
Amana Appliances	-	Y	Y	Y	-	-	-	-	Y (SS)	Y
Maytag	-	Y	Y	Y	-	-	-	-	Y (SI,SS)	-
Estate Appliances	-	-	Y	-	-	-	-	-	-	-
Magic Chef & Ewave	-	-	Y	Y	Y	-	-	-	-	-
Gladiator Garage Works	-	Y	Y	-	-	-	-	-	-	-
Ikea	-	Y	Y	-	-	-	-	-	-	-
Inglis Home Appliances	-	Y	Y	-	-	-	-	-	-	-
Jenn-Air	-	Y	Y	-	-	Y	Y	-	Y (SS,SI,PI,CDD,BI)	-
Kitchen Aid	-	Y	Y	-	-	Y	-	Y	Y (BI,SS,PI)	Y
Roper Appliances	-	-	Y	-	-	-	-	-	-	-
Daewoo Electronics Co.	-	Y	-	-	Y	-	-	-	-	-
Gorenje USA, Inc.	-	Y	NA	NA	NA	NA	NA	NA	NA	NA
Organizacion Mabe[#]	-	Y	Y	-	Y	-	-	-	-	-
Camco Inc.	-	Y	Y	Y	Y	-	-	-	Y (SI,SS,PI)	-
Moffat	-	Y	Y	-	-	-	-	-	-	-
Summit Appliances	-	Y	Y	Y	Y	-	-	Y	-	Y
Atlas Eléctrica[##]	-	-	NA	NA	NA	NA	NA	NA	NA	NA
Indesit Company[###]	-	-	Y	-	-	-	-	Y	-	-

Manufacturer Name	AHAM Member	E* Products	Std Refrig-Freezer	Freezer	Com-pact	Built-In	Custom Door/Inter.	Under Counter	Luxury Unit[oo]	Other″
WiniaMando Inc.	-	-	-	-	-	-	-	-	-	Kimchi
Kenmore[^^]	-	Y	Y	Y	Y	-	-	-	-	-

* Owns Marvel Industries and Northland Corp.
** Includes Frigidaire and White Westinghouse brands.
*** Includes Hotpoint and Monogram brands.
†† Includes the following brands: Amana Appliances, Maytag, Estate Appliances, Magic Chef & Ewave, Gladiator Garage Works, Ikea, Inglis Home Appliances, Jenn-Air, Kitchen Aid, Roper Appliances.
# 48 percent owned by GE. Includes Moffat brand. Owns Camco Inc.
20 percent owned by Electrolux.
Includes Aritson brand.
^^ Brand names that are produced by more than one mfg.
oo SS=Stainless Steel; BI=Built-In; CDD=Customized Designed Door; TD=TV in Door; SI=Size; CB=Convertible; PI=Price
″ Units included: units with more than three doors, units for 'compact kitchens'; refrigerated drawers; commercial-size units

Table 3.2.2 also indicates the types of products that each manufacturer produces. Product types include: standard-size refrigerator-freezers, freezers, compact units, built-in units, custom units, undercounter units, luxury units, and other types. Other types include: units with more than three doors, units for 'compact kitchens' other than compact refrigerators, refrigerated drawers, and commercial-size units.

3.2.3.2 Refrigerator, Refrigerator-Freezer, and Freezer Manufacturer Market Shares

Appliance magazine provides market share data for the most significant manufacturers (*i.e.*, manufacturers with the greatest sales) for the following four product types: (1) standard-size refrigerators and refrigerator-freezers, (2) compact refrigerators, (3) built-in/undercounter refrigerators, and (4) freezers.[4] Table 3.2.3 through Table 3.2.6 show how market shares have changed over at least a ten-year period. Market shares among the largest manufacturers of standard-size refrigerator-freezers have remained relatively stable. Whirlpool Corporation (Whirlpool)'s 2006 acquisition of Maytag Corporation (Maytag) (discussed below) now gives Whirlpool the largest U.S. market share. Also, Haier America Trading, LLC (Haier), a relatively recent entrant to the market, captured six percent of the market in 2008.

Table 3.2.3 Standard-Size Refrigerator-Freezer Manufacturer Market Shares

	Market Share							
Company	**2008**	**2007**	**2006**	**2005**	**2004**	**2002**	**2000**	**1995**
GE	27%	29%	29%	29%	29%	36%	34%	35%
Electrolux	23%	25%	25%	25%	25%	26%	21%	17%
Whirlpool	33%	25%	25%	25%	25%	23%	24%	27%
Maytag	NA	10%	10%	11%	11%	13%	14%	10%
Goodman/Raytheon (Amana)	NA	NA	0%	0%	0%	0%	5%	10%
Haier	6%	4%	3%	2%	2%	2%	0%	0%
W.C. Wood	1%	1%	1%	1%	0%	0%	0%	0%
Other	10%	6%	7%	7%	8%	0%	2%	1%

Source: *Appliance* magazine

The market for compact refrigerators has seen a dramatic shift since 1993 (Table 3.2.4). SANYO North America Corporation (Sanyo) had the largest market share by far in 1993, but now accounts for only seven percent of the market. Haier now has the largest compact refrigerator market share, followed by the joint venture between GE and Mexican appliance company Grupo P.I. Mabe S.A. (Mabe).

Table 3.2.4 Compact Refrigerator Manufacturer Market Shares

Company	Market Share						
	2007	**2006**	**2005**	**2004**	**2002**	**1997**	**1993**
Haier	22%	21%	20.1%	20%	NA	15%	0%
GE/Mabe	16%	16%	16.7%	17%	NA	18%	17%
Sanyo	7%	7%	7.3%	8%	NA	58%	61%
U-Line	5%	5%	4.8%	0%	NA	0%	0%
Danby	3%	3%	2.9%	3%	NA	0%	0%
Avanti	1%	2%	2.5%	0%	NA	0%	0%
Whirlpool/Consul	1%	2%	1.9%	0%	NA	2%	2%
Marvel	2%	2%	1.6%	0%	NA	0%	0%
Wanbao	NA	0%	0%	0%	NA	5%	12%
Others	43%	42%	42.2%	52%	NA	2%	8%

Source: *Appliance* magazine

The reported market for built-in undercounter units has remained relatively stable over the past ten years (Table 3.2.5). The data show that U-Line Corporation (U-Line) has the greatest market share. Note that this market share distribution does not include full-size built-in products.

Table 3.2.5 Built-In Undercounter Refrigerator Manufacturer Market Shares

Company	Market Share						
	2007	**2006**	**2005**	**2004**	**2002**	**2000**	**1995***
U-Line	69%	70%	69%	67%	65%	75%	58%
Marvel	21%	21%	21%	22%	25%	14%	27%
Sub-Zero	6%	6%	6%	7%	6%	10%	12%
Others	4%	3%	4%	4%	4%	1%	3%

Source: *Appliance* magazine; * 1995 data includes compact refrigerators.

Market share data for full-size built-in refrigerators and refrigerator-freezers is not publicly available. Key manufacturers in this product category include Sub-Zero, General Electric's Monagram line, Whirlpool's Kitchenaid line, Viking, and Northland. Manufacturers providing imported products for this market include Liebherr, Bosch, and Miele. AHAM has recently begun collecting shipment data on built-in products. The percentage of overall shipments represented by built-in products has fluctuated between 2005 and 2007 between 1.6% and 2.2%. This includes both full-size and compact (undercounter) built-in products. This data was provided by AHAM as part of the preliminary analysis phase of this rulemaking.

For chest and upright freezers, Electrolux has retained the largest market share for ten years (Table 3.2.6). Haier, which was not in the market in 1995, now captures 16 percent of the market. W.C. Wood was liquidated in 2009 and no longer produces freezers.

Table 3.2.6 Chest/Upright Freezer Manufacturer Market Shares

	Market Share							
Company	**2008**	**2007**	**2006**	**2005**	**2004**	**2002**	**2000**	**1995**
Electrolux (Frigidaire)	64%	66%	66%	67%	68%	68%	69%	67%
W.C. Wood	19%	20%	21%	21%	22%	21%	27%	30%
Haier	16%	13%	12%	11%	9%	9%	3%	0%
Sanyo	1%	1%	1%	1%	1%	2%	1%	1%
Whirlpool	0%	NA	0%	0%	0%	0%	0%	1%
Others	0%	NA	0%	0%	0%	0%	0%	1%

Source: *Appliance* magazine

3.2.3.3 Mergers and Acquisitions

The appliance manufacturing industry has had a continuous history of consolidation. Maytag acquired Jenn-Air Corporation (Jenn-Air) in 1982, Magic Chef, Inc. (Magic Chef) in 1986, and Amana Appliances (Amana) in 2001. Whirlpool acquired the KitchenAid division of Hobart Corporation (KitchenAid) in 1986. White Consolidated Industries (WCI) acquired Frigidaire in 1979, and AB Electrolux acquired WCI (including Frigidaire) in 1986.

Mergers and acquisitions have two purposes. First, they produce large corporations with the financial resources and stability to be successful in a competitive market. Second, mergers and acquisitions mean manufacturers can have a complete line of home appliances. This product diversification allows firms to offer a complete set of appliances to consumers, an important feature in the builder market. There is also increasing worldwide competition in the major appliance market, so mergers and acquisitions are likely to continue.

On August 22, 2005, Whirlpool and Maytag announced plans to merge in a deal worth $2.7 billion.[5] Maytag shareholders approved the merger on December 22, 2005. The U.S. Department of Justice (DOJ) Antitrust Division initiated an investigation into the effects of the merger, including potential lessening of competition or the creation of a monopoly. Opponents of the merger asserted that the combined companies would control as much as 70 percent of the residential laundry market and as much as 50 percent of the residential dishwasher market.[6] Whirlpool claimed that its large potential residential laundry market share was skewed because the company produces washing machines for Sears, which sells them under its Kenmore in-house brand. Whirlpool further stated that it must periodically bid with other manufacturers to keep the Kenmore contract and that Sears controls the pricing of the Kenmore units.[7]

In early January 2006, U.S. Senator Tom Harkin and U.S. Representative Leonard Boswell called on the DOJ to block the merger, claiming it would give Whirlpool an unfair advantage in the home appliance industry. On March 29, 2006, DOJ closed its investigation and approved the merger. DOJ stated that "the proposed transaction is not likely to reduce competition substantially. The combination of strong rival suppliers with the ability to expand sales significantly and large cost savings and other efficiencies that Whirlpool appears likely to achieve indicates that this transaction is not likely to harm consumer welfare."[8]

The DOJ Antitrust Division focused its investigation on residential laundry, although it considered impacts across all products offered by the two companies. DOJ determined that the merger would not give Whirlpool market power in the sale of its products and that any attempt to raise prices would likely be unsuccessful. To support this claim, DOJ provided reasons including: (1) other U.S. brands, including Kenmore, GE, and Frigidaire, are well established; (2) foreign manufacturers, including LG and Samsung, are gaining market share; (3) existing U.S. manufacturers are below production capacity; (4) the large home appliance retailers have alternatives available to resist price increase attempts; and (5) Whirlpool and Maytag substantiated large cost savings and other efficiencies to benefit consumers.[8]

Whirlpool and Maytag completed the merger on March 31, 2006.

In May 2009, W.C. Wood, a major freezer manufacturer, declared bankruptcy in Canada and the U.S. Attempts to sell W.C. Wood were unsuccessful, and on November 16, 2009, W.C. Wood entered liquidation. W.C. Wood had a long-standing relationship with Whirlpool as its freezer supplier. Whirlpool purchased the W.C. Wood facility and assets in Ottawa, OH in December 2009. W.C. Wood had the second largest market share of all freezer manufacturers at the time of its exit from the industry, so the competitive landscape for standard size freezers will change in 2010 and beyond.

3.2.3.4 Distribution Channels

Most residential refrigerators and freezers move directly from manufacturers to retail outlets. Table 3.2.7 identifies the types of retail stores through which major appliances, including refrigerators and freezers, are sold based on data from AHAM *2005 Fact Book*.[9]

Table 3.2.7 Major Appliance Sales by Channel

Type of Store	**Percentage of Appliance Purchases**
Department Store (such as Sears or Kohls)	34.7%
Appliance Store or Consumer Electronics Store	30.9%
Home Improvement Store (such as Lowe's or Home Depot)	23.8%
Discount Store (such as Wal-Mart or K-Mart)	2.0%
Membership Warehouse Club/Store (such as Sam's or Costco)	1.8%
Another type of store	6.8%

Source: AHAM *Fact Book*

A certain share of shipments is purchased through channels other than retail outlets, *e.g.*, by multi-family home builders for installation in new homes. The Consortium for Energy Efficiency (CEE) estimates that 20 to 30 percent of home appliance sales are commercial sales, *i.e.*, sales to single/multi-family builders, contractors, government, public housing, and multi-family property managers.[10] Because single-family builders typically do not include refrigerator-freezers as part of a home sale, the 20 to 30 percent estimate by CEE is probably too high for the refrigerator market.

3.2.3.5 Manufacturer Trade Groups

AHAM is the primary manufacturer trade group representing most manufactures of refrigerators, refrigerator-freezers, and freezers. AHAM provides services to its members including government relations; certification programs for room air conditioners, dehumidifiers, and room air cleaners; an active communications program; and technical services and research. In addition, AHAM conducts other market and consumer research studies and publishes a biennial *Major Appliance Fact Book*. AHAM also develops and maintains technical test procedures for various appliances to provide uniform, repeatable procedures for measuring specific product characteristics and performance features.

3.2.3.6 Compressor Manufacturers and Market Shares

Because the compressor is a key energy-using component of refrigerators, it is important to determine which compressor manufacturers are supplying the U.S. refrigerator market. According to three sources, Embraco is the compressor manufacturer with the largest global market share, although several other manufacturers have significant global market share as well.[11, 12] For the U.S. refrigerator market, based on data from Embraco, it has by far the largest market share.[13] Besides Embraco, there are five other major compressor manufacturers supplying the world refrigerator and freezer market: Appliances Components Companies (ACC), Tecumseh Compressor Company (Tecumseh), Danfoss Compressors GmbH, Matsushita Electric Industrial Co., Ltd. (Matsushita), and LG Electronics, Inc. (LG). Table 3.2.8 lists the compressor manufacturers and their estimated global and U.S. market shares.

Table 3.2.8 Compressor Manufacturers and World and U.S. Market Shares

	World Market Share			U.S. Market Share
Manufacturer	**2005***	**Year not specified****	**2006*****	**2001†**
Embraco	19.5%	~23%	25%	56%
ACC	15.0%	~20%	NA	NA
Tecumseh	13.5%	~8%	NA	NA
Matsushita	12.9%	~9%	18%	NA
LG	10.8%	~8%	NA	NA
Danfoss	8.9%	~9%	15%	<1%
Others	19.4%	~23%	NA	NA

Sources: *Universidade Federal de Santa Catarina, 2006; **Institute for Materials Science, Welding and Forming; ***Unable to cite source; †Embraco, 2001.

3.2.4 Regulatory Programs

The following section details current regulatory programs mandating energy conservation standards for refrigerator/freezers. It covers U.S. Federal energy conservation standards, State standards, standards in Canada and Mexico (which may impact the companies servicing the North American market), and international standards.

3.2.4.1 Federal Energy Conservation Standards

The National Appliance Energy Conservation Act of 1987 (NAECA) (42 U.S.C. 6291–6309) established efficiency standards for refrigerators and refrigerator-freezers with a total refrigerated volume of less than 1104 L (39 ft^3) and for freezers with a total refrigerated volume of less than 850 L (30 ft^3). Compact refrigerators and freezers represent separate product classes and have a volume less than 220 L (7.75 ft^3) *and* a height of 0.91 meters (36 inches) or less. The minimum efficiency levels depend on product class and adjusted volume. The adjusted volume is equal to the fresh food internal volume plus an adjustment factor which depends on the product type times the freezer internal volume. The adjustment factor is 1.63 for refrigerator-freezers, 1.44 for refrigerators with freezer compartments, 1.00 for all-refrigerators (which may have a freezer compartment with less than 0.5 ft^3 volume), and 1.73 for freezers. Maximum annual energy use is expressed as kilowatt-hours (kWh) per year (yr). Note the these adjustment factors have changed under the new test procedure.

NAECA initially established energy conservation standards for refrigerator-freezers that became effective in 1990. DOE amended NAECA with new standards that went into effect in 1993, followed by the current amended standards that became effective in July 2001. Refrigerator-freezers manufactured to meet the 2001 standard typically consume about 30 percent less energy than required under the 1993 efficiency regulations. The 1993 and 2001 standards are summarized in Table 3.2.9 below.

Table 3.2.9 Federal Energy Efficiency Standards for Refrigerators, Refrigerator-Freezers, and Freezers

Product Class	Energy Standard Equations for Maximum Energy Use (kWh/yr)	
	Effective January 1, 1993	Effective July 1, 2001
1. Refrigerators and refrigerator-freezers with manual defrost.	13.5AV+299 0.48av+299	8.82AV+248.4 0.31av+248.4
2. Refrigerator-freezer—partial automatic defrost.	10.4AV+398 0.37av+398	8.82AV+248.4 0.31av+248.4
3. Refrigerator-freezer—automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerator—automatic defrost.	16.0AV+355 0.57av+355	9.80AV+276.0 0.35av+276.0
4. Refrigerator-freezers—automatic defrost with side-mounted freezer without through-the-door ice service.	11.8AV+501 0.42av+501	4.91AV+507.5 0.17av+507.5
5. Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service.	16.5AV+367 0.58av+367	4.60AV+459.0 0.16av+459.0
6. Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service.	17.6AV+391 0.62av+391	10.20AV+356.0 0.36av+356.0
7. Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service.	16.3AV+527 0.58av+527	10.10AV+406.0 0.36av+406.0
8. Upright freezers with manual defrost.	10.3AV+264 0.36av+264	7.55AV+258.3 0.27av+258.3
9. Upright freezers with automatic defrost.	14.9AV+391 0.53av+391	12.43AV+326.1 0.44av+326.1
10. Chest freezers and all other freezers except compact freezers.	11.0AV+160 0.39av+160	9.88AV+143.7 0.35av+143.7
11. Compact refrigerators and refrigerator-freezers with manual defrost.	13.5AV+299* 0.48av+299*	10.70AV+299.0 0.38av+299.0
12. Compact refrigerator-freezer—partial automatic defrost.	10.4AV+398* 0.37av+398*	7.00AV+398.0 0.25av+398.0
13. Compact refrigerator-freezers—automatic defrost with top-mounted freezer and compact all-refrigerator—automatic defrost.	16.0AV+355* 0.57av+355*	12.70AV+355.0 0.45av+355.0
14. Compact refrigerator-freezers—automatic defrost with side-mounted freezer.	11.8AV+501* 0.42**+501*	7.60AV+501.0 0.27av+501.0
15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.	16.5AV+367* 0.58av+367*	13.10AV+367.0 0.46av+367.0
16. Compact upright freezers with manual defrost.	10.3AV+264* 0.36av+264*	9.78AV+250.8 0.35av+250.8
17. Compact upright freezers with automatic defrost.	14.9AV+391* 0.53av+391*	11.40AV+391.0 0.40av+391.0
18. Compact chest freezers.	11.0AV+160* 0.39av+160*	10.45AV+152.0 0.37av+152.0
5A. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service.	NA	5.0AV+539.0 0.18av+539.0
10A. Chest freezers with automatic defrost.	NA	14.76AV+211.5 0.52av+211.5

AV: Adjusted Volume in ft^3; av: Adjusted Volume in L

* Applicable standards for compact refrigerator products manufactured before July 1, 2001. Compact refrigerator products are not separate product categories under the standards effective January 1, 1993.

As discussed in section 3.2.1, two of the product classes listed in the table were made effective through the exception relief process of the Office of Hearings and Appeals. These product classes include (5A) automatic defrost refrigerator-freezers with bottom-mounted freezer and TTD ice service, and (10A) automatic defrost chest freezers.

The Energy Independence and Security Act of 2007 (EISA) (P.L. 110-140), requires that DOE publish a final rule no later than December 31, 2010 to determine whether to amend the standards in effect for refrigerators, refrigerator-freezers, and freezers manufactured on or after January 1, 2014.

3.2.4.2 State Energy Conservation Standards

As part of its Title 20 Appliance Efficiency Regulations, the California Energy Commission (CEC) has established standards for consumer refrigeration products that are not covered by Federal standards. CEC set standards for wine chillers (Table 3.2.10) and freezers that have a total refrigerated volume greater than 850 L (30 ft^3) (Table 3.2.11).[14] The standards for freezers with volume greater than 30 ft^3 are numerically identical to the federal standards for smaller freezers—the California standards simply extend the federal standards beyond the federal size limitation.

Table 3.2.10 California Standards for Wine Chillers

Appliance	**Maximum Annual Energy Consumption (kWh)**
Wine chillers with manual defrost	13.7V + 267
Wine chillers with automatic defrost	17.4V + 344

V = volume in ft^3.

Table 3.2.11 California Standards for Freezers with Volume Greater than 30 cubic feet

Appliance	**Maximum Annual Energy Consumption (kWh)**
Upright Freezers with manual defrost	7.55AV + 258.3
Upright Freezers with automatic defrost	12.43AV + 326.1
Chest Freezers	9.88AV + 143.7

AV = adjusted total volume, expressed in ft^3, which is 1.73 times freezer volume (in ft^3).

3.2.4.3 Canadian Energy Conservation Standards

Refrigerators and freezers are regulated products in Canada under the Canadian Energy Efficiency Regulations. The regulations reference Canadian Standards Association (CSA) CAN/CSA-C300-00, *Energy Performance and Capacity of Household Refrigerators, Refrigerator-Freezers, and Freezers,* for the testing procedure and for maximum annual energy consumption (MAEC) limits for residential refrigerators, refrigerator-freezers, and freezers. The product classes and MAEC limits in the Canadian regulations are the same as in the U.S. Federal standards.

In November 2006, Canada added two new product types to its Regulations (Amendment 9) to harmonize with recent U.S. rulings with respect to these products.[15] These product types are refrigerator-freezers with automatic defrost and with a bottom-mounted freezer with TTD ice service and chest freezers with automatic defrost system. The maximum energy use regulations, listed in Table 3.2.12 below, are identical to the energy standards that DOE's Office of Hearings and Appeals assigned to these classes.

Table 3.2.12 Canadian Energy Standards for Added Refrigerator and Freezer Product Classes

Appliance	**Maximum Annual Energy Consumption (kWh)**
Product Class 5A: refrigerator-freezers with automatic defrost and with bottom-mounted freezers with TTD ice service	0.18av+539
Product Class 10A: chest freezers with automatic defrost system	0.52av + 211.5

av = adjusted volume in liters

Natural Resources Canada (NRCan)'s Office of Energy Efficiency (OEE) amended Canada's Energy Efficiency Regulations to add energy performance standards for residential wine chillers (or wine coolers).[16] The standard includes a test procedure and minimum energy performance standard levels for wine chillers harmonized with those in effect in California. Table 3.2.13 below shows the maximum annual energy consumption limits (in kWh) for residential wine chillers.

Table 3.2.13 Canadian Standards for Wine Chillers

Appliance	**Maximum Annual Energy Consumption (kWh)**
Wine chillers with manual defrost	0.48av + 267
Wine chillers with automatic defrost	0.61av + 344

av = adjusted volume in L.

3.2.4.4 Mexican Energy Conservation Standards

The Mexican Official Standard establishes the maximum energy consumption limits for household refrigerators and freezers using hermetic motor-driven compressors, specifies the test methods for determining such energy consumption and the total refrigerated volume, and provides energy consumption label requirements. This standard applies to household refrigerators up to 1,104 cubic decimeters (39 ft^3) and household freezers of up to 850 cubic decimeters (30 ft^3) using hermetic motor-driven compressors.[17] The new standard levels (NOM-015-ENER-2002) became effective in May 2003.

3.2.4.5 Efficiency Standards Outside North America

According to the Collaborative Labeling and Appliance Standards Program (CLASP) database, all 15 original European Union (EU) member countries, plus 16 other countries outside

North America, have mandatory energy efficiency standards for refrigerator-freezers.[18] The countries other than the original EU member countries are: Algeria, Australia, Bahrain, Chile, China, Chinese Taipei, Costa Rica, Hungary, Indonesia, Iran, Israel, New Zealand, Philippines, Republic of Korea, Thailand, and Viet Nam.

In 2005, the European Parliament adopted a Commission proposal for a directive on establishing a framework for setting eco-design requirements (such as energy efficiency requirements) for all energy-using products in the residential, tertiary (services), and industrial sectors.[19] EU-wide rules for eco-design are intended to ensure that disparities among national regulations do not become obstacles to intra-EU trade. The directive does not directly introduce binding requirements for specific products, but does define conditions and criteria for setting requirements regarding environmentally relevant product characteristics (such as energy consumption), and allows these requirements to be improved quickly and efficiently. The directive will be followed by implementing measures that will establish the eco-design requirements.

It is difficult to compare the standards in other countries with those in the U.S. due to differences in test procedures. The development of an international test procedure under the auspices of the International Electrotechnical Commission has international test procedure harmonization as a key objective. Establishment of Standard IEC 62552, which is currently under development, should make it easier in future to compare international refrigeration product energy standard levels.

3.2.5 Voluntary and other Federal and State Programs

In addition to mandatory standards, there are voluntary programs—*e.g.*, the Federal Energy Management Program (FEMP) and CEE—as well as other Federal and State policies that affect the efficiency of new refrigerators and freezers.

3.2.5.1 ENERGY STAR

Historical ENERGY STAR Requirements

ENERGY STAR is a voluntary program administered by the U.S. government to promote energy efficient consumer products. Table 3.2.14 below shows the history of ENERGY STAR energy use criteria for each of the three covered product categories.

Table 3.2.14 History of ENERGY STAR Energy Use Criteria for Residential Refrigerators and Freezers

Product Group	1997 Initial Criteria	2001 Revision #1	2003 Addition of Freezers and Compacts	2004 Revision #2	2008 Revision #3
Standard-size Refrigerators & Refrigerator-Freezers	20% below 1993 Federal Standard	10% below 2001 Federal Standard	10% below 2001 Federal Standard	15% below 2001 Federal Standard	20% below 2001 Federal Standard
Standard-size Freezers	--------	--------	10% below 2001 Federal Standard	10% below 2001 Federal Standard	10% below 2001 Federal Standard
Compact Refrigerators & Freezers	--------	--------	20% below 2001 Federal Standard	20% below 2001 Federal Standard	20% below 2001 Federal Standard

Prior to the 2008 ENERGY STAR revision, the market share of ENERGY STAR-compliant full-size refrigerators and refrigerator-freezers was near 30%.[20] Within this category, approximately 20 percent of top- and bottom-mount and 50 percent of side-mount refrigerator-freezer units sold in the U.S. were ENERGY STAR compliant. Some States (*i.e.*, Massachusetts, Michigan) have waived state sales tax for purchase of appliances that meet ENERGY STAR levels.

New ENERGY STAR requirements effective in 2008

The current ENERGY STAR criteria, drafted with input from stakeholders and two rounds of public comments, went into effect on April 28, 2008. To support the change, ENERGY STAR released a market analysis[20] and a final report on proposed program requirements.[21] Table 3.2.15 shows the number of models that met the current Federal standard for refrigerators and available models with efficiencies 15 percent, 20 percent, and 25 percent higher than the Federal standard, as of April 2007 (prior to the 2008 revision). ENERGY STAR program staff deemed the number of models offered to consumers at the higher efficiencies to be sufficient to warrant changing the labeling criteria.

Table 3.2.15 Efficiency of Standard Refrigerators and Refrigerator-Freezers on the Market Relative to Current Federal Standard

Efficiency Level	Number of Available Models (prior to 2008 criteria revision)	Percent of Available Models (prior to 2008 criteria revision)
Current Federal Standard (effective July 2001)	2,524	100%
2004 ENERGY STAR Criteria (15% better than Federal Standard)	1,441	57%
2008 ENERGY STAR Criteria (20% better than Federal Standard)	121	4.8%
25% better than Federal Standard	14	0.6%

Source: ENERGY STAR, April 27, 2007[20]

3.2.5.2 Federal Energy Management Program

DOE's FEMP[b] works to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites. FEMP helps Federal buyers identify and purchase energy-efficient equipment, including residential refrigerators and freezers.

Federal agencies are required by the Energy Policy Act of 2005 (EPACT 2005, P.L. 109-58) and Federal Acquisition Regulations (FAR) Subpart 23.2 to specify and buy ENERGY STAR-qualified products or, in categories with no ENERGY STAR label, FEMP-designated products which are among the highest 25 percent of equivalent products for energy efficiency. Table 3.2.16 below shows refrigerator and freezer performance requirements for Federal purchases.

[b] For more information, please visit www.eere.energy.gov/femp.

Table 3.2.16 Performance Requirement for Federal Purchases of Refrigerators and Freezers

Product Class	Total Volume* (ft^3)	Product Class Number(s)***	Annual Energy Use**
Single–Door Manual Defrost	≤2.4	11	255 kWh/year or less
Single–Door Manual Defrost	2.5 to 4.4	11	275 kWh/year or less
Single–Door Manual Defrost	4.5 to 6.4	11	295 kWh/year or less
Single–Door Manual Defrost	≥6.5	1 or 11	315 kWh/year or less
Single–Door Automatic Defrost	≤2.4	13	305 kWh/year or less
Single–Door Automatic Defrost	2.5 to 4.4	13	325 kWh/year or less
Single–Door Automatic Defrost	4.5 to 6.4	13	345 kWh/year or less
Single–Door Automatic Defrost	≥6.5	3 or 13	365 kWh/year or less
Bottom–Mount Freezer	≤18.4	5, 5A, or 15	475 kWh/year or less
Bottom–Mount Freezer	18.5 to 20.4	5 or 5A	485 kWh/year or less
Bottom–Mount Freezer	≥20.4	5 or 5A	495 kWh/year or less
Top–Mount Freezer	≤10.4	3, 6, or 13	340 kWh/year or less
Top–Mount Freezer	10.5 to 12.4	3 or 6	360 kWh/year or less
Top–Mount Freezer	12.5 to 14.4	3 or 6	380 kWh/year or less
Top–Mount Freezer	14.5 to 16.4	3 or 6	400 kWh/year or less
Top–Mount Freezer	16.5 to 18.4	3 or 6	420 kWh/year or less
Top–Mount Freezer	18.5 to 20.4	3 or 6	440 kWh/year or less
Top–Mount Freezer	20.5 to 22.4	3 or 6	460 kWh/year or less
Top–Mount Freezer	22.5 to 24.4	3 or 6	480 kWh/year or less
Top–Mount Freezer	≥24.5	3 or 6	500 kWh/year or less
Side-mount Freezer	≤20.4	4, 7, or 14	560 kWh/year or less
Side-mount Freezer	20.5 to 22.4	4 or 7	580 kWh/year or less
Side-mount Freezer	22.5 to 24.4	4 or 7	600 kWh/year or less
Side-mount Freezer	≥25.5	4 or 7	620 kWh/year or less

* Total volume is the sum of the refrigerator and freezer volumes.

** Annual Energy Use is based on DOE test procedure (10 CFR 430, subpart B, appendix A1).

*** Possible Product Class numbers based on Product Class Descriptions

3.2.5.3 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is a nonprofit corporation that promotes the manufacture and purchase of energy-efficient products and services. CEE promotes energy-efficient refrigerators that use significantly less electricity than the Federal standard. These energy-efficient refrigerators represent the upper end of the ENERGY STAR efficiency levels. Effective January 1, 2007, CEE identifies three tiers for “super-efficient” refrigerators and refrigerator-freezers. Table 3.2.17 below provides the specifications for the CEE.

Table 3.2.17 CEE Tier Levels Refrigerators and Refrigerator-Freezers

Efficiency level	Percent Energy Use below Federal Standard	
	Standard Refrigerators	Compact Refrigerators
CEE Tier 1 (Current ENERGY STAR)	20	20
CEE Tier 2	25	25
CEE Tier 3	30	30

3.2.5.4 ENERGY STAR, FEMP, CEE Summary

Table 3.2.18 below presents maximum unit energy consumption (UEC) values for the current Federal standard and the ENERGY STAR and CEE voluntary standards for (1) a top-mount refrigerator-freezer with automatic defrost with no TTD ice features and 21.4 ft^3 adjusted volume, and (2) a side-mount refrigerator freezer with TTD features and 26.2 ft^3 adjusted volume.

Table 3.2.18 Annual Energy Consumption for Refrigerator-Freezers with Different Specifications

Efficiency Level	Top Mount*	Side-Mount**
2001 Federal Standard	486	671
Former ENERGY STAR (15% below standard)	413	570
CEE Tier 1, current ENERGY STAR (20% below standard)	389	537
CEE Tier 2 (25% below standard)	364	503
CEE Tier 3 (30% below standard)	340	469

* Auto defrost, no TTD features, 18.2 ft^3 total volume, and 21.4 ft^3 adjusted volume.
** Auto defrost, TTD features, 21.7 ft^3 total volume, and 26.2 ft^3 adjusted volume.
Source: DOE FY-2005 Priority Setting TSD; based on ENERGY STAR (2004),[22] FEMP (2005)[23] CEE (2004)[24]

3.2.5.5 Manufacturer Tax Credits for Energy-Efficient Appliances

EPACT 2005 provided tax credits to manufacturers for the production of energy-efficient residential refrigerators. These credits were intended to help manufacturers meet the costs of producing appliances that exceed the Federal standards. The credit program was modified by the Emergency Economic Stabilization Act of 2008 (EESA 2008) and extended through 2010.[25] The credit for residential refrigerators is a per-product credit (see Table 3.2.19). For more information on manufacturer tax credits, refer to appendix 12-C.

Table 3.2.19 Manufacturer Tax Credits for Energy-Efficient Appliances in EESA 2008

Savings relative to 2001 Federal Standard	Applicable Credit Amount	Applicable Years
20% to 22.9%	$50	2008
23% to 24.9%	$75	2008, 2009
25% to 29.9%	$100	2008, 2009, 2010
30% or more	$200	

Notes: 'Refrigerators' refers to residential automatic defrost refrigerator-freezers with an internal volume of at least 16.5 ft^3.

3.2.5.6 Rebates for Highly Energy-Efficient Products

Electric utilities and other organizations promote the purchase of highly energy-efficient refrigerators through consumer rebates. Typically, these programs offer rebates for products meeting existing ENERGY STAR efficiency levels. Some utilities also offer incentives to retire old and inefficient appliances by offering rebates and disposal services for recycling old units in order to encourage consumers to purchase new, more efficient units and to ensure the safe disposal of hazardous waste. Table 3.2.20 below lists some rebates that are offered in 2010.

Table 3.2.20 Rebates Offered for Highly Energy-Efficient Refrigerators and Recycled Refrigerators in 2010

Utility/Organization*	Rebate Level
Ameren Illinois Utilities	$35 (recycling)
Avista Utilities	$25 (ENERGY STAR)
BC Hydro	$50 (ENERGY STAR), $30 (recycling)
Bonneville Power Administration	$25 (ENERGY STAR), $125 (recycling)
City of Palo Alto Utilities	$50 (ENERGY STAR), $35 (recycling)
Commonwealth Edison	$50 (ENERGY STAR)
Efficiency Maine	$75 (ENERGY STAR)
Efficiency Vermont	$25 (ENERGY STAR), $50 (CEE Tier 2), $30 (recycling)
Energy Trust of Oregon	$50 (ENERGY STAR and CEE Tier 1)
Eugene Water & Electric Board	$25 (ENERGY STAR), $30 (recycling)
Idaho Power Company	$30 (ENERGY STAR)
Long Island Power Authority	$75 (ENERGY STAR), $35 (recycling)
Midwest Energy Efficiency Alliance – Illinois	15% off (ENERGY STAR), $75 (recycling)
Midwest Energy Efficiency Alliance – Indiana	$30 (recycling)
Public Service Company of New Mexico	$30 (recycling)
Puget Sound Energy	$30 (recycling)
San Diego Gas and Electric	$25 (ENERGY STAR)
Seattle City Light	$30 (recycling)
Snohomish Public Utility District	$50 (ENERGY STAR), $30 (recycling)
Tacoma Power	$30 (recycling)

* The table includes those programs listed as providing specified rebates for ENERGY STAR refrigerators in the publication "Summary of Residential Appliance Programs in the United States and Canada," by CEE, April 2010. Additional programs may exist.

3.2.5.7 State Tax Incentives for Highly Energy-Efficient Products

According to the Database of State Incentives for Renewables & Efficiency (DSIRE)[26], Michigan and Oregon offer personal tax credits for the purchase of premium-efficiency refrigerators. Missouri, North Carolina, Virginia, and West Virginia offer sales tax incentives for premium-efficiency refrigerators by offering 100% sales tax exemptions at certain times throughout the year.

3.2.6 Historical Shipments and Efficiencies

3.2.6.1 Historical Shipments

Two public sources of information provide historical shipments data on residential refrigerators, refrigerator-freezers, and freezers: *Appliance* magazine[27] and the AHAM *Fact Book*.[9] *Appliance* magazine breaks down refrigerator and refrigerator-freezer shipments into three groups: (1) standard-size units, (2) built-in units, and (3) compact units. Both sources break down freezer shipments into chest and upright units. Unfortunately, neither source provides any further level of disaggregation. As discussed below, standard-size shipments can be broken down into two broad groups: (1) top- and bottom-mount refrigerators and refrigerator-freezers, and (2) side-mount units.

Figure 3.2.1 shows historical shipments of refrigerators and refrigerator-freezers. Figure 3.2.2 shows historical shipments of freezers. In the past decade, annual shipments of standard refrigerator-freezers have grown from 8 million to 11 million, although shipments have dropped off significantly in 2007 and 2008 in response to poor economic conditions. Annual shipments of compact refrigerators grew from one million to roughly 3 million, but shipments dropped starting in 2006. Note that the data for refrigerators include products used in non-residential settings (e.g., hotels and offices), but the size of this market segment is unknown.

Shipments of chest and upright freezers have grown less rapidly than those of standard refrigerator-freezers. These shipments rose from 1.5 million in 1997 to 2.5 million in 2002, but shipments dropped starting in 2005 and are now at 2 million annually. Shipments of compact freezers are roughly 0.5 million.

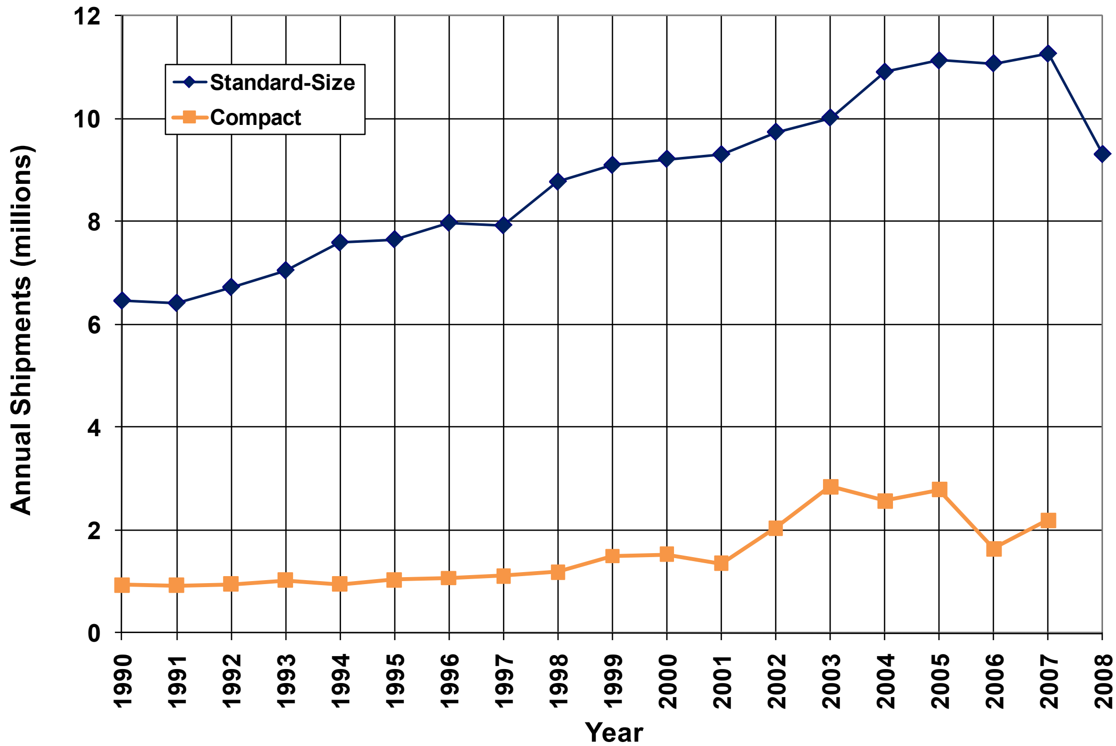

Figure 3.2.1 Annual Shipments of Refrigerators and Refrigerator-Freezers

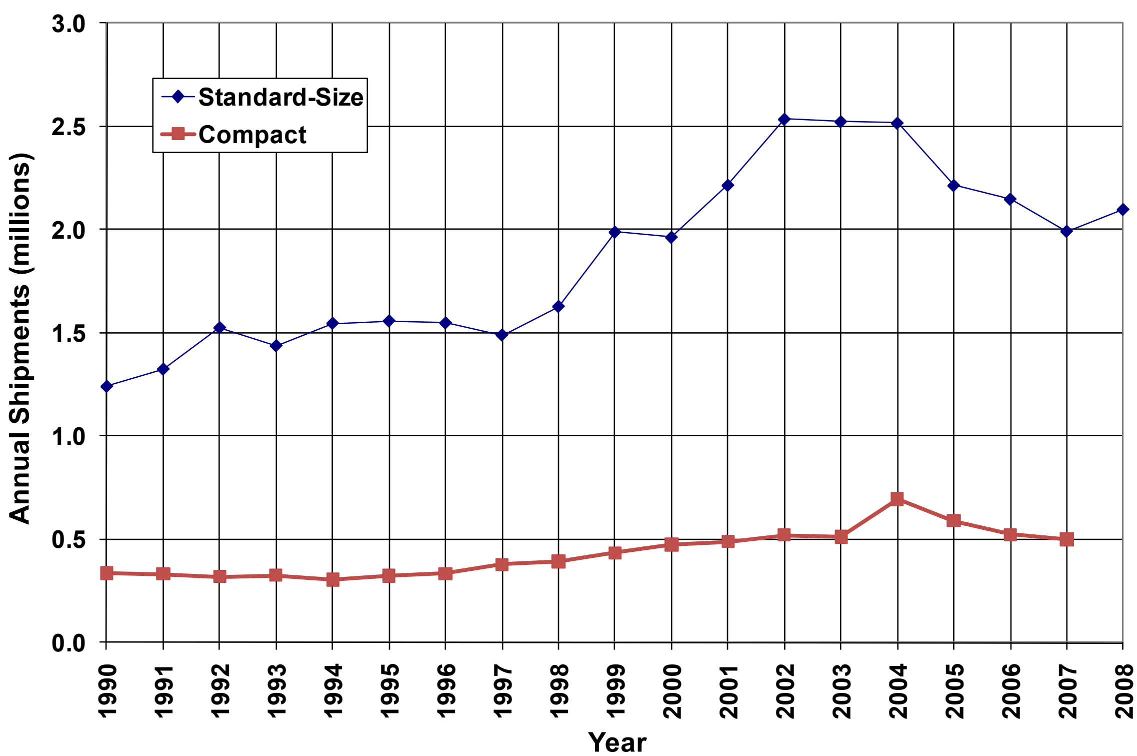

Figure 3.2.2 Annual Shipments of Freezers

For DOE's 2005 technical analysis of amended energy conservation standards for residential refrigerator-freezers, AHAM provided historical shipments data for the time period 1998–2004, broken down into three broad groups: (1) top- and bottom-mount refrigerator-freezers, (2) side-mount units, and (3) single-door units.[28] Table 3.2.21 below shows market share data for only two of the above three groups—top- or bottom-mount refrigerator-freezers and side-mount refrigerator-freezers. According to DOE's 2005 technical analysis, these two product groupings account for over 99 percent of standard-size refrigerator-freezer shipments. Data provided by AHAM as part of the preliminary analysis phase shows that in recent years single-door units accounted for 0.2% or less of shipments of standard-size refrigerators and refrigerator-freezers. This data also shows a strong shift towards bottom-mount refrigerator-freezers in the last few years, coinciding with reduction in market share of both side-mount and top-mount refrigerator-freezers.

Table 3.2.21 Market Shares of Standard Refrigerator-Freezer Product Classes

Year	Top- Mount Refrigerator- Freezer (percent)	Bottom- Mount Refrigerator- Freezer (percent)	Side-Mount Refrigerator-Freezer (percent)
1998	69.3		29.9
1999	68.8		30.8
2000	68.3		31.3
2001	67.5		32.1
2002	66.6		32.8
2003	63.7		34.5
2004	63.4		35.1
2005	62.5	2.0	35.2
2006	54.5	10.6	34.6
2007	53.9	13.6	32.4

Source: AHAM

Based on data from The NPD Group for 2004,[29] DOE estimated that (1) top-mount refrigerator-freezers without TTD ice service in the size category range of 14 to 21 ft^3 [c] comprise 81 percent of total top- and bottom-mount refrigerators, and (2) side-mount refrigerator-freezers with TTD ice service in the size category range of 21 to 30 ft^3 comprise 98 percent of total side-mount refrigerator-freezer shipments.

3.2.6.2 Historical Efficiencies

The average efficiency of new refrigerators and freezers has increased greatly since the 1980s. Figure 3.2.3 below (which shows annual electricity consumption) indicates the changes in efficiency resulting from the Federal standards that took effect in 1990, 1993, and 2001. Note that the average efficiency trends shown in the chart reflect changes in product size and features as well as changes in the efficiency within specific types of products. In particular, the growing

[c] Size category is based on ft^3 of total refrigerated volume (fresh food volume plus freezer volume).

market share of side-mount refrigerator-freezers placed upward pressure on the average annual electricity use of new refrigerator-freezers.

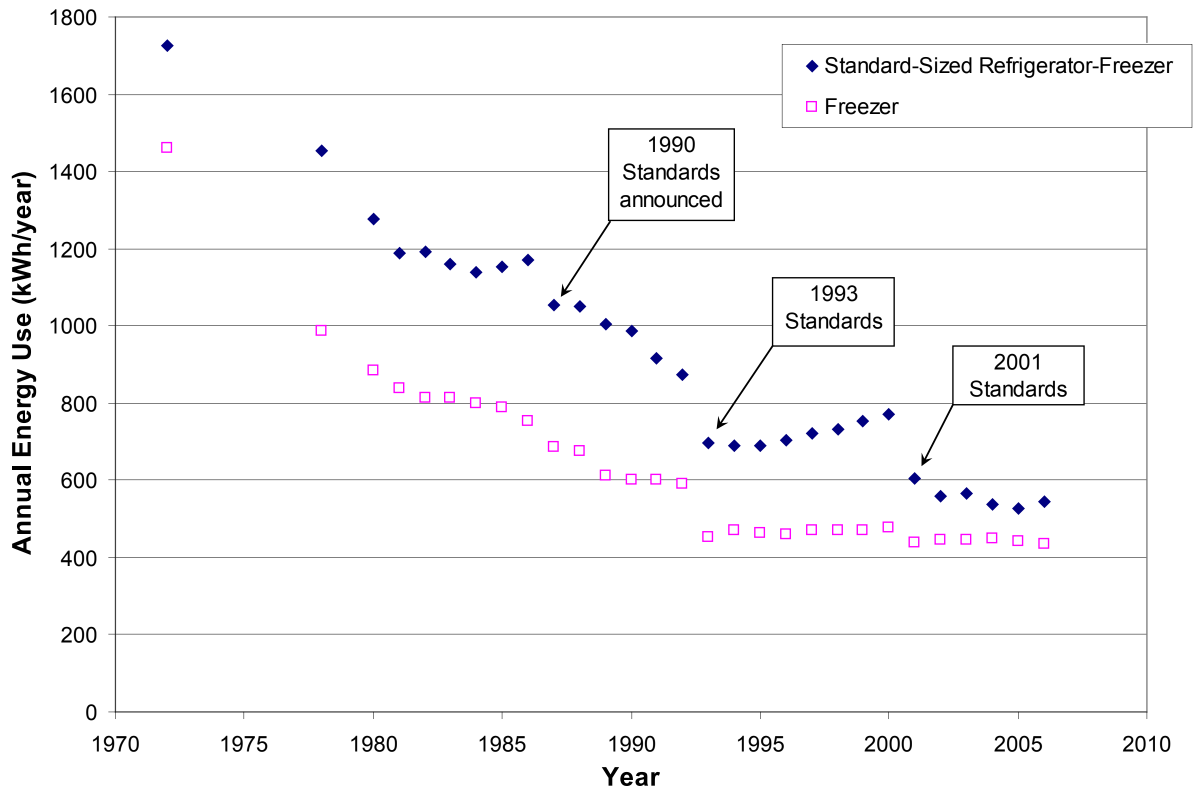

Figure 3.2.3 Average Annual Electricity Use of New Refrigerator-Freezers and Freezers
Source: AHAM

ENERGY STAR sales data are an indicator of the demand for very energy-efficient products. The market share of ENERGY STAR labeled refrigerator-freezers grew from 17 percent in 2001 to 33 percent in 2004 (Table 3.2.22) and held steady in the low 30 percent range in the following two years.[30]

Table 3.2.22 Sales of ENERGY STAR Labeled Refrigerator-Freezers

Year	Energy Star Criteria	Percent of Total
1998	20% below 1993 Standard	19%
1999		24%
2000		27%
2001	10% below 2001 Standard	17%
2002		20%
2003		26%
2004	15% below 2001 Standard	33%
2005		33%
2006		31%

Source: ENERGY STAR

3.2.6.3 Imports and Exports

The share of domestic shipments of refrigerators and freezers accounted for by imports grew significantly in the 1994-2004 period. Refrigerator imports totaled nearly six million units in 2004. Over one-third of the imports came from Mexico. Freezer imports totaled around one million units in 2004.[9]

Annual refrigerator exports—mostly to Canada—were in the 1.0 to 1.1 million units range in the 1994-2004 period, while annual freezer exports ranged between 200,000 and 250,000 units. [9]

3.2.7 Saturation in U.S. Homes

Saturation refers to the percentage of homes with a given product. DOE used four primary sources of information on the saturation and ownership of refrigerators, refrigerator-freezers, and freezers in U.S. homes: (1) a 2001 report prepared for AHAM by NFO Research, Inc.,[31] (2) *Appliance* magazine, (3) the Energy Information Administration (EIA)'s Residential Energy Consumption Survey (RECS),[32,33,34] and (4) a 2005 AHAM report entitled *Major Appliance Saturation & Marketing Factors Study*.[35] Only RECS provides market saturations for recently-built housing; this information is useful for forecasting future shipments to new housing.

The saturation of standard refrigerators has been close to 100 percent for two decades (Table 3.2.23). The RECS data show that the share of households with two or more refrigerators grew from 13 percent in 1993 to 15 percent in 2001 and to 19 percent in 2005 (the current percentage with two or more is likely even higher).

Table 3.2.23 Standard Refrigerator Saturation in U.S. Homes in 1987–2008 Period

Year	Refrigerators, Standard				
	Appliance Magazine	NFO 2001	RECS		
			All	1 unit	2 or more
1987	99.9%				
1988					
1989					
1990		96.7%			
1991					
1992	99.0%				
1993	99.3%		98.6%	85.8%	12.8%
1994	99.5%				
1995	99.7%				
1996	99.8%	93.9%			
1997	99.8%		98.9%	85.8%	13.2%
1998	99.8%				
1999	99.8%				
2000	99.9%				
2001	99.0%	93.1%	99.3%	82.9%	14.6%
2002	99.0%				
2003	99.0%				
2004	99.0%				
2005	99.0%		99.9%	77.7%	19.2%
2006	99.0%				
2007	99.0%				
2008	99.0%				

The data on saturation of compact refrigerators vary greatly (Table 3.2.24). The estimates for 2005 vary from a low of 3.7 percent (RECS) to a high of 17.0 percent (*Appliance* magazine). Comparatively, NFO's estimate for 2001 is 5.6 percent.

Table 3.2.24 Compact Refrigerator Saturation in U.S. Homes in 1987–2008 Period

Year	Refrigerators, Compact				
	Appliance Magazine	NFO 2001	RECS		
			All	1 unit	2 or more
1987					
1988					
1989					
1990		7.4%			
1991					
1992	7.4%				
1993	8.7%		3.2%	3.2%	0.0%
1994	9.2%				
1995	9.7%				
1996	11.2%	5.8%			
1997	12.1%		2.8%	2.8%	0.1%
1998	12.6%				
1999	14.5%				
2000	16.0%				
2001	16.5%	5.6%	3.1%	3.0%	0.1%
2002	16.5%				
2003	16.5%				
2004	17.0%				
2005	17.0%		3.7%	3.1%	0.6%
2006	18.0%				
2007	19.0%				
2008	19.0%				

The data on freezer saturation are also somewhat varied (Table 3.2.25). *Appliance* magazine reports that freezer saturation has risen from 40 percent in 1993 to 45 percent in 2005, but the NFO study reports that the 2001 level (41 percent) was lower than in 1990 (45 percent). RECS shows a much lower freezer saturation in 2001 (32 percent) than the other sources, and also shows a declining trend.

Table 3.2.25 Freezer Saturation in U.S. Homes in 1987-2008 Period

	Freezers				
			RECS		
Year	Appliance Magazine	NFO 2001	All	1 unit	2 or more
1987	40.7%				
1988					
1989					
1990		45.4%			
1991					
1992	38.2%				
1993	40.0%		34.5%	30.5%	4.0%
1994	40.0%				
1995	41.2%				
1996	42.5%	42.4%			
1997	42.4%		33.2%	30.2%	2.9%
1998	42.8%				
1999	42.9%				
2000	44.0%				
2001	47.0%	41.0%	32.0%	28.8%	3.2%
2002	47.5%				
2003	47.5%				
2004	47.0%				
2005	45.0%		31.6%	29.0%	2.6%
2006	43.0%				
2007	42.0%				
2008	43.0%				

As shown in Table 3.2.26, RECS data indicate that in new housing (1) the saturation of freezers is lower, and (2) the share of households with two or more refrigerators is higher in recently-built homes than in the total population of homes. For freezers, this result is in accordance with the declining saturation of freezers in the total population seen in Table 3.2.25.

Table 3.2.26 Refrigerator and Freezer Saturation in New U.S. Homes

	Standard Refrigerators			Freezers		
	New Homes*			New Homes*		
Year	All	1 unit	2 or more	All	1 unit	2 or more
1993	99.7%	90.4%	9.2%	30.3%	27.8%	2.5%
1994						
1995						
1996						
1997	99.6%	85.8%	13.8%	35.9%	33.1%	2.6%
1998						
1999						
2000						
2001	100%	82.5%	15.6%	28.4%	26.3%	2.1%
2002						
2003						
2004						
2005	100%	75.0%	26.1%	27.2%	23.9%	3.3%

Source: RECS surveys; * "New homes" refers to homes built in the 1988-1993 period for the 1993 RECS, the 1992-1997 period for the 1997 RECS, and the 1996-2001 period for the 2001 RECS, and the 2001-2005 period for the 2005 RECS.

3.2.8 Product Retail Prices

3.2.8.1 Historical Retail Prices

AHAM has reported average consumer retail prices for refrigerator-freezers and freezers in past Fact Books. Table 3.2.27 lists the prices for eight years spanning 1980–2002. The real price of refrigerator-freezers and freezers (expressed in 2008 $) declined during the 1980s and 1990s. However, in 2002, the prices of both types of products increased relative to the year 1998.

Table 3.2.27 Refrigerator-Freezer and Freezer Average Retail Prices

		Year							
Product	**Price**	**1980**	**1985**	**1986**	**1991**	**1993**	**1994**	**1998**	**2002**
Refrigerator-Freezers	nominal $	$598	$702	$684	$732	$692	$713	$657	$788
	2008 $	$1,563	$1,405	$1,344	$1,157	$1,031	$1,036	$868	$943
Freezers	nominal $	$426	$479	$449	$434	$334	$344	$315	$405
	2008 $	$1,113	$958	$882	$686	$498	$500	$416	$485

Source: AHAM Fact Books.

3.2.8.2 Refrigerator-Freezer 2004 Retail Prices

DOE's most recent technical analysis of amended energy conservation standards for residential refrigerator-freezers published in October 2005 provided the retail price of the two largest product classes of refrigerator-freezers: top-mount refrigerator-freezers without TTD features and side-mount refrigerator-freezers with TTD features.[28] The analysis also established the retail price of products meeting existing ENERGY STAR levels.

Baseline Retail Prices

DOE determined the retail price of baseline-efficiency top-mount refrigerator-freezers without TTD features and side-mount refrigerator-freezers with TTD features from data purchased from NPD Group. The NPD Group dataset included information about the average price of more than 2000 refrigerator models sold in 2004 in the United States.[d] Table 3.2.28 below summarizes the retail price data for three capacity sizes for each of the product types. The retail prices correspond to baseline-efficiency products, *i.e.*, products that just meet the existing energy conservation standards.

Table 3.2.28 Baseline Unit Retail Prices from 2005 DOE Report (2004$)

Product Type	**14-17 ft^3**	**18-20 ft^3**	**21-22 ft^3**
Top-Mount without TTD	$329	$386	$457
	21-23 ft^3	**24-26 ft^3**	**27-30 ft^3**
Side-Mount with TTD	$702	$789	$926

Source: The NPD Group/NPD Houseworld – POS.

Price of ENERGY STAR

DOE's October 2005 report also provided incremental retail price estimates of ENERGY STAR products relative to baseline products. At the time, ENERGY STAR levels specified 15 percent lower energy consumption than the federal energy standard level. DOE used two approaches to estimate the retail prices: (1) the application of manufacturer and retailer markups to manufacturer costs, and (2) a retail price analysis of ENERGY STAR compliant products based on data from the NPD Group. Table 3.2.29 below summarizes the retail price increments associated with meeting ENERGY STAR relative to baseline models of several different capacity sizes. Note that the two approaches yield roughly the same average retail price increment of meeting ENERGY STAR with the exception of the 27–30 ft^3 side-mount refrigerator.

Table 3.2.29 Average Retail Price Increment of ENERGY STAR from 2005 DOE Report (2004$)

Product Type	**Approach**	**14-17 ft^3**	**18-20 ft^3**	**21-22 ft^3**
Top-Mount without TTD	Markups	$38	$35	$42
	Retail Prices	$28	$49	$63
Product Type	**Approach**	**21-23 ft^3**	**24-26 ft^3**	**27-30 ft^3**
Side-Mount with TTD	Markups	$54	$35	$183
	Retail Prices	$47	$66	$88

Source: DOE, 2005.

[d] The data also included information about the refrigerator brand, manufacturer, attributes (e.g., total refrigerated volume, number and type of shelves), and sales, and whether each model has an Energy Star rating. The data cost $25,000 to purchase.

3.2.8.3 2007 Manufacturer-Suggested Retail Prices

DOE collected retail price data for several refrigerator-freezer and freezer models from five manufacturers' Internet web sites: General Electric, Whirlpool, Frigidaire, Maytag, and LG Electronics. The price data reflect manufacturer-suggested retail prices and, therefore, may not reflect actual sales prices. Even so, DOE conducted a statistical analysis of the data to determine the effect of certain attributes, including the impact of meeting existing ENERGY STAR levels.

DOE collected data on 1,268 refrigerator-freezer and freezer models. The collected data set included information about the retail price and model number of refrigerator-freezers and freezers sold in 2007 in the U.S., coupled with information about the brand, attributes (*i.e.*, color, stainless steel, built-in, French doors), and whether the product met existing ENERGY STAR levels. DOE sorted the data into the following product types: (1) side-mount refrigerator-freezers consisting of 523 models, (2) top-mount refrigerator-freezers consisting of 340 models, (3) bottom-mount refrigerator-freezers consisting of 281 models, (4) chest freezers consisting of 46 models, and (5) upright freezers consisting of 54 models.

Figure 3.2.4 through Figure 3.2.8 present price distributions for each product type, showing variation in price of products which do not meet ENERGY STAR criteria as well as variation in price for products with comply with ENERGY STAR. The price distributions of side-mount and top-mount refrigerator-freezers in Figure 3.2.4 and Figure 3.2.5 indicate that ENERGY STAR generally increases the price and that there is a wider price variation for ENERGY STAR products. Also, both refrigerator-freezer types exhibit skewed price distributions, *i.e.*, more models are low-priced with relatively few high-priced models (as an example, fewer than 10 models were priced above $1,300 for top-mounts). The price distributions for bottom-mount refrigerator-freezers, Figure 3.2.6 below, show that French-door configurations are more of a factor in contributing to high price than ENERGY STAR efficiency levels. Most bottom-mount models already meet ENERGY STAR, and those models configured with French doors are distinctly more expensive. The price distributions for upright freezers show that ENERGY STAR models are generally more expensive (Figure 3.2.7). For chest freezers, there are several models with and without ENERGY STAR that are priced similarly, but there are no low-priced models that qualify for ENERGY STAR (Figure 3.2.8).

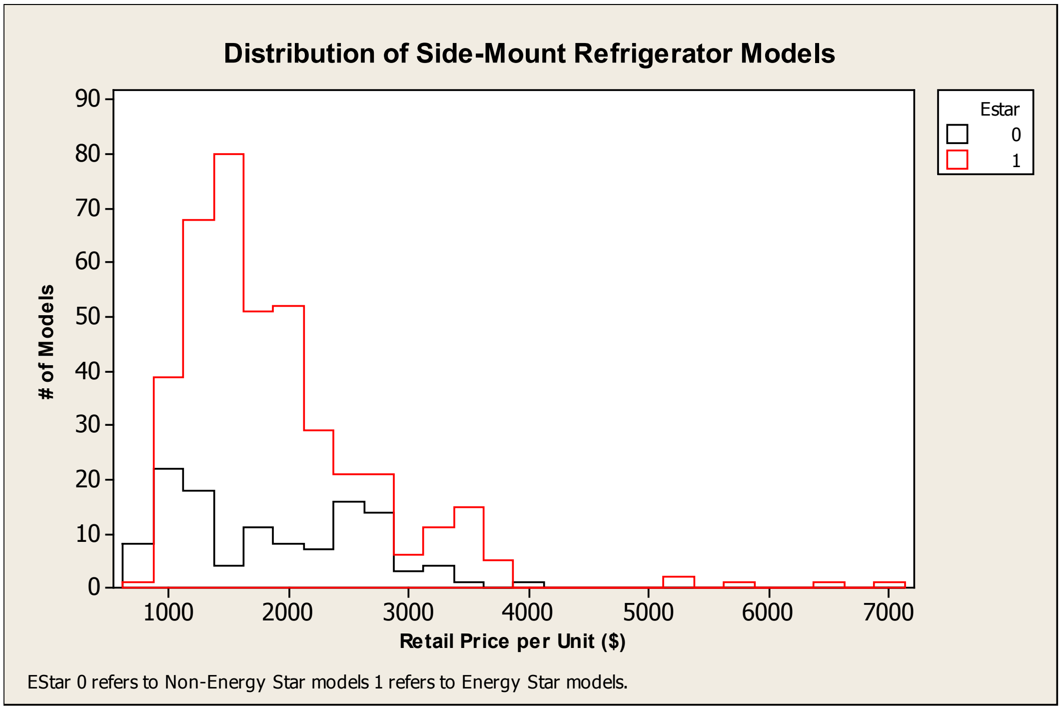

Figure 3.2.4 2007 Manufacturer-Suggested Retail Price Distribution of Side-Mount Refrigerator-Freezers with and without ENERGY STAR (2007$)

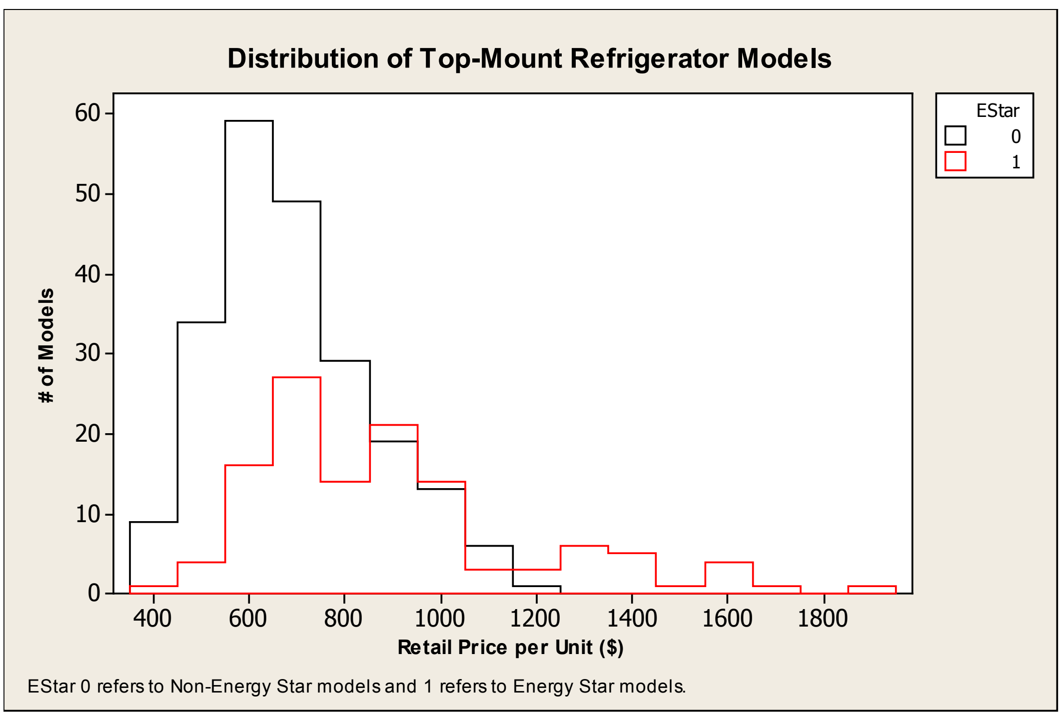

Figure 3.2.5 2007 Manufacturer-Suggested Retail Price Distribution of Top-Mount Refrigerator-Freezers with and without ENERGY STAR (2007$)

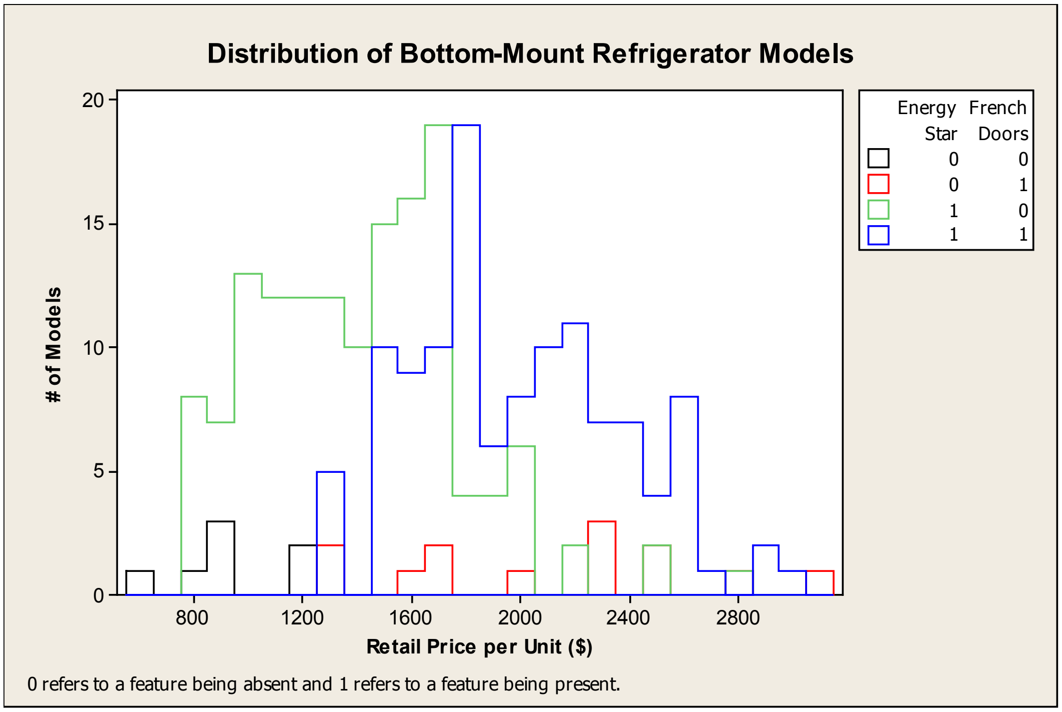

Figure 3.2.6 2007 Manufacturer Suggested Retail Price Distribution of Bottom-Mount Refrigerator-Freezers with and without ENERGY STAR (2007$)

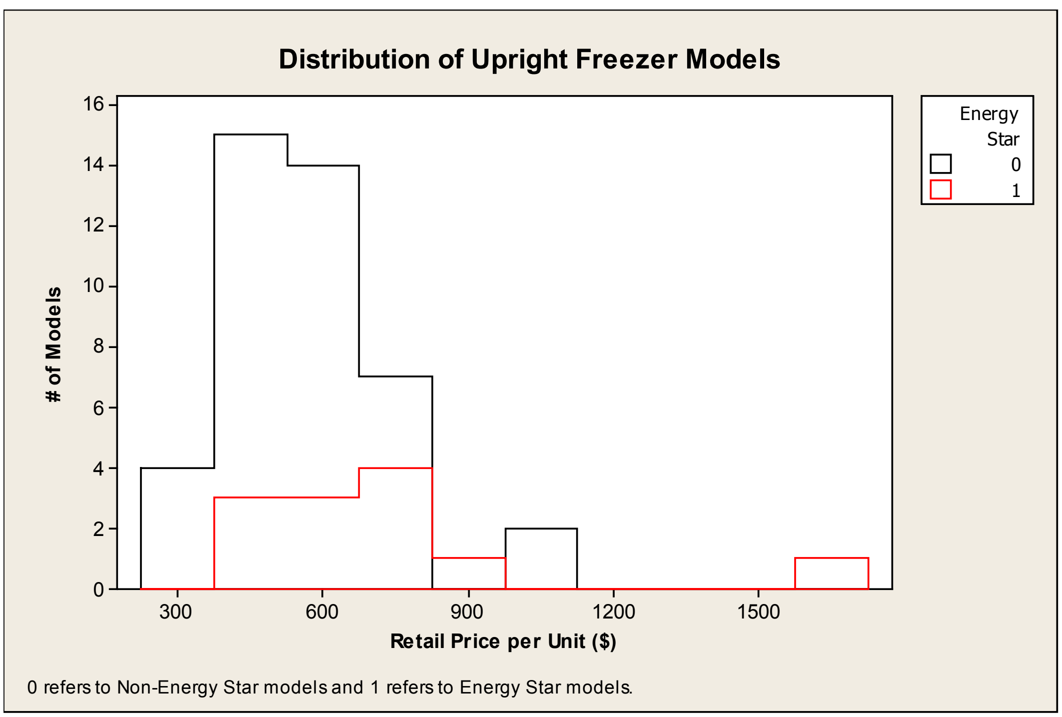

Figure 3.2.7 2007 Manufacturer-Suggested Retail Price Distribution of Upright Freezers with and without ENERGY STAR (2007$)

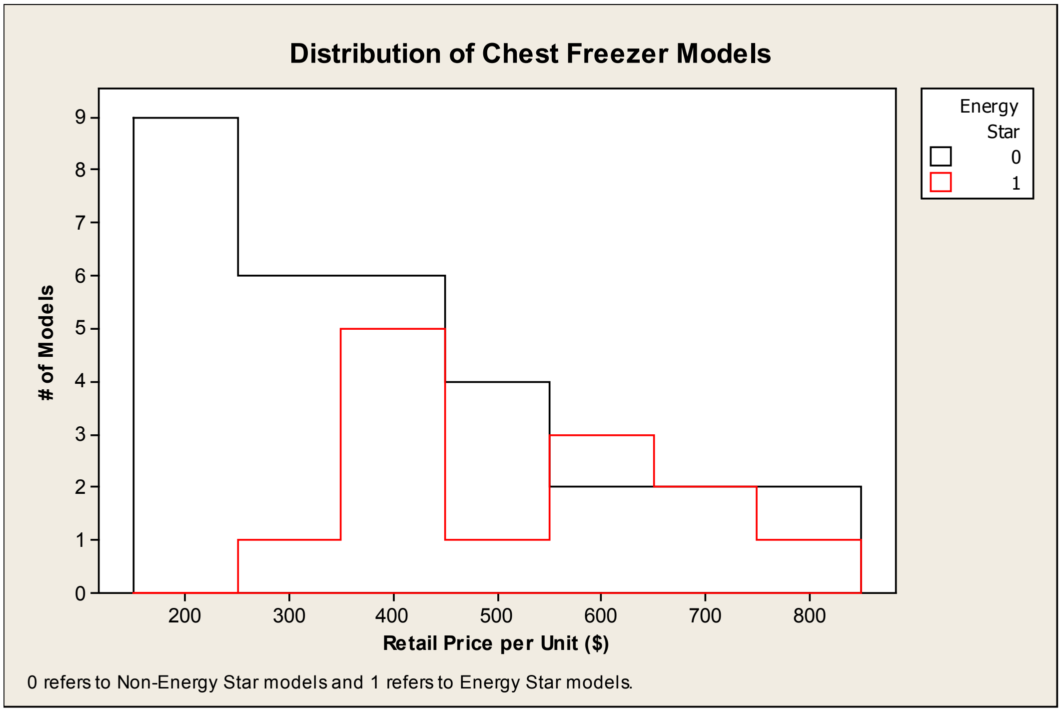

Figure 3.2.8 2007 Manufacturer-Suggested Retail Price Distribution of Chest Freezers with and without ENERGY STAR (2007$)

DOE also performed regression analysis on each of the five product types to estimate the incremental price of the different attributes. For the regression analysis, DOE confined the sample to models with prices within two standard deviations of the mean value. DOE did this to remove outliers from the sample. Removing the outliers lowered the sample size to 92 to 95 percent of the original size, depending on the product type. Specifically, the side-mount refrigerator-freezer sample was reduced from 523 to 502, the top-mount refrigerator-freezer sample was reduced from 340 to 321, the bottom-mount refrigerator-freezer sample was reduced from 281 to 272, the upright freezer sample was reduced from 54 to 53, and the chest freezer sample was reduced from 46 to 43. DOE performed the regression analysis with two types of regression equations that it formulated to determine the price increment due to each attribute: (1) a 'basic' equation where price is a function of only ENERGY STAR qualifying levels (the focus variable); and (2) a 'complete variable' equation where price is a function of ENERGY STAR (the focus variable), product attributes (stainless steel, built-in, French doors), and the brand.

Table 3.2.30 presents the summary results of the regression analysis. The first column in the table indicates the product type and the second column presents the 'constant' price (i.e., the price without any of the attributes under consideration, also referred to as a baseline model) for each product type. The 'coefficients' represent the price adder for a product with a specific attribute (*i.e.*, ENERGY STAR, French doors for bottom-mount products, stainless steel cabinet, and brand). If the value is positive, than the 'coefficient' for the attribute is added to the 'constant' price. If the value is negative, than the 'coefficient' for the attribute is subtracted from the 'constant' price. For example, for side-mount refrigerator-freezers, the 'coefficient' for ENERGY STAR is $208. Therefore, the added retail price of an ENERGY STAR side-mount refrigerator-freezer is $208, raising the baseline price from $1128 to $1336. Also presented in Table 3.2.30 are the adjusted R-squared value and the number in the sample. In a multiple linear regression model, adjusted R square measures the proportion of the variation in the dependent variable (retail price) accounted for by the explanatory variables.[e]

Table 3.2.30 Regression Analysis of the Incremental Price of ENERGY STAR and other Attributes based on 2007 Manufacturer-Suggested Retail Prices (2007$)

Product Type	Constant (Baseline)	Coefficients (Price Adder)								Adj R^2	Number in Sample
		Energy Star	French Door	Stain-less	Brand						
					Frigidaire	GE	Whirlpool	Maytag	LG		
Side-Mount	$1128	$208	NA	$156	-245	$375	-$231	-$252	$431	0.65	502
Top-Mount	$660	$63	NA	$97	-$54	$80	$28	$49	NA	0.40	321
Bottom-Mount	$1285	-$31*	$332	$143	NA	$283	-$83	$70	-$212	0.58	272
Upright Freezer	$495	$107	NA	$215	$56*	$40*	-$41*	-$40*	NA	0.35	53
Chest Freezer	$352	$121	NA	NA	$116*	$116*	-$100*	-$99*	NA	0.17	43

* Although numerical values are provided, the regression analysis indicated that these attributes were not significant factors in determining the incremental product price at a 95 percent confidence interval.

DOE found that the incremental price effect of meeting ENERGY STAR levels is significant at a 95 percent confidence level for all product types with the exception of bottom-mount refrigerator-freezers. In the case of side-mount refrigerator-freezers, qualifying for ENERGY STAR adds $208 to the price of the baseline model, while for top-mount refrigerator-freezers it adds $63. These price increments are significantly higher than those from DOE's October 2005 technical report (see Table 3.2.29 above). Because the analysis conducted for the 2005 technical report was more rigorous (for example, DOE conducted the 2005 retail price analysis using sales-weighted point-of-sale data), the price increments for meeting ENERGY STAR based on the 2007 manufacturer suggested retail price data are likely not as accurate a price indication of meeting ENERGY STAR. Rather, the analysis based on the 2007 prices simply confirms that ENERGY STAR products are more expensive than baseline products. In the case of upright and chest freezers, the analysis shows that the price increase associated with meeting ENERGY STAR is $107 and $121, respectively.

For bottom-mount refrigerator-freezers, meeting ENERGY STAR levels is not a significant factor at a 95 percent confidence level. The French door attribute is significant and adds over $330 to the price of a baseline unit. This is consistent with the price distributions of bottom-mount models presented in Figure 3.2.6 above.

The analysis suggests that stainless steel plays a significant role in the price of side-mount, top-mount, and bottom-mount refrigerator-freezers and upright freezers. The 'coefficient'

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[e] Unlike R squared, adjusted R squared allows for the degrees of freedom associated with the sums of the squares in its calculation. Therefore, even though the residual sum of squares decreases or remains the same as new explanatory variables are added, the residual variance does not. For this reason, adjusted R square is generally considered to be a more accurate goodness-of-fit measure than R square.

of brand suggests an effect similar to stainless steel. Brand is significant for the three refrigerator-freezer product types but is not significant in the case of freezers.

3.2.8.4 Refrigerator-Freezer and Freezer 2008 Retail Prices

To determine retail prices for the year 2008, DOE drew upon proprietary retail price data collected by The NPD Group.[36] These data reflect prices and sales at many retail outlets in the United States, representing more than 50 percent of retail sales nationwide. The data include model number, refrigerated volume, configuration of doors and ice-making, and whether the unit is an ENERGY STAR product. Based on these data DOE developed a sales-weighted price distribution for non-ENERGY STAR appliances for seven of the 20 product classes.[f] Additional details about this price data are provided in Chapter 8 of this TSD. The average baseline retail prices before sales tax for each of the seven product classes are shown in Table 3.2.31. With the exception of product class 3 (top-mount refrigerator-freezers), the retail prices in Table 3.2.31 are relatively close to the manufacturer-suggested retail prices in Table 3.2.30.

Table 3.2.31 Residential Refrigeration Products: Average Baseline Retail Price

Product Class	Baseline Retail Price *2008$*
Product class 3: Top-mount refrigerator-freezer	1,005
Product class 5: Bottom-mount refrigerator-freezer	1,313
Product class 7: Side-by-side refrigerator-freezer with TTD*	1,333
Product class 9: Upright freezer	469
Product class 10: Chest freezer	483
Product class 11: Compact refrigerator	151
Product class 18: Compact freezer	193

* Through-the-door ice service.

3.3 TECHNOLOGY ASSESSMENT

This section provides a technology assessment for refrigerators, refrigerator-freezers, and freezers. Contained in this technology assessment are details about product operations and components (section 3.3.1), an examination of possible technological improvements for each product (section 3.3.2), and a characterization of the product efficiency levels currently commercially available (section 3.3.3).

3.3.1 Product Operation and Components

This section provides a brief description of the components and operation of refrigerators, refrigerator-freezers, and freezers. These descriptions provide a basis for understanding the technologies used to improve product efficiency.

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[f] DOE assumed that prices for non-ENERGY STAR models are a reasonable approximation of prices for the baseline models.

3.3.1.1 Product Operation

Refrigerators, refrigerator-freezers, and freezers are household appliances designed for the refrigerated storage of food products. Definitions for these product types and their operating temperature ranges are discussed in section 3.2.1.

Figure 3.3.1 shows a schematic representation of a typical refrigeration circuit used in residential refrigeration products. As described by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Refrigeration Handbook*,[37] the refrigeration process consists of the following steps:

1. Electrical energy is supplied to a motor that drives a compressor, which draws cold, low-pressure refrigerant vapor for the evaporator and compresses it.
2. The resulting high-pressure, high-temperature discharge gas then passes through the condenser, where it is cooled to saturation condition, condensed to a liquid, and possibly subcooled while heat is rejected to the ambient air.
3. Liquid refrigerant passes through a metering (pressure-reducing) capillary tube to the evaporator, which is at low pressure.
4. The low-pressure, low-temperature liquid in the evaporator absorbs heat from its surroundings, evaporating to a gas, which is again withdrawn by the compressor.

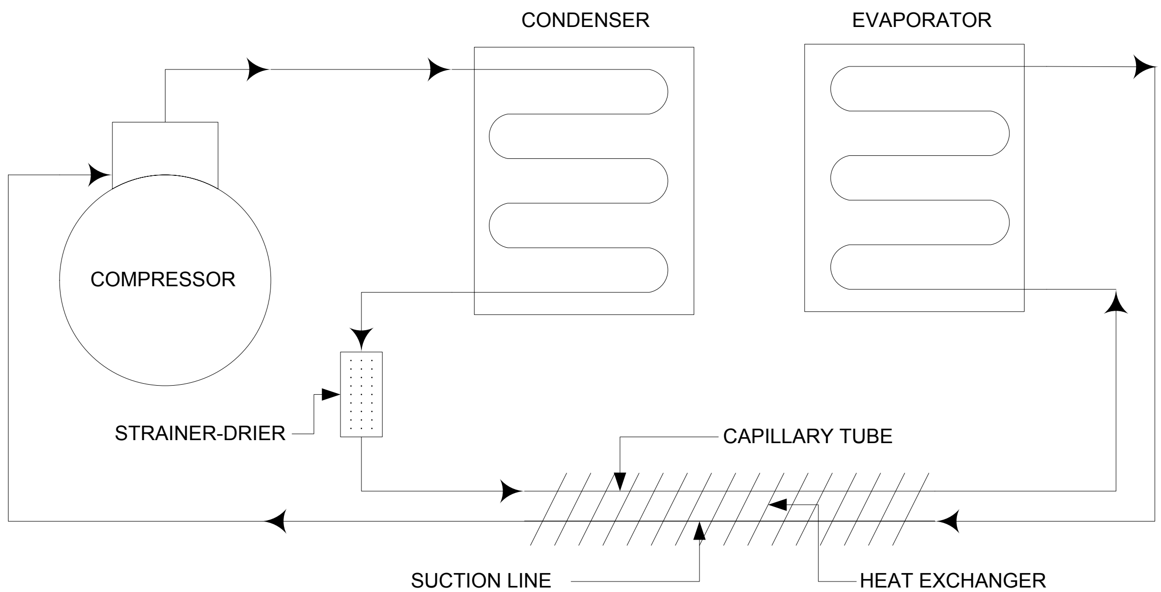
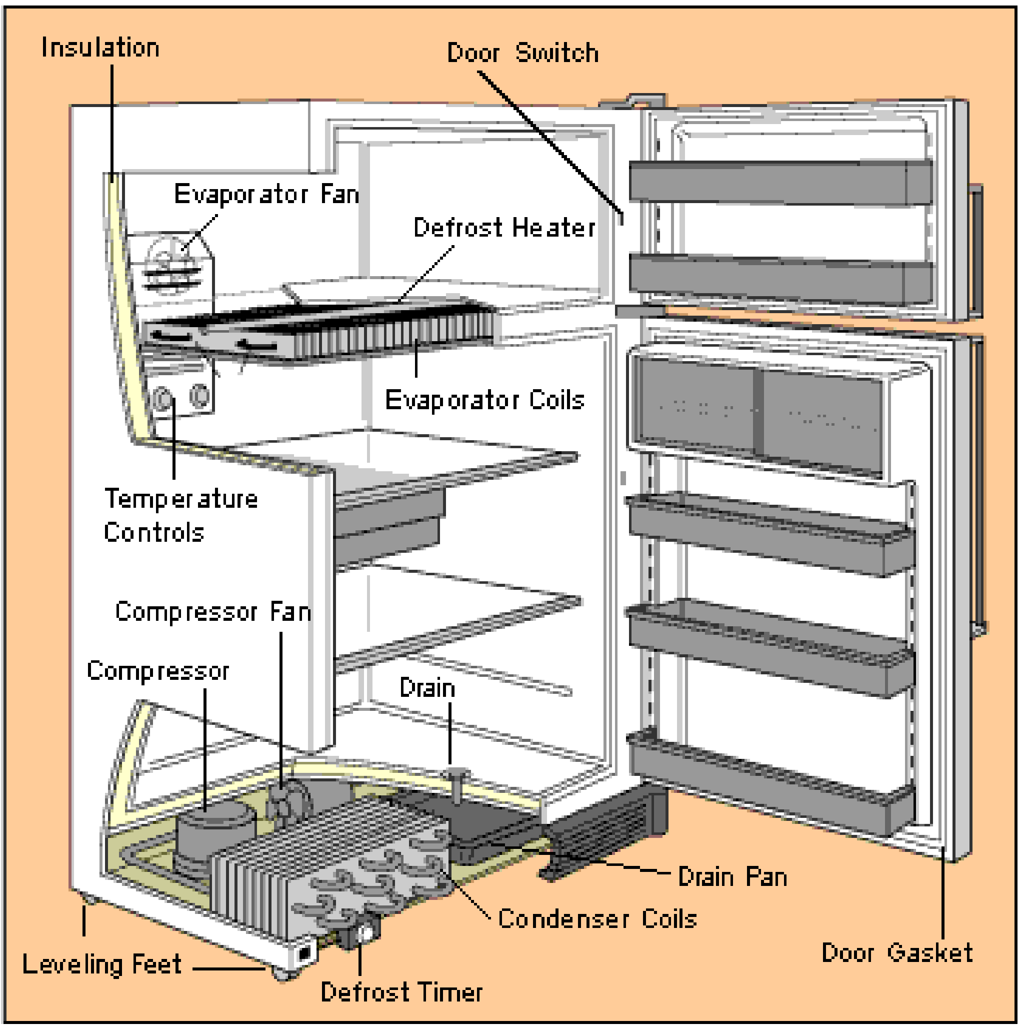


Figure 3.3.1 Refrigeration Circuit

In Figure 3.3.1 above, the metering or flow control device pictured is a non-adiabatic capillary tube. In this configuration, the capillary tube is soldered to the suction line to evaporate the residual liquid in the suction line and warm the vapor. This suction line heat exchanger (or the non-adiabatic capillary) increases the refrigeration capacity of the system by the amount of heat being transferred from the capillary to the suction side. Non-adiabatic capillary tubes are the most common type of metering device in refrigerator-freezers. The other type of metering device, an adiabatic capillary tube, is used in some refrigeration products. In this configuration, the capillary tube does not exchange heat with the suction line and the refrigerant expands from the high pressure to the low pressure adiabatically.

3.3.1.2 Primary Components

The illustration in Figure 3.3.2 (from RemodelGuide.com[38]) shows the components and layout of a typical top-mount refrigerator-freezer. The components and layout are similar in side-mount and bottom-mount refrigerator-freezers. Freezers also have a similar layout and components, but are slightly less complicated due to the fact that they have no fresh food compartment. The text that follows describes the following operations or components: automatic defrost, cooling, temperature control, lighting, ice maker, ice and water dispenser, and door seals and hinges.



Source: RemodelGuide.com

Figure 3.3.2 Top-Mount Refrigerator-Freezer Components

Automatic defrost

Almost all standard-size refrigerator-freezers are self-defrosting. Manual defrost is still used in chest freezers, some upright freezers, and in compact refrigerators and freezers. Self-defrosting refrigerator-freezers and freezers automatically melt frost that accumulates in the freezer compartment. The typical automatic defrost system has three functional components: a defrost timer, a defrost heater, and a defrost thermostat.

- *Defrost timer:* The timer is a clock that is energized with the compressor. The timer initiates defrost after a set interval of compressor operation, typically twelve hours.

- *Defrost heater:* The defrost heater is an electric resistance heating element. It is located just beneath or on the side of the evaporator coil, which is concealed behind a panel in the freezer compartment. The heater melts any ice or frost that builds up. A heater is typically also energized in the drip pan to prevent freeze of melted condensate and clogging of the drip pan drain.

- As the frost and ice melt, the resulting water drips into a drip pan. The pan is connected to a tube that drains the water into a shallow pan at the bottom of the refrigerator-freezer or freezer. The water is then evaporated by air which is drawn by a fan through the condenser and over the compressor shell. In some products which do not use forced convection condensers, particularly freezers, a special pan is mounted on top of the compressor shell and the water is evaporated using heat from the compressor.

- *Defrost thermostat:* The process ends when the defrost thermostat mounted on the evaporator tubing senses that a sufficiently high temperature has been attained.

Cooling

All residential refrigerators, refrigerator-freezers, and freezers work by removing heat from the air in the cabinet. They all have the key components shown in Figure 3.3.1: a compressor, a condenser, a metering or flow control device (usually a capillary tube), and an evaporator.

- *Compressor:* The compressor compresses refrigerant, providing the energy input necessary to drive the cycle. In most residential refrigeration products, the compressor is located at the bottom rear of the unit. In built-in refrigerator-freezers the compressor is often located on top of the refrigerator behind a grill or grate. The compressor runs whenever the refrigerator thermostat calls for cooling.

- *Condenser:* The condenser is a heat exchanger located on the outside of the unit. The three most prevalent condenser configurations are as follows:
  - Forced-convention condensers use fans to move air through them to provide cooling. These condensers are usually located under the unit near the compressor. They can be fabricated of steel tubes with steel wire fins or copper tubes with aluminum fins.
  - Natural convection "static" condensers which don't use fans are mounted to the back of the unit. They generally have steel tubes and steel wire fins.

- Hot wall condensers are integrated into the outer shell of the unit. A serpentine of tubing is attached to the inside of the shell and provided with good thermal contact to the shell. This is the common configuration in freezers and it is common in compact refrigerators.

• *Metering or Flow Control Device (Capillary Tube):* The metering device in most household refrigerator-freezers is a capillary tube. As discussed above in section 3.3.1.1, there are two common types of capillary tubes—adiabatic and non-adiabatic, although non-adiabatic are the most common. The capillary tube controls the pressure and flow of the refrigerant as it enters the evaporator.

• *Evaporator:* The evaporator is a heat exchanger located inside the unit. Similar to the condenser, there are three main configurations for evaporators:
  - Forced convection evaporators use fans to move air through them to provide cooling. They are constructed of aluminum tubes and aluminum fins or copper tubes and aluminum fins. They are generally located on the rear wall of the freezer compartment behind a panel. They can also be located in the mullion separating the freezer and fresh food compartments, as shown in Figure 3.3.2. The evaporator fan circulates air through the evaporator and into both the freezer and fresh food compartments. Because the evaporator absorbs heat, it is very cold, thereby causing any water vapor in the air to freeze on it as frost. Most refrigerator-freezers using this type of evaporator employ automatic defrost.
  - Roll bond evaporators fabricated from layers of aluminum sheet primarily use natural convection cooling. The refrigerant passages are formed into the evaporator walls. They are used in single-door refrigerators and are configured either as a flat plate at the rear of the cabinet or a rectangular box. In the latter configuration, the interior of the box is the freezer compartment. While these evaporators generally use natural convection and do not use an evaporator fan, some products with rear-mounted flat roll bond evaporators use fans for performance enhancement. Manual defrosting is required to defrost these evaporators.
  - Cold wall evaporators are integrated within the walls of the freezer. This configuration is used in nearly all chest freezers and in many upright freezers. The evaporator consists of tube serpentines attached to the insulation side of the cabinet interior liner. These evaporators use natural convection heat transfer.

Temperature control

All refrigerators, refrigerator-freezers, and freezers have a thermostat or electronic temperature control to maintain the proper temperature. Thermostats are mechanical devices which interrupt the electricity connection to the compressor when the temperature is sufficiently low. Electronic control systems generally use thermistors as temperature sensors, using relays mounted on the circuit boards to activate the compressor and other components such as the evaporator and condenser fans.

Lighting

Refrigerators, refrigerator-freezers, and freezers with internal lighting normally have only one functional lighting component—the switch—which is usually a white push-button mounted to be depressed by operation of the door. Closing the door turns off the light. Refrigerators traditionally used standard appliance incandescent light bulbs, but many new designs are using LED lighting.

Ice maker

Many standard-size refrigerator-freezers come equipped with an ice maker, and nearly all are convertible to installation of an ice maker. The ice maker is a located within the freezer compartment. Ice maker systems have two basic functional components: the icemaker itself, and the water fill valve. The most common ice makers operate as follows:

- The ice maker sends a signal to the water fill valve (normally located on the outside back of the refrigerator, near the bottom) to open and let water into the ice maker tray (or mold). Water fill control is usually by timed opening of the valve (usually 7-10 seconds).
- When the ice has frozen and reached a sufficiently low temperature (10 to 15 °F), sensed with a thermostat located in thermal connection with the ice tray, the ice maker begins to harvest (eject) the cubes.
- To harvest the cubes, the ice maker first turns on a small heater beneath the tray. The heater warms the tray, to help release the ice cubes. Then a sweep fork rotates and pushes the cubes up and out of the tray.
- While the ice maker is dumping the cubes into a the ice storage bin, a metal wire similar to a coat hanger swings up to let the cubes drop below it. When the cubes have dropped, the wire rotates back down. If the holding bin is full of ice, the wire rotate far enough, which stops further production of ice. If the sensing wire can rotate down fully, the ice maker refills with water and repeats the process.

Ice and water dispenser

Many standard-size refrigerator-freezers have a through-the-door (TTD) ice and/or water dispenser. There are several different systems for delivering ice and water through the refrigerator door. What follows is an explanation of the common attributes of all of the systems.

- *Ice dispenser:* For a refrigerator-freezer to provide ice through the door, the ice maker first dumps the ice it produces into a large bin, as discussed above. To request ice at the door, the user presses a lever that activates a switch. The switch turns on a motor that rotates an auger which pushes ice out of the bin, through a chute to the user. Some dispensers also have blades which chop the ice to allow delivery of crushed ice.
- *Water dispenser:* The water dispenser is activated much like the ice dispenser. To request water at the door, the user presses a lever on the front of the refrigerator that activates a switch. The switch turns on an electric water valve at the back of the refrigerator-freezer. Water flows through the valve into a tube, then flows into a reservoir located in the fresh food compartment in which the water is chilled. As new water enters the reservoir, the water that is displaced flows through a separate tube through the dispenser.

Door Seals

All refrigerator, refrigerator-freezer, and freezer doors have a seal—a vinyl gasket attached to the door(s). The seal prevents infiltration of warm ambient air into the cabinet. The seal is lined with a magnet which helps to hold the door closed and create a tight seal. The magnetic portion of the gasket is aligned to face the steel extension of the cabinet's external shell which wraps partially around the front face of the cabinet. Some gasket systems use opposing magnets on the cabinet side to improve door sealing force.

3.3.2 Technology Options

Table 3.3.1 lists the technology options for improving the efficiency of residential refrigeration products. The technology options are categorized by their associated component or system. Each technology option category and the options available for improving the component or system category are discussed below.

Table 3.3.1 Technology Options for Refrigerators, Refrigerator-Freezers, and Freezers

Insulation	**Expansion Valve**
Improved resistivity of insulation	Improved expansion valves
Increased insulation thickness	**Cycling Losses**
Vacuum-insulated panels	Fluid control or solenoid valve
Gas-filled panels	**Defrost System**
Gasket and Door Design	Reduced energy for automatic defrost
Improved gaskets	Adaptive defrost
Double door gaskets	
Improved door face frame	Condenser hot gas
Reduced heat load for TTD feature	**Control System**
Anti-Sweat Heater	Temperature control
Condenser hot gas	Air-distribution control
Electric heater sizing	**Other Technologies**
Electric heater controls	Alternative refrigerants
Compressor	Component location
Improved compressor efficiency	
Variable-speed compressors	**Alternative Refrigeration Cycles**
Linear compressors	Lorenz-Meutzner cycle
Evaporator	Dual-loop system
Increased surface area	Two-stage system
Improved heat exchange	Control valve system
Condenser	Ejector refrigerator
Increased surface area	Tandem system
Improved heat exchange	**Alternative Refrigeration Systems**
Force convection condenser	Stirling cycle
Fans and Fan Motor	Thermoelectric
Evaporator fan and fan motor improvements	Thermoacoustic
Condenser fan and fan motor improvements	

3.3.2.1 Insulation

The primary thermal load on a refrigerator or freezer is the heat transfer through the walls and doors into the cabinet. In one study of an 18.6 ft^3 top-mount refrigerator-freezer, the wall and door heat loads were estimated to account for almost 60 percent of the total thermal load.[39]

Nearly all residential refrigeration products use polyurethane (PU) foam insulation for both the cabinets and the doors. Through the 1980s, CFC-11, a chlorofluorocarbon (CFC), was used as a blowing agent in almost all PU foam insulation. However, under the Montreal Protocol, all CFCs were banned from use by the mid 1990s due to their high ozone depletion potential (ODP). In the 1990s, most manufacturers adopted use of HCFC-141b, a hydrochlorofluorocarbon (HCFC), which has significantly less ODP. However, because HCFC-141b has non-zero ODP, it was banned from production in the U.S. after January 1, 2003. In response to the phase-out of HCFC-141b, AHAM's Appliance Research Consortium (ARC) investigated several alternatives, including two hydrofluorocarbons (HFCs), HFC-134a and HFC-245fa, and cyclopentane, a hydrocarbon (HC). HFCs and HCs both have zero ODP. HCs have a much lower global warming potential (GWP) than HFCs, but they are flammable. ARC, DOE, and EPA sponsored research at Oak Ridge National Laboratory (ORNL) to determine the thermal conductivities of the three alternatives and of HCFC-141b. Based on thermal conductivity, ORNL identified HFC-245fa as the most attractive substance because it had the lowest energy penalty relative to HCFC-141b (see Table 3.3.2).[40] In addition, accelerated lifetime performance tests conducted by ORNL indicated that the thermal conductivity of HFC-245fa foam insulation increases by a smaller percentage than either HFC-134a or cyclopentane foams. Finally, despite the fact that HCs are used in Europe, flammability and volatile organic compound concerns led ARC to determine that HFCs were a more suitable replacement blowing agent.[41] As a result, many manufacturers are currently using HFC-245fa blowing agent for PU foam insulation.

Table 3.3.2 Thermal Conductivity of Freshly-Sliced Foam Specimens at 75 ºF (23.9 ºC)

	Slice Thickness			
	0.4 inch (1.0 cm)		**1.5 in (3.8 cm)**	
Blowing Agent	*Btu-in/hr-ft²-ºF*	*mW/m-K*	*Btu-in/hr-ft²-ºF*	*mW/m-K*
HCFC-141b	0.132	19.0	0.128	18.4
HFC-245fa	0.138	19.9	0.132	19.0
Cyclopentane	0.150	21.6	0.145	20.9
HFC-134a	0.160	23.1	0.155	22.3

Source: ORNL, 2003.[40]

Improved Resistivity of Insulation

Past research has investigated improving the resistivity of PU foam insulation through the use of additives in the foam.

Research conducted in 1996 demonstrated that adding carbon black provides a means of improving the thermal insulation properties of PU foam. The research showed that PU foam systems using carbon black in conjunction with either HCFC-141b or cyclopentane was able to lower *k*-factors by six to nine percent in panels and in cabinets.[42]

Increased Insulation Thickness

Based on DOE's 1995 technical support document (TSD) for refrigerators, refrigerator-freezers, and freezers, the insulation thickness range for refrigerator-freezers in the mid-1990s was 1.5 to 2.75 inches (3.81 to 7.0 cm) in the doors and 1.5 to 3 inches (3.81 to 7.62 cm) in the cabinet walls. Walls of freezers and freezer compartments tended to be near the higher end while walls of refrigerators and fresh food compartments were nearer the lower end.[43]

Also based on the DOE 1995 TSD, adding 0.5 to 1 inch (1.27 to 2.54 cm) more insulation increases the overall efficiency of the product. Energy reductions associated with these wall thickness increases range from a few percent to over 10 percent. Therefore, DOE considered the addition of more insulation as a technology option to improve efficiency. Although the technology to implement this change is readily available, manufacturers indicated during the rulemaking leading to the April 27, 1997 final rule establishing the current minimum efficiency levels that adding insulation would not be the first technology option they would choose to improve efficiency. Significant investments would be required in foaming systems, tooling, and molding to accommodate thicker insulation. Increased packaging and shipping costs must also be considered. Greater insulation thickness results in either decreased interior volumes, increased exterior dimensions, or some combination of both. Since kitchen dimensions and designed spaces for refrigerator-freezers are limited, there are restrictions on increasing the exterior size of the product. Reducing interior volume is considered undesirable because it impacts consumer utility.

Vacuum-Insulated Panels

Vacuum-insulated panel (VIPs) technology is based on the reduction in conductivity which occurs in a low vacuum, the same concept which is used to reduce heat leakage in thermos bottles. VIPs used in refrigeration products consist of a sealed package with a fill material which provides support to prevent the panel from collapsing and interferes with molecular mean free path as the intermolecular spacing increases at lower vacuum levels. VIPs can be foamed in place between the cabinet liner and wrapper to decrease the heat leakage and energy required to maintain the cabinet at low temperature. Different configurations are commercially available through advances in manufacturing technologies. As a result, VIPs are available in a variety of geometries (*e.g.*, flat, curved, cylindrical) with added features (*e.g.*, holes, cut-outs).[44] Typical VIPs generally consist of a core material and an airtight envelope. Some VIPs also include absorber to absorb gas which leaks through the envelope.

Several core materials have been used in the manufacture of VIPs including polystyrene, open-cell PU, silica powder, and glass fiber. Research sponsored by the European Commission has evaluated these core materials based on their cost and characteristics, including density and manufacturing time. Table 3.3.3 below summarizes the VIP characteristics manufactured with the above core materials.[45] Each of the core materials has associated advantages and disadvantages that dictate their acceptability for an appliance application.

Table 3.3.3 Comparison of Various VIP Core Materials

Property		Polystyrene	Open-cell PU	Silica Powder	Glass Fiber
Thermal Conductivity at 10 Pascals (Pa) abs. (0.1 millibar (mbar))	(*mW/m-K*)	4.8 – 5.8	9.7	5.8	2.4
	(*Btu-in/hr-ft^2-ºF*)	0.033 – 0.040	0.067	0.040	0.017
Manufacturing Time		Fast	Medium	Medium	Long
Density (*kilogram*(*kg*)*/cubic meter (m^3)*)		80 – 144	64	192	128
Drying Need		No	Yes	Yes	No
Thermal Stability		Low	Medium	Good	Very Good
Recyclability		Yes	Difficult	Yes	NA
Cost		Low	Medium	High	Very High

Source: European Commission, 2000.[45]

ORNL also has evaluated the performance of three types of VIPs: a silica powder filler encapsulated in a polymer barrier film; a fibrous glass insulation filler encapsulated in a stainless steel barrier; and an undisclosed insulation filler encapsulated in a stainless steel barrier.[46] Table 3.3.4 summarizes the center-of-panel thermal conductivities of the panels. For the silica powder and glass fiber filled VIPs, the thermal conductivities in Table 3.3.4 are comparable to those in Table 3.3.3.

Table 3.3.4 Center-of-Panel Thermal Conductivity of VIPs

Property		Silica Powder	Glass Fiber	Unknown
Thermal Conductivity*	(*mW/m-K*)	5.2 – 5.4	2.0 – 2.6	2.7 – 3.1
	(*Btu-in/hr-ft^2-ºF*)	0.034 – 0.038	0.014 – 0.018	0.019 – 0.022

***** For each filler, the reported thermal conductivities are a range of values from nine separate VIPs.

Source: Vineyard et al, 1998.[46]

ORNL also determined the thermal performance of the VIPs it studied as part of a composite panel. The composite panel consisted of a one-inch VIP surrounded by PU foam insulation to form a two-inch-thick panel. The PU foam insulation was blown with a variety of bowing agents, but, due to the age of the study (from the mid-1990s), ORNL considered neither HFC- nor HC-based blowing agents. For the three VIPs presented in Table 3.3.4, silica power, glass fiber, and unknown, the average composite panel thermal resistances were 21.5, 20.7, and 20.9 hr-ft^2-ºF/Btu, respectively.[46] The lower thermal conductivities reported in Table 3.3.4 for the glass fiber and unknown filled VIPs relative to the silica powder VIP were offset by the heat conduction through their stainless steel encapsulation material.

Of significant concern for VIPs is their long-term thermal conductivity integrity. VIP thermal conductivity increases dramatically as the pressure within the VIP exceeds 100 Pa abs. (1 mbar). The pressure increase in the VIP over time is related to several factors, including: residual gases in the VIP after vacuum, degassing from the VIP core material, and gas diffusion through the envelope pores. Improved envelopes and absorbers have been developed to prevent pressure increases from occurring in VIPs. For example, for the three composite VIPs that it analyzed, ORNL measured only a five-percent reduction in overall thermal resistance over a three-year period. ORNL demonstrated that this reduction in thermal resistance was less than the corresponding reduction for a panel without any VIPs, *i.e.*, panels consisting only of PU foam insulation.[46]

Recent announcements regarding VIPs include the following. Matsushita's VIP technology (trade name of "U-Vacua") was awarded the Minister of Economy, Trade and Industry Prize at the 17th Energy Conservation Awards sponsored by the Energy Conservation Center of Japan in January, 2007.[47] Matsushita claims that its VIP technology has achieved the world's highest level of insulation efficiency with a thermal conductivity of 1.2 mW/m-K (0.008 Btu-in/hr-ft^2-ºF) at 24 ºC (75.2 ºF).[48] Electrolux announced in 2003 the use of VIP technology in a freezer that they claimed reduced energy use by 35 percent relative to PU foam insulation.[49] Va-Q-tek has recently introduced its va-Q-plus VIP technology.[50]

Gas-Filled Panels

Gas-filled panels (GFPs) use thin polymer films and low-conductivity gas to create a device with excellent thermal insulation properties. GFPs are essentially hermetic plastic bags that can take on a variety of shapes and sizes. Inside the outer barrier is a cellular structure called a baffle which is filled with the low-conductivity gas.

Research conducted at LBNL in the mid-1990s has demonstrated the effectiveness of GFPs based on the use of different gases, including xenon and krypton. Table 3.3.5 below summarizes the thermal performance characteristics of different GFPs, based on their center-of-panel and whole-panel performance.[51] LBNL has also conducted research to demonstrate that GFPs, when used in refrigerator-freezers, can reduce energy consumption by approximately eight percent relative to PU foam insulation.[52]

Table 3.3.5 Comparison of Various Gas-Filled Panel Core Materials

	Center of Panel Performance		**Whole Panel Performance**					
	Thermal Conductivity		**Panel Thickness**		**Mean Temp.**		**Thermal Conductivity**	
Gas Fill	*mW/m-K*	*Btu-in/hr-ft^2-ºF*	*mm*	*inches*	*ºC*	*ºF*	*mW/m-K*	*Btu-in/hr-ft^2-ºF*
Xenon	7.4	0.051	24.1	0.95	6.8	44.2	7.4	0.051
Krypton	11.6	0.080	25.2	0.99	11.9	53.4	10.77	0.074
			49.8	1.96	12.3	54.1	1.17	0.008
Argon	19.9	0.138	NA	NA	NA	NA	NA	NA
Air	28.1	0.195	NA	NA	NA	NA	NA	NA

Source: LBNL[51]

In addition, ORNL determined the thermal conductivity of an insulation panel containing radiation baffles within a polymer barrier film and filled with krypton gas at atmospheric pressure. The range of thermal conductivities of nine of these GFPs ranged from 0.088 to 0.092 Btu-in/hr-ft^2-ºF (12.6 to 13.2 mW/m-K). ORNL also analyzed the GFPs as part of a composite assembly consisting of a one-inch panel surrounded by PU foam insulation to form a two-inch-thick panel. The average composite panel thermal resistance was determined to be 18.2 hr-ft^2-ºF/Btu. Finally, ORNL measured only a five-percent reduction in overall thermal resistance over a three-year period, which was less than the reduction observed in a panel consisting only of PU foam insulation.[46]

Although research has demonstrated that GFPs have better thermal performance than PU foam insulation, no known refrigeration products are using the technology. A significant problem in using GFPs is their lack of structural integrity in the resulting product.

3.3.2.2 Gasket and Door Design

A significant portion of the heat gain to refrigerators and freezers occurs around the edges of the doors and through the gaskets on the door edges. An analysis of thermal loads on an 18.6 ft^3 top-mount refrigerator-freezer revealed that over 28 percent of the total heat load into the cabinet came from 'edge' loads, *i.e.*, loads due to heat transfer into the food compartments via paths around the perimeter of the cabinet aperture.[39] Table 3.3.6 summarizes the various 'edge' loads as well as the heat loads through the walls and doors and other sources. If the 'edge' effect losses can be reduced, the efficiency of the refrigerator can be increased. This section only addresses the 'edge' effect loads from the wall and door flanges and the door gasket. Heat loads from the anti-sweat heaters are discussed in the following section (section 3.11.2.3).

Table 3.3.6 Overall Cabinet Loads

Component	**Percent of Total**
'Edge' Effect Loads	**28.5%**
Heat gain due to conduction along the wall steel flange	5.3%
Heat input due to conduction along the door steel flange	7.1%
Heat conduction directly through the door gasket or seal	2.7%
Heat input due to conduction in the mullion region	1.7%
Heat input due to mullion region anti-sweat heater	7.7%
Heat input due to cabinet anti-sweat condenser tube	4.0%
Wall and Door Loads	**59.1%**
Miscellaneous Loads (heat inputs due to evap fan, defrost heaters, and compressor)	**12.4%**

Source: Boughton et al, 1996.[39]

Improved Gaskets

Design of door gaskets is a balance between improving the thermal-efficiency performance of the gasket and ensuring that the door is not difficult to open. If the gasket magnet force is too strong, it becomes difficult to open the door. Based on a European Commission study, door handles have been designed specifically to facilitate door openings by providing leverage and relieving the pressure differential which can build up by freeing a small section of the gasket before the door is opened.[45] Although materials and designs for improving the air tightness of door gaskets exist, apparently no general criteria have been established to enable different designs to be classified.

An EPA report from 1992 describes theoretical modeling and experimental research on gasket heat loads and concludes that replacing about half of either the metal door flange or cabinet flange with plastic can reduce the heat flow through the gasket region by 25 percent.[53] However, this study did not address the impacts on the convection on the cabinet side of the gasket associated with different geometries of the "throat" region between the door dikes and the cabinet wedge or with different evaporator air flow rates. Based on DOE's 1995 TSD, improvements in gasket design can reduce refrigerator-freezer annual energy consumption by one to three percent.[43] Due to the age of both the EPA and DOE research, it is uncertain how much further gaskets can be improved.

Double Door Gaskets

A double door gasket is an additional inner door seal gasket that is added to the gasket design. This further reduces heat leakage and infiltration into the refrigerator and freezer.

Based on information drawn from DOE's 1995 TSD, manufacturers did not introduce double door gaskets in the mid-1990s because of performance problems and cost. Ice can form between the gaskets, greatly reducing their effectiveness. In addition, the gaskets are visually unattractive and they increase the difficulty of meeting safety regulations for minimum door-opening force.

Improved Door Face Frame

As discussed above, cabinet heat loads stem not only from conduction though the refrigerator walls but also from conduction along the external metal casing. The metal shell provides the structural integrity; however, its presence means that heat loads are transferred along the metal shell into the cabinet. This heat transfer into the cabinet is also referred to as the 'edge effect.'

Using a plastic cover on the internal flange can reduce the 'edge effect' heat losses by approximately 50 percent.[39] It is expected that the use of low-conductivity plastics to reduce conduction losses in this area are already being employed in most current U.S. refrigerator-freezer designs.

Reduced Heat Load for TTD Feature

Through-the-door features that provide ice and/or water service displace insulation in the door. These features can make it difficult to apply foam in the doors. This technology option, which is applicable only to those product classes that include TTD ice service, utilizes improved design methods to reduce the heat load of TTD features.

Based on the DOE 1995 TSD, door-design improvements that reduce the heat load from TTD features can reduce refrigerator-freezer annual energy consumption from two to four percent.[43] The TSD provided little explanation of the details of these design changes, citing only "foam insulation" and "improved design methods".

3.3.2.3 Anti-Sweat Heater

Anti-sweat heaters are commonly used in standard-size refrigerator-freezers. In general, compact refrigerators, compact refrigerator-freezers, and compact freezers do not use anti-sweat heat. These heaters apply heat to external surfaces near door gaskets, including the mullion region between the freezer and fresh food compartments and along the perimeter of the cabinet. If electric resistance heaters are used for this purpose, the heaters contribute to energy consumption both with their wattage input and with the heat load they generate that enters the cabinet. Most modern refrigerator-freezers use refrigerant tubes inserted in the cabinets in close proximity to the regions requiring heat. Both hot discharge gas from the compressor and warm liquid leaving the condenser are used to provide this heat, although a majority of products use warm liquid. As reported above in section 3.11.2.2, the heat loads from both electric and refrigerant type anti-sweat heaters can be significant. For the example illustrated in Table 3.3.6, the contribution of the mullion anti-sweat heater represents 7.7 percent of the total cabinet heat load. However, the load associated with the anti-sweat heater of modern designs may be lower due to evolution of design practices to reduce such loads.

Hot Gas or Warm Liquid

The direct electricity consumption of the anti-sweat heaters can be eliminated by using a hot gas or warm liquid refrigerant loop to warm external surfaces to eliminate moisture buildup. This approach is used extensively in residential refrigerator-freezers to reduce energy use—the technology is already part of all or nearly all standard-size refrigerator-freezers.

Electric Heater Sizing

For those products using electric resistance anti-sweat heaters, unnecessarily high-wattage heaters may be used. Therefore, energy use can be decreased by reducing the heater wattage. For those products that still use electric resistance anti-sweat heaters, DOE is unaware to what extent the wattage of the heater is excessive.

Electric Heater Controls including Variable Antisweat

For those products using electric resistance anti-sweat heaters, control schemes can be used to limit the amount of energy used. One option, which is included on some current refrigerator-freezer models, is to use an on-off switch that allows the user to turn off the heater if "sweating" is not an issue. The DOE Energy test procedure calls for testing with the switch in the on position in order to measure annual energy use.[54] However, DOE understands that most manufacturers measure annual energy use as an average of a test with the heater on and a test with the heater off.

Another option is to control the anti-sweat heater based on temperature and humidity conditions. As discussed in section 3.2.2, DOE is considering incorporating into the test procedure for refrigerators and refrigerator-freezers an adaptation of a test procedure for which a waiver was granted to GE. The waiver provides a method for calculating the annual energy use contribution of electric anti-sweat heaters which are controlled to operate only as much as needed to avoid moisture accumulation, based on the input of ambient temperature and/or humidity sensors. 73 FR 10425 (February 27, 2008)

3.3.2.4 Compressor

The compressor is the primary energy-consuming component in a refrigerator, refrigerator-freezer, or freezer. Therefore, technologies that can advance compressor efficiency have a significant effect on overall product efficiency.

Residential refrigeration products use positive-displacement compressors in which the entire motor-compressor is hermetically sealed in the welded steel shell. Two types of compressors have been used in residential refrigeration products over the years—reciprocating and rotary. However, predominantly reciprocating compressors are now used in U.S. products.

Almost all compressors are directly driven by two-pole squirrel-cage induction motors running at approximately 3,000 rpm on 60 Hz power. Three types of induction motors have been used in refrigerator compressors: resistance start/induction run (RSIR), capacitor start/induction run (CSIR), and resistance start/capacitor run (RSCR). Of the three motor types, the RSIR motor is the least efficient. As a result of the U.S. energy efficiency standards that took effect in 1993 and 2001, the vast majority of compressor motors now use the RSCR type.

Refrigerator compressor capacities range from as low as 125 Btu/hr (for compact refrigerators) to as high as 2,000 Btu/hr, although maximum capacities are more typically 950 Btu/hr for U.S. residential refrigerator-freezers. Two organizations have established conditions for rating the performance of refrigerator compressors: ASHRAE and Comité Européen des Constructeurs de Matériel Frigorifique (CECOMAF).[g] Table 3.3.7 below shows the rating conditions of these two organizations. The rating conditions are almost identical, except for the liquid temperature—this is the temperature leaving the condenser or any subcooling loop such as an anti-sweat heating loop. Because the CECOMAF liquid temperature is higher, compressor capacities and efficiencies under ASHRAE rating conditions are approximately 30 percent higher than for CECOMAF conditions. The actual operating conditions for compressors in residential refrigeration products under DOE energy test conditions can be significantly different than these rating conditions. Most notably, the condensing temperatures are generally significantly lower than 130 ˚F.

Table 3.3.7 Compressor Rating Conditions

Rating Condition	ASHRAE	CECOMAF
Evaporator	-10 ºF (-23.3 ºC)	-10 ºF (-23.3 ºC)
Condenser	130 ºF (54.4 ºC)	131 ºF (55 ºC)
Ambient	90 ºF (32.2ºC)	89.6 ºF (32 ºC)
Suction Gas	90 ºF (32.2ºC)	89.6 ºF (32 ºC)
Liquid	90 ºF (32.2 ºC)	131 ºF (55 ºC)

Compressor efficiency is also a function of refrigeration capacity. Based on data from DOE's 1995 TSD, maximum expected compressor efficiencies for the year 1998 demonstrated that efficiency drops off with decreasing cooling capacity.[43] The expected maximum compressor efficiencies for the year 1998 as reported in the 1995 TSD are shown below in Table 3.3.8 below. A year 2000 European Commission study to support energy standards of domestic refrigeration appliances also noted the drop in efficiency as capacity drops.[45] The reduced efficiency for lower-capacity compressors has been attributed to optimization of performance for higher-capacity compressors[55] and to the higher importance of mechanical losses and losses associated with re-expansion of gases left in the clearance volume as the swept volume of the reciprocating piston decreases.

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[g] CECOMAF is a European appliance manufacturer trade association formed in 1958. It merged with EUROVENT in 1996 to become EUROVENT/CECOMAF. This organization is now called EUROVENT.

Table 3.3.8 Estimated 1998 Maximum Compressor Efficiencies

Product Class Served	Capacity Range*		Maximum Efficiency by 1998*	
	W	*Btu/hr*	*Coefficient of Performance (COP)*	*Energy Efficiency Ratio (EER), Btu/hr-W*
The Five Standard Refrigerator-Freezers	220 to 278	750 to 950	1.64	5.60
	176 to 205	600 to 700	1.60	5.45
Auto Defrost Upright Freezers	250 to 278	850 to 950	1.64	5.60
Manual Defrost Upright Freezers	161 to 176	550 to 600	1.51	5.15
Manual Defrost Chest Freezers	147 to 161	500 to 550	1.45	4.95
Compacts	117	400	1.38	4.70
	103	350	1.26	4.30
	59	200	1.04	3.55
	41	140	0.76	2.6

Source: DOE, 1995 TSD.

* Performance based on ASHRAE rating conditions. Performance based on the use of refrigerant R-134a.

More recent compressor performance data was collected as part of the engineering analysis, and the results of this investigation is presented in Chapter 5. The highest efficiency single-speed compressors available for standard-size refrigerator-freezers have EER near 6.25 Btu/hr-W.

Improved Compressor Efficiency

Conversion to high-efficiency compressors is fairly straightforward for manufacturers to implement as long as the appropriate compressors are available. As indicated above, maximum efficiencies for compressors that are utilized in the most common types of U.S. refrigerator-freezers range to near 6.25 Btu/hr-W.

Variable-Speed Compressors

Variable-speed compressors allow efficiency improvement as compared to single-speed compressors since they can provide a better match of thermal loads during the vast majority of hours when the loads are low. Most of the time, the compressor would operate at low speed with a high percentage of on-time. This would lower energy consumption by reducing off-cycle losses and by allowing the heat exchangers to operate with lower mass flow, thus boosting their effectiveness. However, careful consideration must be given to how variable speed compressors are implemented, because increased fan run times could negate compressor energy savings.

Electronics are used by variable-speed compressors to vary the speed. They use either inverter-driven induction motors or permanent magnet motors. Most U.S. residential refrigeration products do not currently use variable-speed compressors, but the use of these compressors is becoming more common.

Various past studies have illustrated a range of energy savings achievable through use of variable speed compressors. Arthur D. Little reported savings of approximately 25 percent compared to single-speed motor systems in 1999.[56] Research conducted by Tecumseh Products

Company demonstrated that energy savings of 15 percent as well as reduction of sound and vibration levels.[57] Simulation analyses conducted at the University of Illinois demonstrated that steady-energy savings ranging from four to 14 percent could be realized through the use of a two-speed compressor in concert with multiple-speed evaporator and condenser fans. The research also demonstrated that an additional 0.5 to four percent in energy consumption could be saved through the reduction of cycling frequency, i.e. the number of starts.[58]

Embraco has developed its third generation variable-speed compressor that utilizes a permanent magnet motor controlled by a programmable electronic unit.[59] Table 3.3.9 presents the rated performance of some of Embraco's variable-speed compressors. The rated efficiencies of these variable-speed compressors are not necessarily higher than the best efficiencies of single-speed compressors--evaluation of the benefits of variable-speed compressors requires consideration of the system performance rather than just rated performance.

Table 3.3.9 Efficiencies of Some of Embraco's Variable-Speed Compressor Models

	Capacity Range*		**Efficiency***	
Model	*W*	*Btu/hr*	*COP*	*EER*
VEGY6H (1600-4500 revolutions per minute (rpm))	98 – 281	676 – 959	Up to 1.78	Up to 6.07
VEGY7H (1600-4500 rpm)	111 – 314	379 – 1071	Up to 1.81	Up to 6.18
VEGY8C (1600-4000 rpm)	132 – 319	450 – 1088	Up to 1.79	Up to 6.11

Source: Embraco, 2006.
* Performance based on ASHRAE rating conditions. Models utilize refrigerant R-134a.

Linear Compressors

Linear compressors employ a different design than either reciprocating or rotary compressors and are reportedly more efficient than either. These compressors use a linear rather than rotary motor, thus eliminating the crankshaft and linkage which converts the rotary motion to the linear motion of the piston of a reciprocating compressor. Elimination of the mechanical linkage reduces friction and side-forces. The linear motor requires power electronics and a controller to assure proper piston throw. Most linear compressor designs use a free piston arrangement and can be controlled for a range of capacities through adjustment of piston displacement. Early work on the concept suggested that the compressors can operate without requiring oil, which could provide additional energy benefit by improving heat transfer in the evaporator. Refrigerator noise levels can also be reduced by utilizing linear compressors in the same way that this can be done with variable-speed compressors, by operating most of the time at low capacity.[60]

An early version of the linear compressor design was developed by Sunpower for integration into refrigerators for the European market using isobutene (R-600a) as a refrigerant.[61] LG has developed a linear compressor for household refrigerators which does require use of oil. LG claims that its line of linear compressors is up to 20 percent more efficient than reciprocating designs.[62] Table 3.3.10 presents the rated efficiencies of LG's linear compressors.[63] LG reports the efficiency of its linear compressors only at "LG Reference Conditions," which are significantly different than the ASHRAE rating conditions. Under ASHRAE conditions, compressors are rated with evaporating and condensing temperatures of -10ºF (-23.3ºC) and

130ºF (54.4ºC), respectively, while the "LG Reference Conditions" are based on evaporating and condensing temperatures of -14.8ºF (-26ºC) and 100.4ºF (38ºC), respectively. It is not clear what the liquid and suction vapor temperatures for the LG conditions are—these temperatures also impact capacity and power input. At the same evaporating and condensing temperatures and with liquid and suction vapor conditions consistent with the ASHRAE test conditions, a high efficiency rotating-shaft reciprocating compressor such as the Embraco EGX70HLC would have an operating EER of about 6.9 Btu/hr-W. Hence, the LG linear compressor may be about 9% more efficient than the best current-technology rotating-shaft reciprocating compressors.

Table 3.3.10 Efficiencies of LG's Current Linear Compressor Models

	Capacity Range*		Efficiency*	
Model	*W*	*Btu/hr*	*COP*	*EER*
DLF81LACT	310	1058	2.14	7.3
FA81LACT	293	1000	2.20	7.5
FA72LACT	276	941	2.20	7.5
FA63LACT	241	823	2.20	7.5
FA54LACT	207	706	2.20	7.5

Source: LG, 2007.
* Performance based on 'LG Reference' rating conditions. Models utilize refrigerant R-134a.

In the trade press, LG has expressed willingness to license the linear compressor technology to competitors.[64] However, because the LG design is proprietary, the widespread use of linear compressors is uncertain.

3.3.2.5 Evaporator

The evaporator is a key component of the refrigeration system. As discussed earlier in section 3.11.2, there are three basic evaporator designs depending on the refrigeration product: standard-size refrigerator-freezers and upright freezers with automatic defrost typically use a forced-convection finned-tube design; compact refrigerators and refrigerator-freezers and small-size standard refrigerator-freezers generally use a roll-bond design; and chest freezers and upright freezers with manual defrost typically use a coil design that is integrated within the walls of the unit. Some manual defrost freezers also use evaporators which are integrated with the wire shelving. In the case of the finned-tube designs used in standard-size refrigerator-freezers, design, modeling, and experimental studies have been conducted to evaluate their heat transfer performance.[65, 66] Evaporator performance can be enhanced by increasing the heat exchanger surface area or improving the heat exchange performance.

Increased Surface Area

Increasing the heat exchanger surface area can be achieved by increasing the face area of the evaporator or adding more tube rows. These measures are limited by the geometry of the refrigeration product. There is a tradeoff between increasing the volume occupied by the heat exchanger and reducing the interior volume of the refrigerator.

In its 1995 TSD, DOE considered increasing the evaporator surface area for most of the product classes analyzed; this resulted in an estimated one to two percent reduction in annual energy consumption.[43] In the 1995 TSD, DOE based cost and efficiency improvements for this technology on estimates by manufacturers. No details were provided on how exactly the evaporator surface area was increased. Therefore, it is uncertain to what extent design efforts to increase the evaporator surface area have been employed in current U.S. refrigerator-freezer designs.

Improved Heat Exchange

Improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes. These types of fin and tube enhancements are common in air-conditioning applications where slit and louvered designs are used to enhance the fin surface and different types of internally-grooved surfaces are used to enhance the tubing. In its 1995 TSD, DOE considered enhancing the evaporator's heat exchange performance for many of the product classes analyzed; this resulted in an estimated one to two percent reduction in annual energy consumption.[43] In the 1995 TSD, DOE based cost and efficiency improvements for this technology on estimates by manufacturers. No details were provided on how exactly the evaporator heat exchange performance was enhanced. Therefore, it is uncertain to what extent design efforts to enhance the evaporator heat exchange performance have been employed in current U.S. refrigerator, refrigerator-freezer, and freezer designs.

Heat exchanger technologies that could potentially improve evaporator performance are microchannel heat exchangers, electrohydrodynamic enhancement, and the adoption of phase-change materials. In the case of microchannel heat exchangers, past research has demonstrated that the use of such heat exchangers in domestic refrigerators can provide system efficiencies comparable to current technologies while reducing refrigerant charge.[67] Electrohydrodynamic enhancement employs high-voltage fields to improve the heat exchange performance. However, safety issues involved in using such high voltages in domestic appliances have not yet been resolved. In addition, no prototypes are available to test and evaluate this technology for domestic refrigerators and freezers. Finally, with regard to phase-change materials, Thomson (a French manufacturer) has integrated into its heat exchangers a phase-change material that enables higher average evaporation temperatures than conventional designs, thereby yielding energy savings.[45] It is unclear for any of these technologies whether they will ever achieve widespread use in refrigerator-freezers.

Research has also been conducted on the use of a ground-source heat exchanger as a means of rejecting heat from the cabinet and improving the efficiency of a refrigerator-freezer. Although the use of such a design reduced energy consumption considerably, it is likely not practical for most domestic refrigeration products.[68]

3.3.2.6 Condenser

The condenser, like the evaporator, is a key component of the refrigeration system and is located on the outside of the unit. As discussed in section 11.1.2, there are three basic condenser designs depending on the refrigeration product: Standard-size refrigerator-freezers typically use a forced-convection finned-tube design; compact refrigerators and refrigerator-freezers generally use a wire-and-tube "static" design which uses natural convection cooling; and freezers typically use a hot wall condenser that is integrated within the shell of the unit. In the case of the static condensers used in compact units, modeling studies have been conducted to evaluate their heat transfer performance.[69] Modeling studies have also been performed on hot-wall condensers.[70, 71] Condenser performance can be enhanced by increasing the heat exchanger surface area or improving the heat exchange performance.

Increased Surface Area

Increasing the heat exchanger surface area can be achieved by increasing the face area of the condenser or adding more tube rows. These measures can be limited by the geometry of the refrigeration product. There may be a tradeoff between increasing the volume occupied be by the heat exchanger and reducing the interior volume of the refrigerator.

In its 1995 TSD, DOE considered increasing the condenser surface area for many of the product classes analyzed; this resulted in an estimated one to two percent reduction in annual energy consumption.[43] In the 1995 TSD, DOE based cost and efficiency improvements for this technology on estimates by manufacturers. No details were provided on how exactly the condenser surface area was increased. Therefore, it is uncertain to what extent design efforts to increase the condenser surface area have been employed in current U.S. refrigerator-freezer designs.

Improved Heat Exchange

Improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes. These types of fin and tube enhancements are common in air-conditioning applications where slit and louvered designs are used to enhance the fin surface and different types of internally grooved surfaces are used to enhance the tubing. In its 1995 TSD, DOE considered enhancing the condenser's heat exchange performance for some freezer and compact unit product classes; this resulted in approximately a two percent estimated reduction in annual energy consumption.[43] In the 1995 TSD, DOE based cost and efficiency improvements for this technology on estimates by manufacturers. No details were provided on how exactly the condenser heat exchange performance was enhanced. Therefore, it is uncertain to what extent design efforts to enhance the condenser heat exchange performance have been employed in current U.S. refrigerator, refrigerator-freezer, and freezer designs.

As with evaporators, other heat exchanger technologies could be employed to improve condenser performance. Microchannel heat exchangers, electrohydrodynamic enhancement, and the adoption of phase-change materials are all applicable to condensers, although phase-change materials have only been used in evaporators. It is unclear for any of these technologies whether they will ever achieve widespread use in refrigerator-freezers.

The same research that investigated the use of ground-source heat exchangers as means of rejecting heat for the cabinet also examined its application for rejecting heat from the condenser. The technology was demonstrated to be effective at reducing the energy use of a refrigerator-freezer, but is likely not practical for most domestic refrigeration products.[45]

Forced-Convection Condenser

Most standard-size refrigerator-freezers use forced-convection condensers. In contrast, most standard-size freezers use hot wall condensers. The forced convection configuration can provide higher heat transfer effectiveness. However, space for housing a forced convection condenser and its associated fan is not always available. The consideration of conversion to forced-convection condensers will depend on whether a particular product class is designed in a way that allows housing of the condenser and fan in a suitable location.

3.3.2.7 Fan and Fan Motor

Fans are used to increase evaporator and condenser heat transfer. Because most refrigerator-freezers use forced-convection condensers which rely on fans for air movement, fan and fan-motor technology options for the condenser are applicable. However, many manual-defrost refrigerators and freezers—specifically chest freezers and small, under-counter-type refrigerators—use static condensers and/or natural convection evaporators and, as a result, do not use fans and fan motors.

For those refrigeration products that do utilize fans, refrigerator manufacturers purchase fans and fan motors from outside vendors. Therefore, conversion to more-efficient fan motors can be accomplished relatively easily when more-efficient fans and fan motors are available.

Fan and Fan Motor Improvements

Evaporator can condenser fans are typically of axial design. Evaporator fan blades are typically either 100mm or 110mm in diameter. Because the evaporator fan and fan motor are located within the refrigerated cabinet and the electric energy input adds to the refrigeration load, more-efficient evaporator fan or evaporator fan motor designs contribute to efficiency improvements in two ways: (1) reducing the power consumption of the fan motor and (2) reducing the power consumption of the compressor due to decreased heat losses into the cabinet from the fan motor.

One source of inefficiency for axial fans lies in their tendency to throw air outward. The Pax Group™ has developed a fan (PAX fan) that employs streamlined blades with patented geometrical shapes which reportedly provide better airflow direction and improved efficiency. Tests performed with the PAX fan have demonstrated a reduction in fan-motor power of 23 percent and an overall reduction in refrigerator energy consumption of 3.9 percent relative to a refrigerator with a typical axial fan blade design.[72] However, because the PAX fan is proprietary, the widespread use of the design is highly uncertain.

Before the 1993 U.S. energy efficiency standards took effect, most evaporator and condenser fan motors were shaded pole induction designs, with efficiencies between 10 and 15 percent and power input of about 15 Watts (W). Higher-efficiency motor designs include permanent split capacitor motors (PSC) induction motors with 20 to 30 percent efficiency, and brushless DC motors, with near 65 percent efficiency.

3.3.2.8 Expansion Valve

The metering device in most household refrigerator-freezers is a capillary tube. As discussed above in section 11.1.1, there are two common types of capillary tubes—adiabatic and non-adiabatic. In the non-adiabatic configuration, the capillary tube is soldered to the suction line to evaporate the residual liquid in the suction line and to warm the vapor to near-ambient temperature. The suction line heat exchanger (or the non-adiabatic capillary) improves efficiency because it increases the refrigeration capacity of the system by the amount of heat being transferred from the capillary to the suction side. Non-adiabatic capillary tubes are the most common type of metering device in refrigerator-freezers. The other type of metering device, an adiabatic capillary tube, is used in some refrigeration products. In this configuration, the capillary tube does not exchange heat with the suction line and the refrigerant expands from the high pressure to the low pressure adiabatically. Research has been conducted to develop models to study the performance of both types of capillary tubes.[73, 74]

Improved Expansion Valve

Automatic, adjustable thermostatic or electronic expansion valves may provide improved performance. The technology for this design option is available; however, a modification in system design is required. DOE has not be able to identify any data demonstrating that improved expansion valves will save energy in domestic refrigerators.

3.3.2.9 Cycling Losses

Off-cycle refrigerant migration reduces a refrigeration product's efficiency by transferring heat from outside the cabinet into the evaporator. Changes in refrigerator design that reduce this aspect of cycling losses can increase the unit's efficiency.

Fluid Control or Solenoid Valve

A fluid control or solenoid valve installed after the condenser to effectively isolate the evaporator from the condenser during the off-cycle can be used to prevent any refrigerant migration. Research has demonstrated that solenoid valves can yield substantial energy savings.[75] However, there are drawbacks to using solenoid valves. First, refrigeration migration allows the system pressure to equalize, reducing the required starting torque of the compressor motor. A solenoid valve would increase the required starting torque of the compressor motor. Second, adding such a valve could negatively affect system reliability.

3.3.2.10 Defrost System

Section 3.11.1.2 provides a description of typical automatic defrost systems for refrigerator-freezers. Most units use electric heaters to defrost the ice buildup on the evaporator located in the freezer section of a refrigerator-freezer. Energy use associated with defrost includes the energy input for the heater and also the refrigeration system energy used to remove the defrost heat from the cabinet.

Reduced Energy for Automatic Defrost

In some cases, the defrost heat supplied is more than required. Thus, energy savings can be achieved by reducing the defrost heat by either using a smaller heater, reducing the heater on-time, reducing the frequency of defrost, or a combination of these.

In its 1995 TSD, DOE found that most manufacturers had already significantly reduced the electric heat for auto defrost in order to comply with the energy efficiency standards that became effective in 1993.[43] There may be limited additional energy savings possible through optimization of automatic defrost.

Adaptive Defrost

To reduce the energy used for defrost, adaptive defrost can be used. An adaptive defrost system can control both the defrost time and the amount of defrost heat. Adaptive defrost systems make use of controls to adjust the time between defrost cycles to the appropriate amount for the door opening frequency, ambient conditions, and other consumer usage patterns which affect the introduction of moisture into the cabinet. In a typical automatic defrost system, a mechanical timer initiates defrost after a specified time period, usually 10 to 12 hours of compressor on-time. By allowing adjustment of the time between defrosts, energy use can be reduced. The DOE energy test procedure includes modified test procedures for evaluating the energy use of products with adaptive defrost. In its 1995 TSD, DOE estimated that energy consumption can be reduced by three to four percent with adaptive defrost.[43] It is unclear what percentage of the refrigerator market currently uses adaptive defrost.

Condenser Hot Gas

Another method of reducing the energy required for defrost is to eliminate the need for electric heaters by substituting condenser hot gas in their place. In a condenser hot gas defrost system, the compressor continues to run and a valve opens allowing hot compressed refrigerant to flow to the evaporator. Many frost-free refrigerator-freezers in the 1960s and 1970s used such a defrost system.

3.3.2.11 Control System

The control systems discussed here pertain to those controlling the temperature and air-distribution within the refrigeration product.

Temperature Control

Conventional thermostats are thermomechanical devices that are not very accurate. The inaccuracy of these devices may produce large temperature fluctuations within the cabinet and, in turn, thermodynamic inefficiencies. Electronic thermostats are available that can provide more precise and repeatable temperature control than conventional thermostats. This can result in improved efficiency. Electronic thermostat systems can also account for more parameters than just the cabinet temperature, such as the room temperature, to better regulate product operation and reduce compressor run times.

Air-Distribution Control

For refrigerator-freezers, better air distribution between the freezer and fresh food compartments can improve temperature control and reduce energy consumption. Improving the distribution of cold air within the refrigerator-freezer allows the temperature difference between the air and foodstuffs to be minimized, enabling the evaporation temperature to be raised and, thereby, reducing energy consumption. It is uncertain to what degree the air distribution control in current refrigerator-freezer models can be improved. However, the fact that several patents have been issued in the U.S. since 1995 regarding air distribution implies that improvements in air distribution control are possible.[45]

3.3.2.12 Other Technologies

Alternative refrigerants and changing the location of refrigeration components can also improve the efficiency of refrigeration products. These two technology options are discussed below.

Alternative Refrigerants

Through the 1980s, CFC-12, a chlorofluorocarbon, was used as the refrigerant in almost all refrigerators, refrigerator-freezers, and freezers. However, under the Montreal Protocol, all CFCs were banned from use by the mid-1990s due to their high ozone depletion potential (ODP). In the early 1990s, many alternative refrigerants were evaluated as a replacement for CFC-12. Of the alternatives considered, the industry settled on HFC-134a as the replacement for CFC-12. Although initial research demonstrated that HFC-134a as a drop-in replacement yielded efficiencies which were four to 10 percent less than CFC-12, further work showed that with the appropriate superheat and subcooling taken into consideration, HFC-134a could yield essentially equivalent system efficiencies as CFC-12.[76]

Because HFC-134a exhibits some global warming potential (GWP), research continued to find an alternative refrigerant with less or no GWP. For example, R-152a has a lower GWP than HFC-134a but, primarily due to flammability concerns and the potential liability issues it posed to refrigerator manufacturers, it was dismissed as a potential alternative.

Naturally occurring substances such as carbon dioxide, ammonia, and hydrocarbons are all considered to be environmentally safe refrigerants with very low GWP. Hydrocarbons in particular are attractive due to their similar thermodynamic properties to CFC-12. Much research has been conducted showing the efficiency benefits of hydrocarbons. For example, the performance of propane/isobutane and propane/butane mixtures in domestic refrigerators has been shown to be equal to or better than products using CFC-12.[77, 78] Hydrocarbon flammability has been pointed out as a significant drawback and has prevented their adoption in U.S. products. In contrast, European refrigerator manufacturers started manufacturing products with isobutane in the 1990s. However, recently the General Electric Company announced the intention to introduce this refrigerant in the U.S.[79]

Component Location

In its 1995 TSD, DOE saw energy savings potential in more optimal placement of certain components. For example, if the compressor and condenser are located on the top of the refrigerator-freezer, DOE determined that they can operate more efficiently because heat is more readily convected away from the system and, in addition, the condenser fan can be eliminated. As described previously, traditionally, the compressor and condenser are located at the bottom rather than the top of the refrigerator-freezer so the user can have easy access to the food compartments, to key center of gravity low, and to provide air flow and a heat source near the tray which collects defrost water to assure quick re-evaporation of water. Locating the condenser and compressor at the top of the unit would require modification of traditional practice and consumer preference. It would also require product redesign, which could potentially increase manufacturing costs.

Another option is to locate the evaporator fan motor outside the cabinet to reduce internal loads from the heat loss of the motor. However, it is difficult to prevent air leakage where the motor shaft penetrates the cabinet wall. The 1995 TSD concluded that the lack of experimental data prevented the evaluation of component relocation.[43]

3.3.2.13 Alternative Refrigeration Cycles

Alternative refrigeration cycles may have the potential to improve system efficiency. Several alternative refrigeration cycles for refrigerator-freezers are described below. Dual-loop refrigerator-freezers using two independent refrigeration cycles (one for the fresh food compartment and the other for the freezer compartment) are available on the market. Also, dual-evaporator units likely utilizing a control valve system are also being marketed. The other alternatives listed below have been demonstrated in prototypes to reduce energy consumption but it is uncertain as to whether they can be mass produced as a practical alternative to today's current conventional refrigeration systems.

Lorenz-Meutzner Cycle

In a conventional refrigerator-freezer, the temperature of the freezer and fresh food compartments are around 5ºF (-15ºC) and 38ºF (3.3ºC), respectively. This suggests that the fresh food compartment with a smaller temperature lift (i.e., the temperature difference between the evaporator and condenser) can operate with a higher efficiency than that of the freezer. By using zeotropic[h] refrigerant mixtures, the Lorenz-Meutzner cycle exploits the inherent thermodynamic advantages of the temperature glide exhibited during evaporation or condensation of the refrigerant mixture. By choosing a refrigerant mixture with very wide temperature glide, the refrigerant mixture can pass sequentially through the freezer and fresh food compartment evaporators, providing refrigeration at the two evaporating temperature levels using a single compressor. As compared to a conventional refrigerator-freezer, the hardware differences include a high-temperature evaporator for the fresh food compartment and a low-temperature heat exchanger between the fresh food and freezer evaporators. Lorenz and Meutzner in their research determined that their cycle using an R-22/R-11 refrigerant mixture (50 percent of each)

[h] A zeotropic mixture consists of two or more refrigerant components. Zeotropic mixtures have what is referred to as a temperature glide when they boil and condense: at a fixed pressure, the temperature is higher for higher quality (i.e. vapor fraction). Unlike zeotropes, azeotropic mixtures consist of two or more refrigerant components that behave like a single refrigerant, exhibiting no temperature glide.

achieved up to 20 percent energy savings compared to a conventional refrigerator-freezer using R-12 only.[80]

Subsequent research validated Lorenz and Meutzner's findings and demonstrated the viability of the cycle based on the use of different zeotropic refrigerant mixtures, including mixtures composed of hydrocarbons. For example, as compared to a conventional refrigerator-freezer, experimentation on an 18 ft^3 top-mount refrigerator-freezer demonstrated that a modified Lorenz-Meutzner cycle yielded 16.6 percent, 14.6 percent, and 16.7 percent energy savings with binary mixtures of R-22/R-123, propane/n-pentane, and propane/n-butane, respectively.[81]

Because the industry settled on the use of HFC-134a to replace CFC-12, interest in the Lorenz-Meutzner cycle as an alternative to conventional refrigeration cycles declined.

Dual-Loop System

One of the best methods to reduce the thermodynamic irreversibilities resulting from the operation with a single evaporator in a refrigerator-freezer is to employ two separate refrigeration cycles. This system, referred to as a dual-loop system, has two completely separate refrigeration cycles which provide cooling for the freezer and fresh food compartments independently. In practice, the theoretical benefits of such a cycle are not achieved due to the use of two compressors that are smaller and less efficient than the original single compressor. Also, dual-loop systems are physically larger and would either increase the product's external dimensions or decrease the usable refrigerator volume.

Research has demonstrated that the energy savings due to a dual-loop system are a function of the cabinet load ratio (defined as the ratio of the fresh food to the freezer cabinet loads) and the ratio of the freezer and refrigerator cycle efficiencies. Depending on these two parameters, a dual-loop system using HFC-134a can reduce energy consumption by up to 30 percent compared to a conventional refrigerator-freezer.[82]

There are numerous products currently on the market that incorporate dual-compressor systems, including Bosch's Integra line of bottom-mount refrigerator-freezers,[83] Sun Frost's RF19 model,[84] Northland's 48-inch side-mount refrigerator-freezer,[85] Sub-Zero's built-in line of refrigerator-freezers,[86] Liebherr refrigerators,[87] etc.

Two-Stage System

The two-stage system employs one condenser, two evaporators, two compressors, and at least one suction-line heat exchanger. The increased efficiency of this system over a conventional system is obtained due to a smaller work requirement that results from the low-pressure ratio for each of the two compressors.[88] The two-stage system offers the advantage of having one fewer component (a condenser) than the dual-loop system, but has many of the same disadvantages (e.g., either increased external dimensions or decreased internal volume).

Control Valve System

The control valve system has two evaporators, one for the fresh food compartment and one for the freezer compartment, but only one compressor and one condenser. Two different length capillary tubes and a control valve are installed between the fresh food and freezer evaporator inlets and the condenser outlet. The valve directs the flow of the refrigerant through one of the evaporators at a time. That is, only one of the two compartments is cooled at any given time. With this configuration, the fresh food compartment is cooled at a higher evaporator temperature than the freezer compartment. Experimental research conducted on this system configuration indicated that the energy efficiency can be improved by 8.5 percent over that of a conventional refrigerator-freezer.[89]

GE offers a refrigerator-freezer system called the ClimateKeeper2™ system that uses two evaporators.[90] Also, KitchenAid and Jenn-Air both offer under-counter compact refrigerator-freezers that use dual evaporators.[91] [92] The system details of none of these products is clearly described in the product literature.

Ejector Refrigerator

One of the intrinsic losses in a conventional refrigeration cycle is the throttling of the refrigerant in the capillary tube. Throttling is an isenthalpic process in which work that could be extracted in the expansion process is not captured. In the ejector refrigerator, some of this work can be captured and used to raise the pressure of refrigerant entering the compressor above that of the evaporator. Simulation research has been conducted on an ejector refrigerator that consists of one compressor, one condenser, two capillary tubes, two evaporators (one for the fresh food compartment and the other for the freezer compartment), and an ejector. In this refrigerator, saturated liquid refrigerant exits the condenser and expands in the capillary tube to the fresh food evaporator. In the fresh-food compartment, the refrigerant is partially evaporated. At the outlet of the evaporator, the liquid refrigerant is separated from the vapor in a separator. The vapor flows to the ejector, where it is accelerated to high velocity. The liquid expands in a second capillary tube to the freezer evaporator, where it evaporates entirely. The vapor leaving the freezer evaporator is entrained in the high-velocity flow of the vapor which left the fresh food evaporator. The mixed flow is decelerated to increase its pressure. The mixed flow higher pressure flow passes to the compressor suction port to be compressed. This particular ejector refrigerator was shown to have an efficiency which is 12.4 percent higher than a conventional refrigerator-freezer.[93]

Tandem System

Like the control valve system and the ejector refrigerator, the tandem system uses two evaporators (one for the fresh food compartment and another for the freezer compartment), one condenser, and one compressor. Refrigerant flows in series first through the fresh food evaporator, then the freezer evaporator, and it passes a second time through the fresh food evaporator. The warm liquid refrigerant leaves the condenser and flows to fresh food evaporator without a first expansion. In the fresh food evaporator the refrigerant liquid undergoes heat exchange with the evaporating refrigerant which has passed through the freezer evaporator. The temperature of the liquid is reduced by this heat exchange. The liquid then passes through the capillary tube where its pressure is reduced. The two-phase refrigerant then passes through the freezer evaporator and absorbs heat from the freezer compartment. This vaporization process only occurs when the freezer evaporator fan is turned on by the freezer thermostat. The refrigerant then passes back through the fresh food evaporator. Here, if the refrigerant has not already been vaporized (i.e., the freezer compartment does not require cooling), it vaporizes as a result of absorbing heat from the fresh food compartment and the warm liquid. The superheated refrigerant then flows to the compressor suction port. At the beginning of the compressor run, the fresh-food compartment fan is turned on first. Thus, the fresh food compartment is cooled before the system reaches steady state. As a result, the system uses the pull-down period of each cycle, which is generally not suitable for cooling the freezer, to cool the fresh food compartment. This particular tandem system was shown to reduce energy use by 18 percent compared to a conventional refrigerator-freezer.[94]

3.3.2.14 Alternative Refrigeration Systems

Alternative refrigeration systems do not use vapor compression to provide refrigeration. Three alternative refrigeration systems are discussed below: the Stirling cycle, thermoelectric cooling, and thermoacoustic cooling. Although research and development has been conducted on each of these systems, and thermoelectric compact refrigerators and wine coolers are currently being marketed, none are a viable alternative for standard-size refrigerators, refrigerator-freezers, and freezers.

Stirling Cycle

A Stirling-cycle machine is a device that operates on a closed regenerative thermodynamic cycle, with cyclic compression and expansion of the working fluid at different temperature levels, and where the flow is controlled by volume changes, so that there is a net conversion of heat to work or vice versa. ‘Regenerative’ refers to the use of an internal heat exchanger, the regenerator, which is an essential part of the Stirling cycle. A Stirling refrigeration cycle compresses and expands an inert gas in a single cylinder. Heat is rejected at one end of the cylinder and absorbed at the opposite end. In the absence of all thermodynamic losses, the efficiency could be higher than for vapor compression systems, but there are various technical difficulties that have so far limited the use of Stirling-cycle cooling to small prototype domestic refrigerators. There is no circulating refrigerant fluid and the hot and cold heat areas are relatively small, which creates heat exchange challenges for any but the lowest-capacity systems.

Thermoelectric

Thermoelectric cooling occurs when a current is passed across the junction of two dissimilar metals. One side of the device becomes hot and the other cold. Materials (semiconductors) have relatively recently been developed that have allowed for the use of this type of cooling in some applications. Thermoelectric cooling devices have no moving parts, do not age, and have extremely long lifetimes. There are several compact refrigerators and wine coolers using thermoelectric cooling that are being marketed, including several models offered by Avanti Products.[95] However, they have very low efficiency and are not yet suitable for standard-size domestic refrigerator-freezers.

Thermoacoustic

Acoustic cooling uses a sound generator inside a closed tube to vibrate a gas and cause alternate compression and expansion and therefore heating and cooling. The efficiency of prototypes have not been as high as vapor compression systems and the devices have been physically large for the amount of cooling produced.

3.3.3 Energy Efficiency

DOE gathered data on the energy efficiency of residential refrigerators, refrigerator-freezers, and freezers currently available in the marketplace. DOE created a database of the current models by surveying manufacturers' websites. The data provide an overview of the energy efficiency of each product class covered by this rulemaking.

For the models in the DOE database, Figure 3.3.3 through Figure 3.3.22 present by product class the relationship between rated annual energy use and adjusted volume. The information is presented according to the current product class structure, because the data does not provide additional segregation according to the new product classes. In each figure, lines representing the maximum allowable energy consumption (i.e., the current minimum efficiency standard) and the current ENERGY STAR level (that took effect in April 2008 for standard-size refrigerators and refrigerator-freezers), are provided. This allows for a quick visual inspection of the number of models that met the ENERGY STAR level.

The data representing all-refrigerators are highlighted in the figures for product classes 1, 3, 11, and 13. For product classes 1 and 11, the products which are not all-refrigerators could be either basic refrigerators or manual defrost refrigerator-freezers. For product classes 3 and 13, the products which are not all-refrigerators are refrigerator-freezers. The percentage of all-refrigerators is high for product class 11 and very high for product class 13.

The DOE survey found no current models in product class 6, top-mount refrigerator-freezers with through the door ice and with automatic defrost. DOE still provides a figure for this class to show the maximum allowable energy consumption for this product class. Many of the other product classes also have few products.

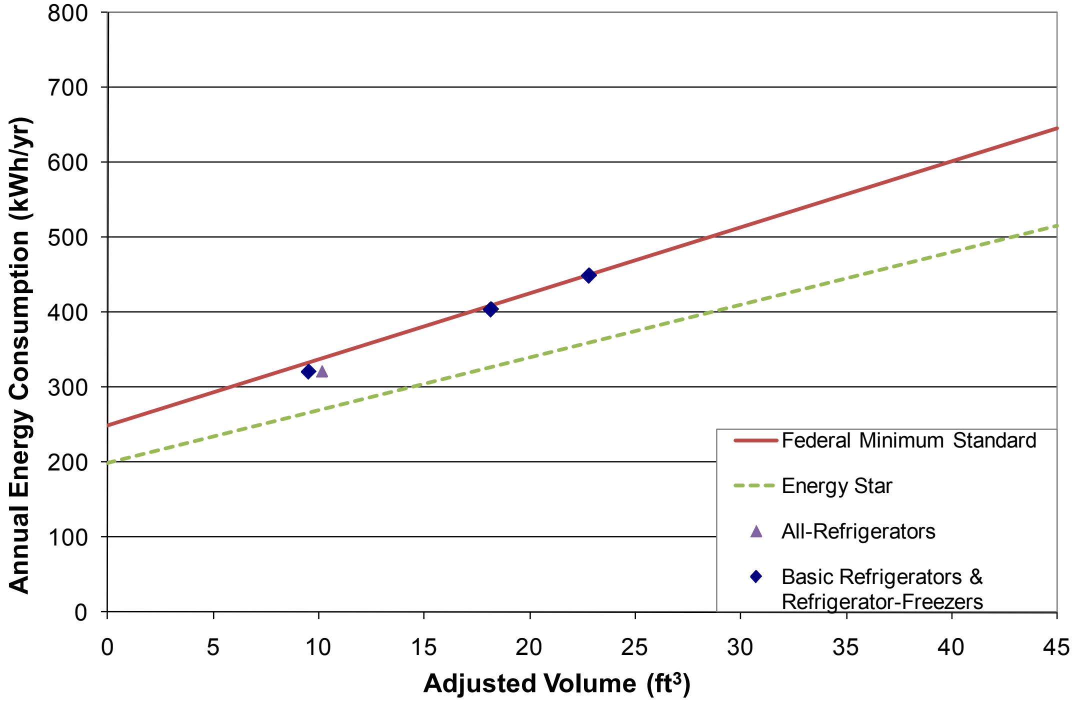

Figure 3.3.3 Annual Energy Consumption for Refrigerators and Refrigerator-Freezers with Manual Defrost (Product Class 1)

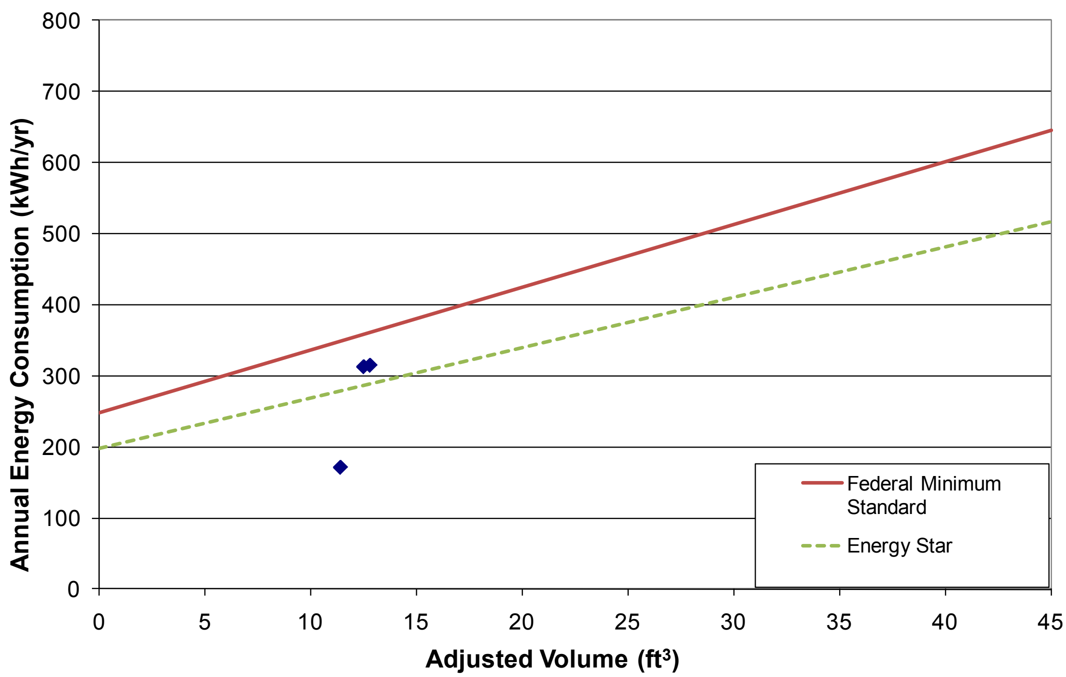

Figure 3.3.4 Annual Energy Consumption for Refrigerator-Freezers with Partial Automatic Defrost (Product Class 2)

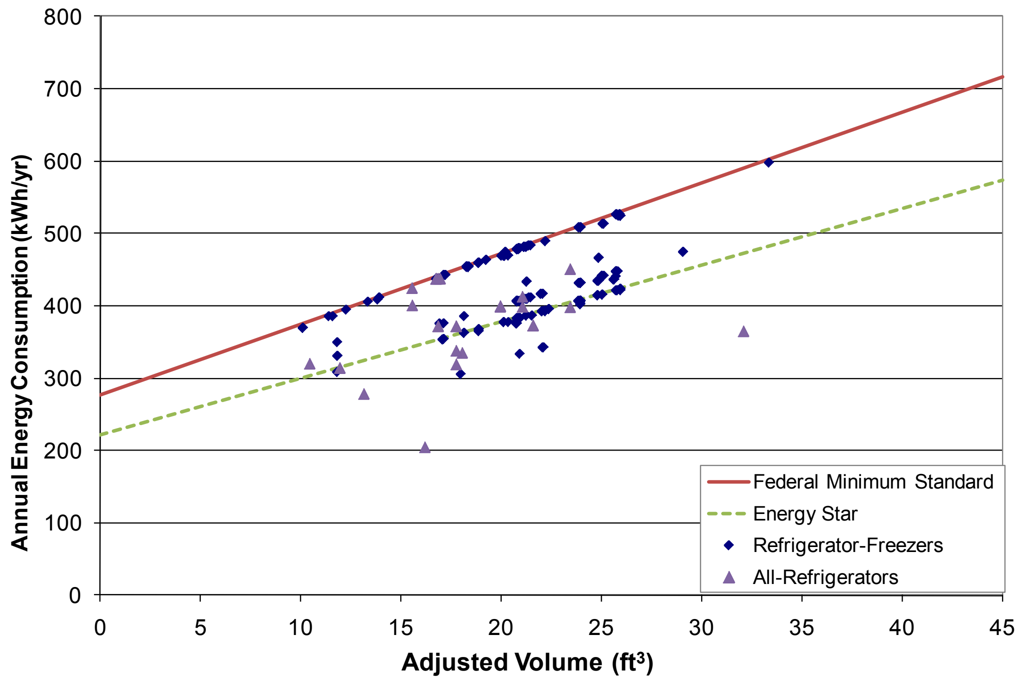

Figure 3.3.5 Annual Energy Consumption for Top-Mount Refrigerator-Freezers with Automatic Defrost without TTD Ice Service and All-Refrigerators with Automatic Defrost (Product Class 3)

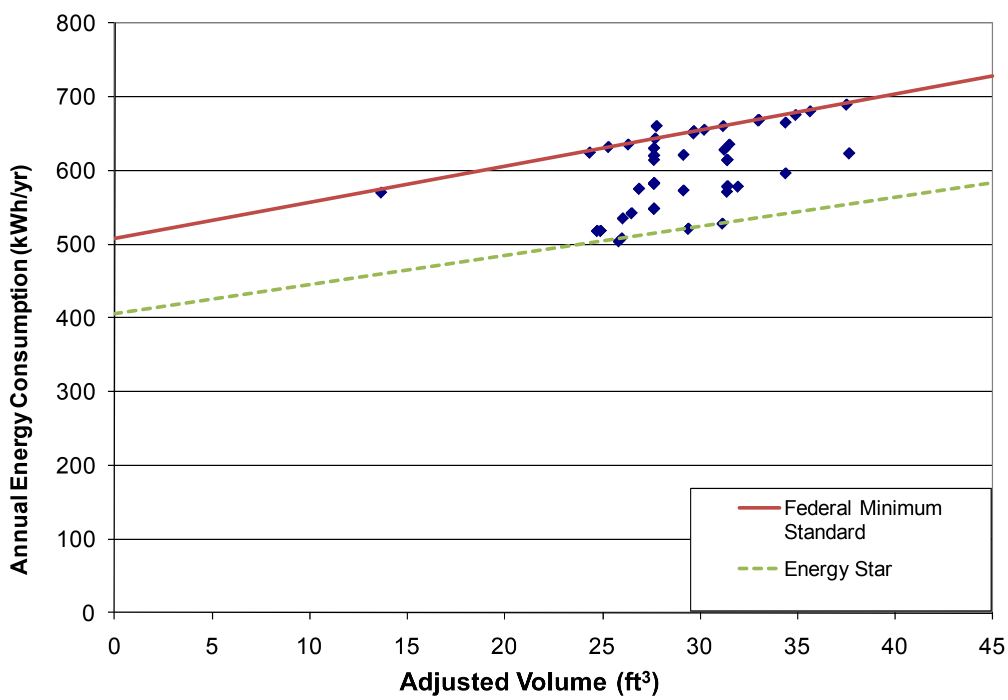

Figure 3.3.6 Annual Energy Consumption for Side-Mount Refrigerator-Freezers with Automatic Defrost without TTD Ice Service (Product Class 4)

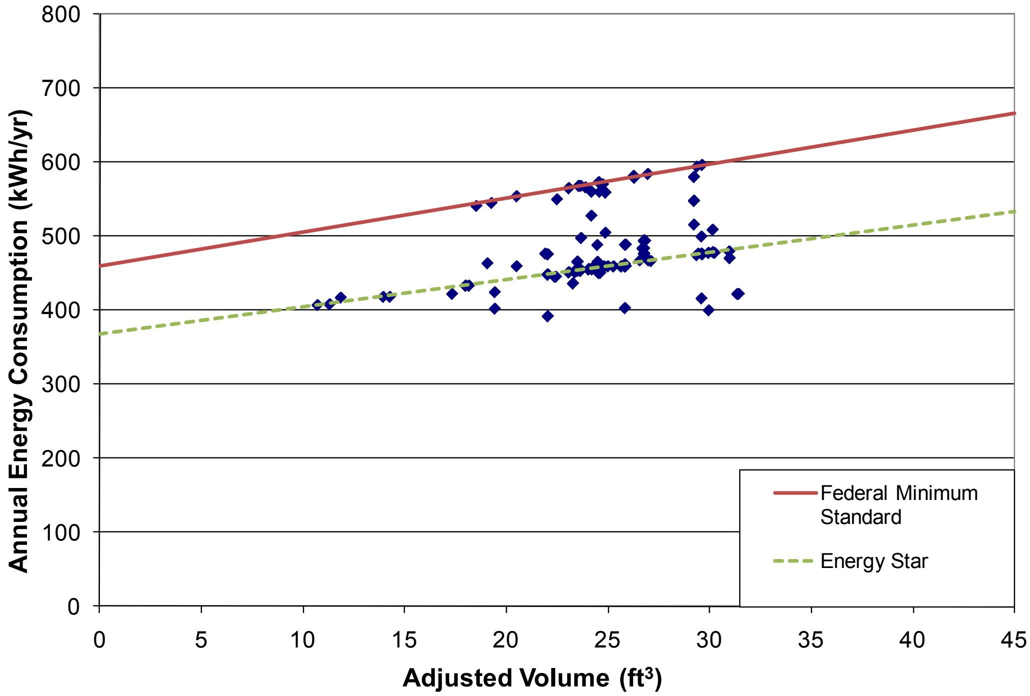

Figure 3.3.7 Annual Energy Consumption for Bottom-Mount Refrigerator-Freezers with Automatic Defrost without TTD Ice Service (Product Class 5)

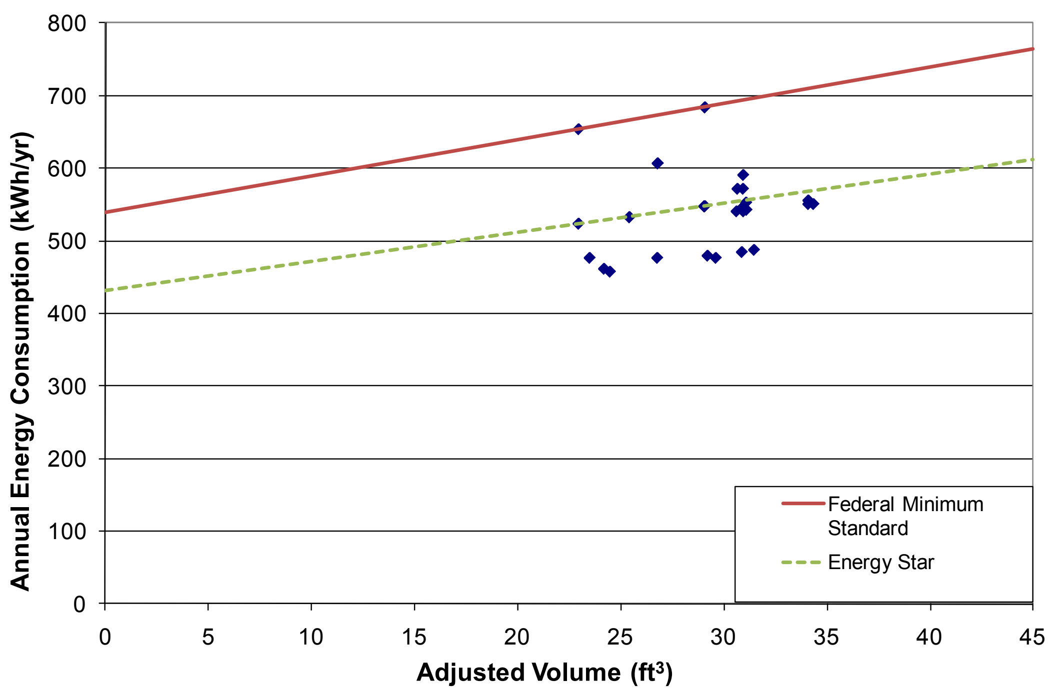

Figure 3.3.8 Annual Energy Consumption for Bottom-Mount Refrigerator-Freezers with Automatic Defrost with TTD Ice Service (Product Class 5A)

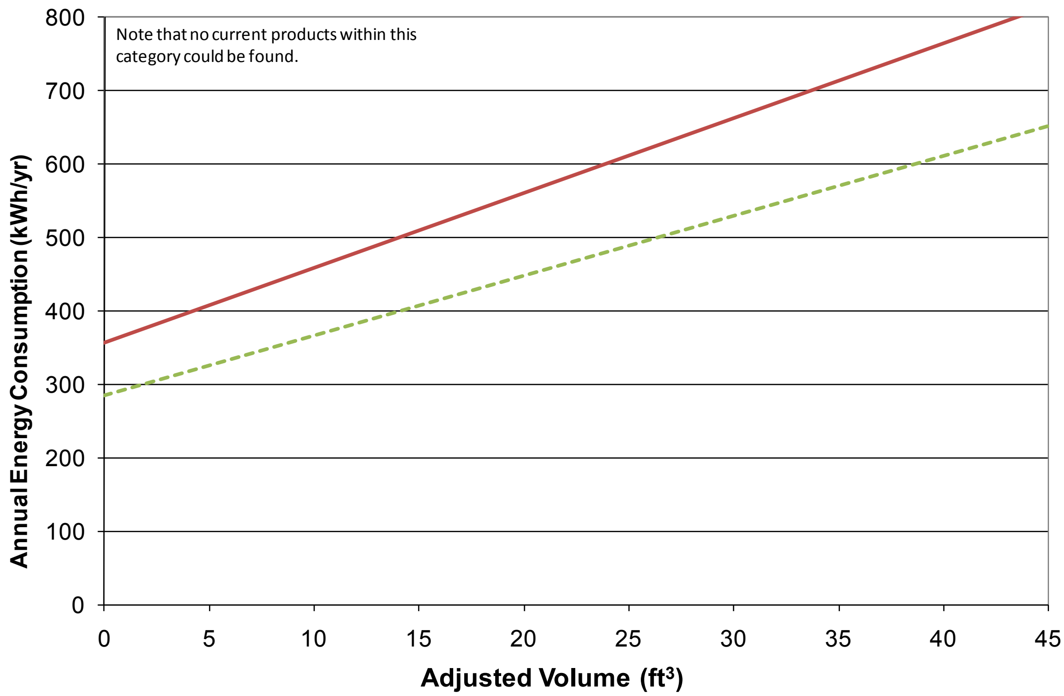

Figure 3.3.9 Annual Energy Consumption for Top-Mount Refrigerator-Freezers with Automatic Defrost with TTD Ice Service (Product Class 6)

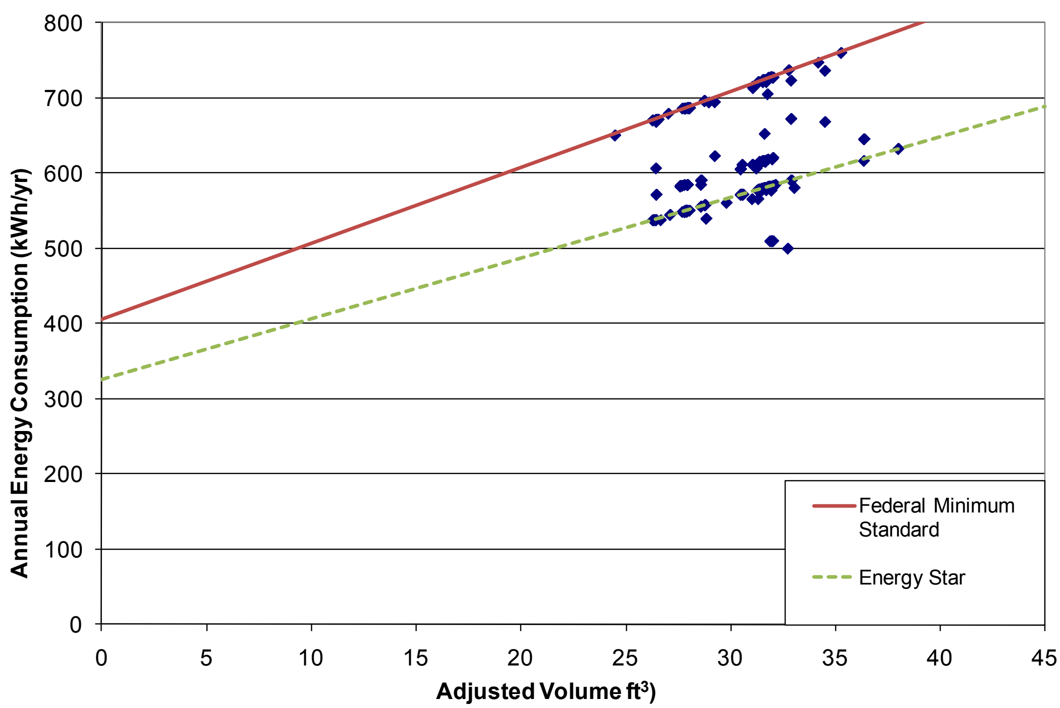

Figure 3.3.10 Annual Energy Consumption for Side-Mount Refrigerator-Freezers with Automatic Defrost with Through-the-Door Ice Service (Product Class 7)

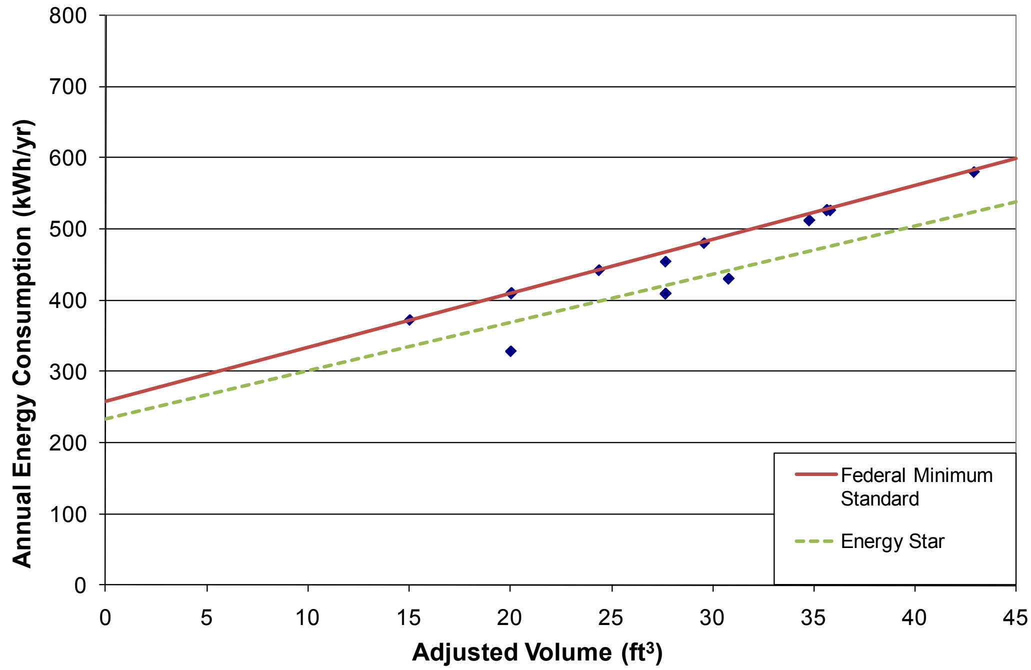

Figure 3.3.11 Annual Energy Consumption for Upright Freezers with Manual Defrost (Product Class 8)

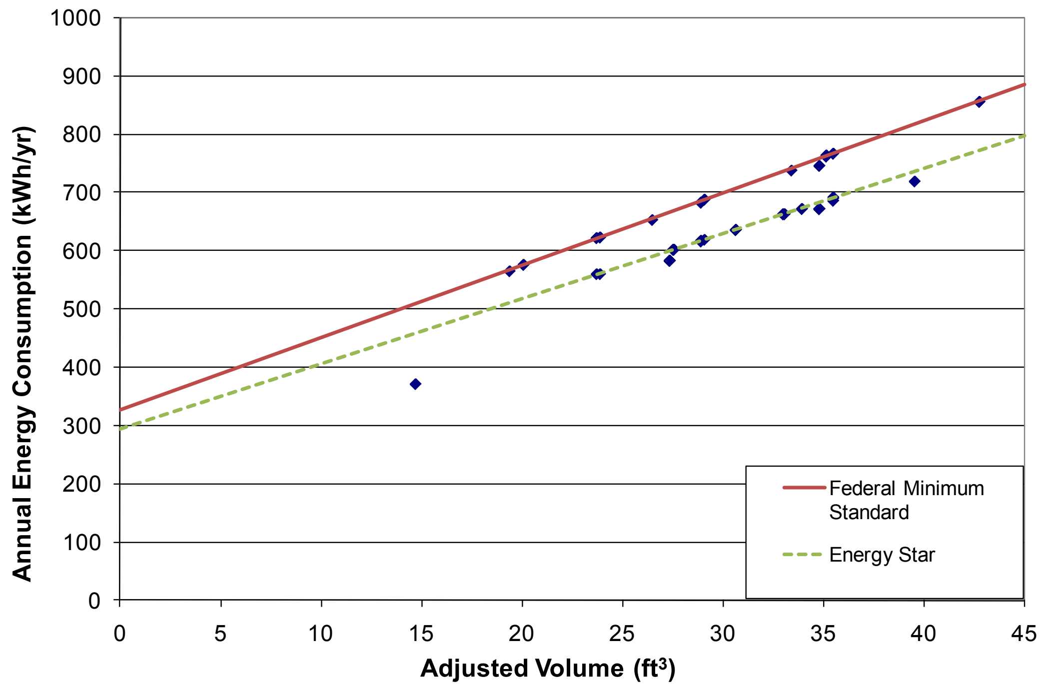

Figure 3.3.12 Annual Energy Consumption for Upright Freezers with Automatic Defrost (Product Class 9)

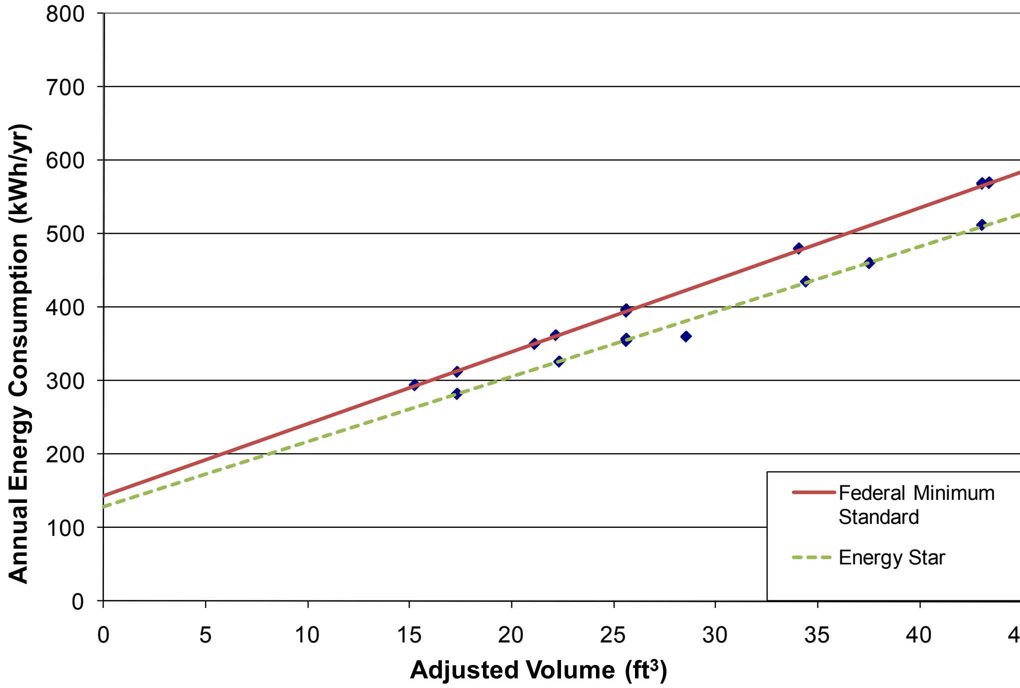

Figure 3.3.13 Annual Energy Consumption for Chest Freezers and all other Freezers except Compact Freezers (Product Class 10)

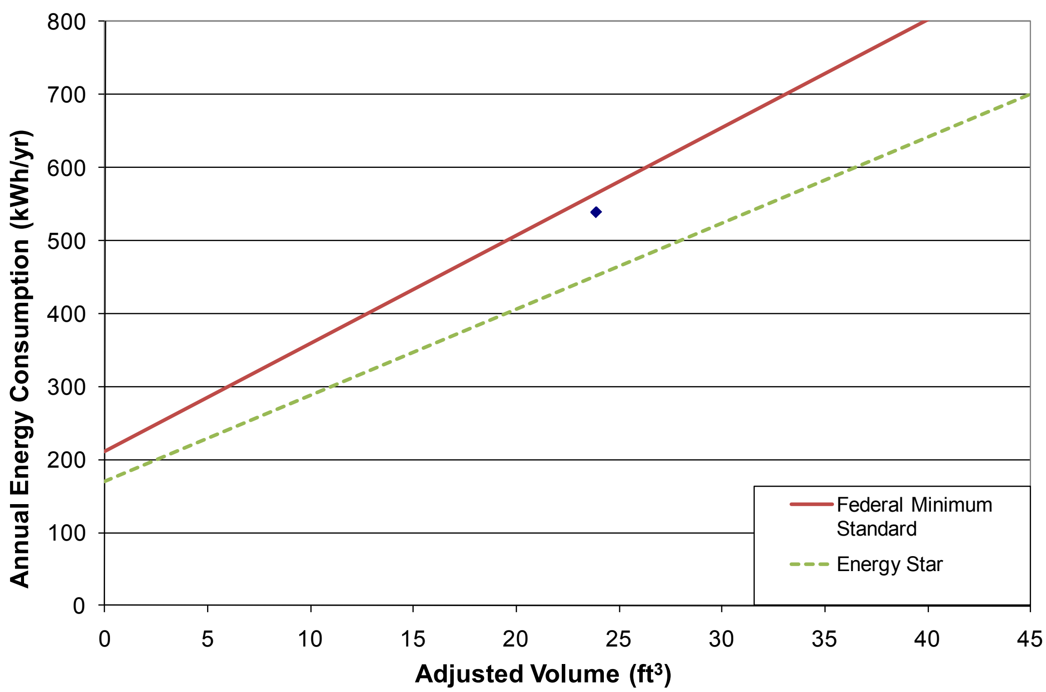

Figure 3.3.14 Annual Energy Consumption for Chest Freezers with Automatic Defrost (Product Class 10A)

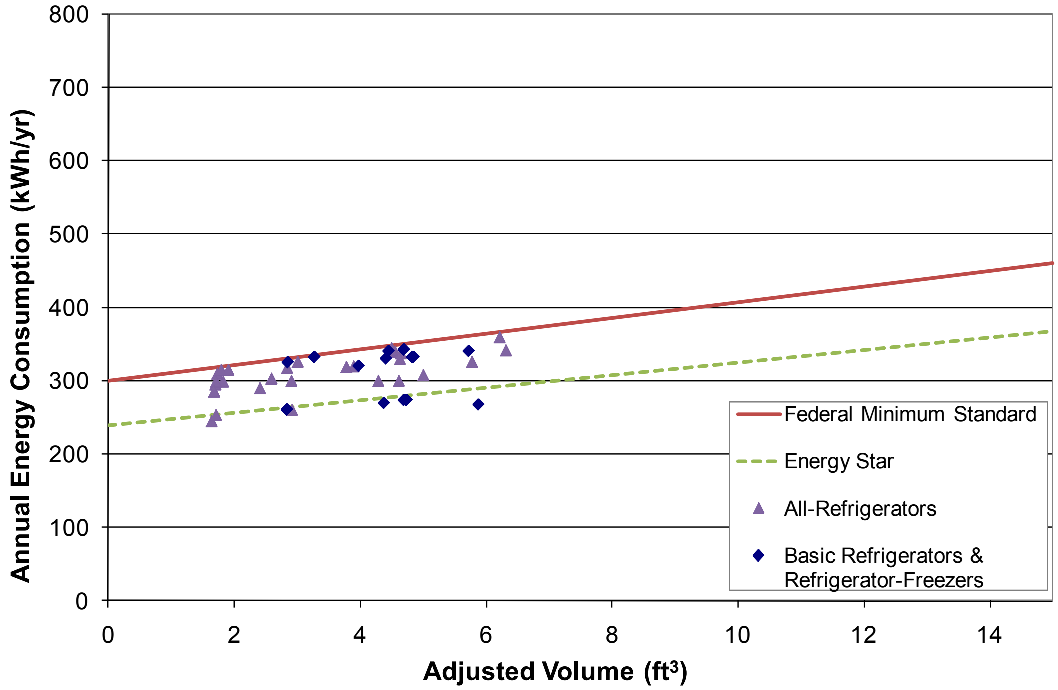

Figure 3.3.15 Annual Energy Consumption for Compact Refrigerators and Refrigerator-Freezers with Manual Defrost (Product Class 11)

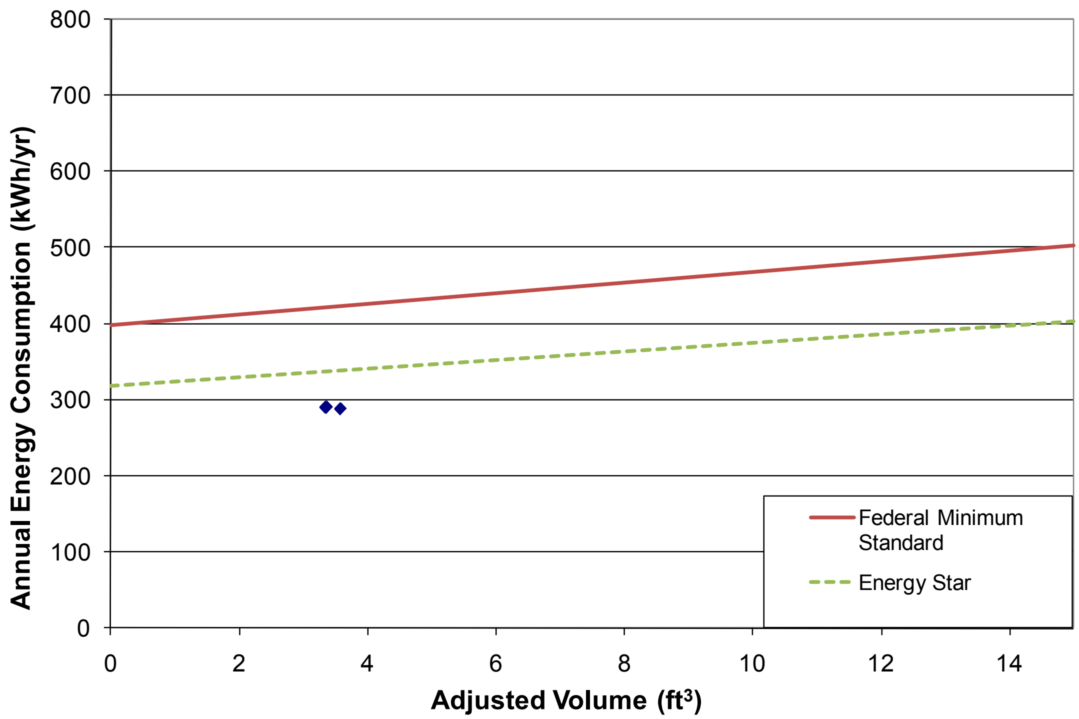

Figure 3.3.16 Annual Energy Consumption for Compact Refrigerator-Freezers with Partial Automatic Defrost (Product Class 12)

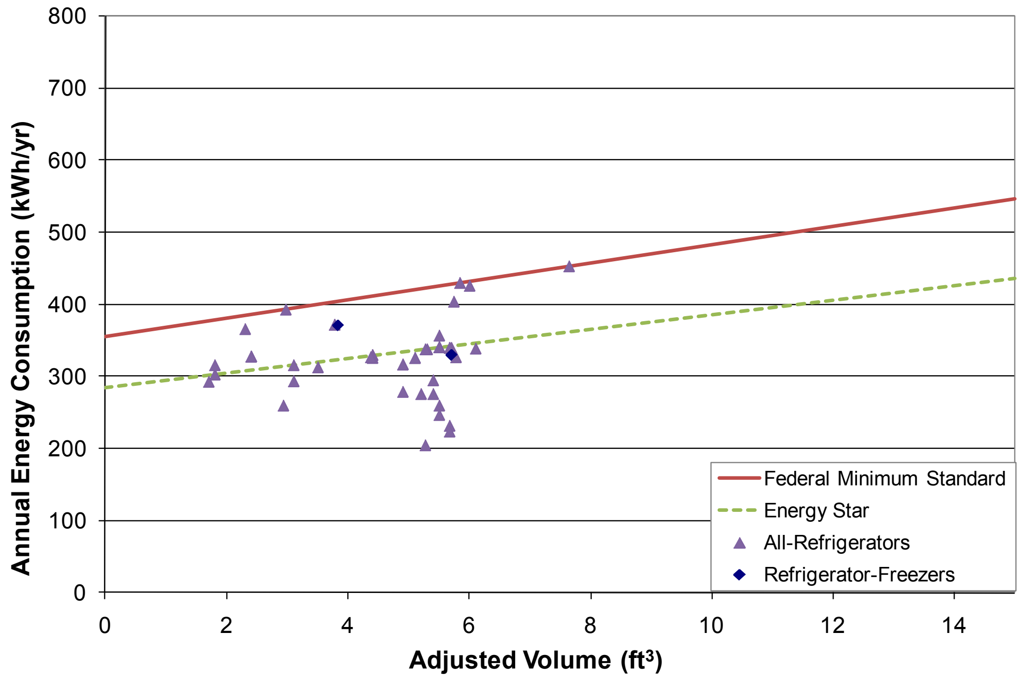

Figure 3.3.17 Annual Energy Consumption for Compact Top-Mount Refrigerator-Freezers with Automatic Defrost and All-Refrigerators with Automatic Defrost (Product Class 13)

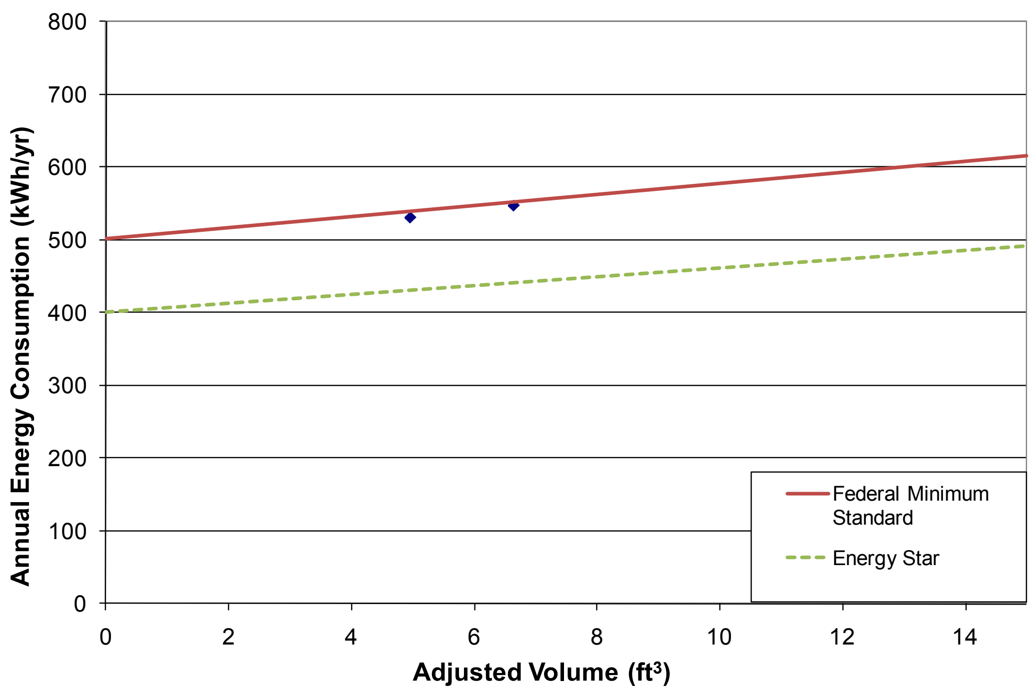

Figure 3.3.18 Annual Energy Consumption for Compact Side-Mount Refrigerator-Freezers with Automatic Defrost (Product Class 14)

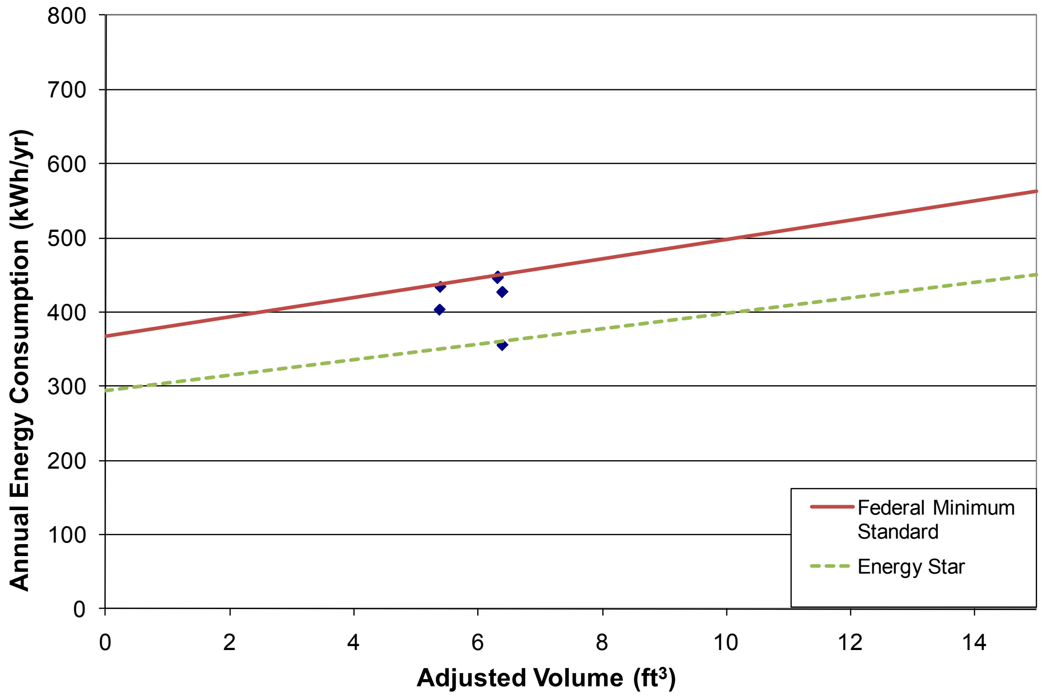

Figure 3.3.19 Annual Energy Consumption for Compact Bottom-Mount Refrigerator-Freezers with Automatic Defrost (Product Class 15)

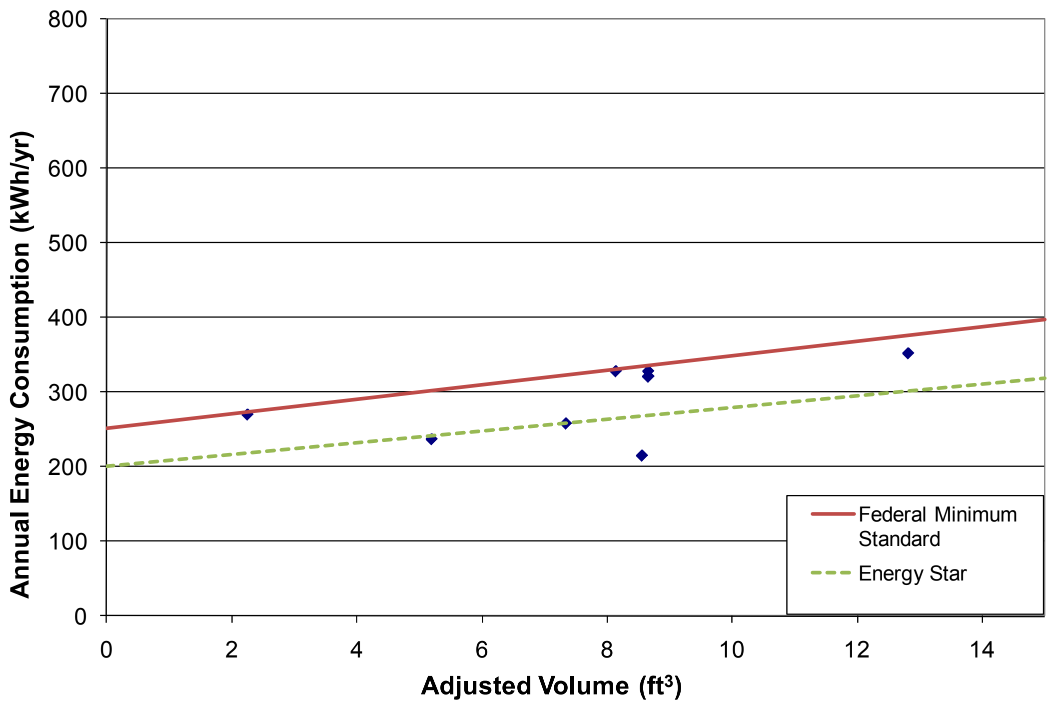

Figure 3.3.20 Annual Energy Consumption for Compact Upright Freezers with Manual Defrost (Product Class 16)

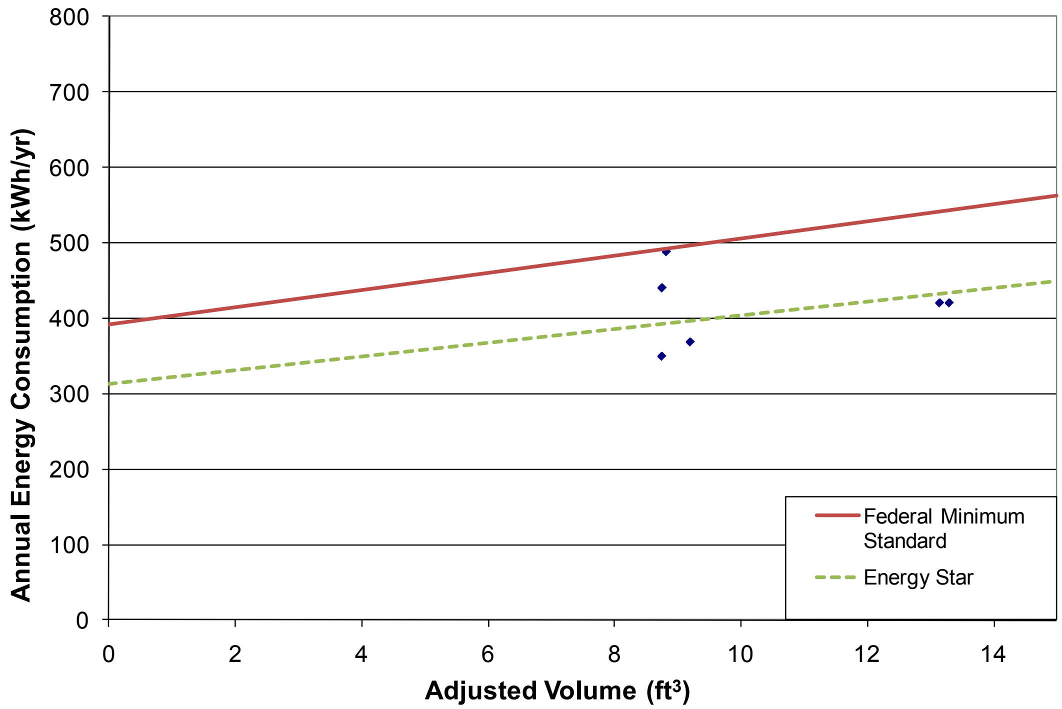

Figure 3.3.21 Annual Energy Consumption for Compact Upright Freezers with Automatic Defrost (Product Class 17)

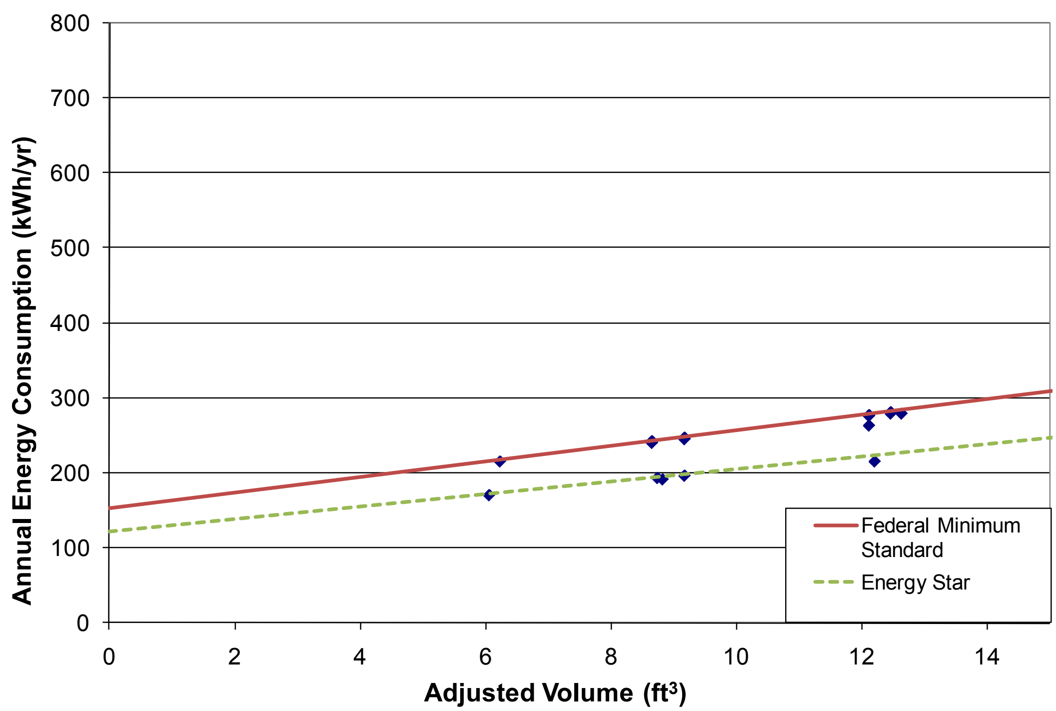

Figure 3.3.22 Annual Energy Consumption for Compact Chest Freezers (Product Class 18)

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CHAPTER 4. SCREENING ANALYSIS

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CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

This chapter details the screening analysis that the U.S. Department of Energy (DOE) conducted in support of the ongoing energy conservation standards rulemakings for refrigerators, refrigerator-freezers, and freezers.

In chapter 3, the market and technology assessment (MTA), DOE presented an initial list of technologies that can improve the energy efficiency of residential refrigeration products. The purpose of the screening analysis is to evaluate the technologies that improve equipment efficiency to determine which technologies to consider further and which to screen out. DOE consulted with a range of parties, including industry, technical experts, and others to develop a list of technologies for consideration. DOE evaluated the technologies pursuant to the criteria set out in the Energy Policy and Conservation Act (EPCA), as amended. (42 U.S.C. 6311-6317)

Section 325(o) EPCA establishes criteria for prescribing new or amended standards designed to achieve the maximum improvement in energy efficiency. Further, EPCA directs the Secretary of Energy to determine whether a standard is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A), as directed by 42 U.S.C. 6316(a)(1)-(3)). EPCA also establishes guidelines for determining whether a standard is economically justified. (42 U.S.C. 6295(o)(2)(B)) Appendix A to subpart C of Title 10, Code of Federal Regulations, Part 430 (10 CFR Part 430), "Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products" (the Process Rule), sets forth procedures to guide DOE in its consideration and promulgation of new or revised equipment energy conservation standards. These procedures elaborate on the statutory criteria provided in 42 U.S.C. 6295(o) and, in part, eliminate problematic technologies early in the process of prescribing or amending an energy efficiency standard. In particular sections 4(b)(4) and 5(b) of the Process Rule guide DOE in determining whether to eliminate from consideration any technology that presents unacceptable problems with respect to the following criteria:

Technological feasibility. Technologies incorporated in commercial equipment or in working prototypes will be considered technologically feasible.

Practicability to manufacture, install, and service. If mass production of a technology in commercial equipment and reliable installation and servicing of the technology could be achieved on the scale necessary to serve the relevant market at the time of the effective date of the standard, then that technology will be considered practicable to manufacture, install, and service.

Impacts on equipment utility or equipment availability. If a technology is determined to have significant adverse impact on the utility of the equipment to significant subgroups of customers, or result in the unavailability of any covered equipment type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as equipment generally available in the United States at the time, it will not be considered further.

Adverse impacts on health or safety. If it is determined that a technology will have significant adverse impacts on health or safety, it will not be considered further.

In sum, if DOE determines that a technology, or a combination of technologies, has unacceptable impacts on the policies stated in section 5(b) of the Process Rule, it will be eliminated from consideration. If a particular technology fails to meet one or more of the four criteria, it will be screened out. Section 4.2 documents the reasons for eliminating any technology.

4.2 SCREENED-OUT TECHNOLGIES

This section describes the technologies that DOE eliminated for failure to meet one of the following four factors: (1) technological feasibility; (2) practicability to manufacture, install, and service; (3) impacts on equipment utility or equipment availability; and (4) adverse impacts on health or safety.

DOE also eliminated some technologies that were determined to provide little or no potential for energy use reduction for one of the following additional reasons: (a) technology already used in baseline products and incapable of generating additional energy efficiency or reducing energy consumption, (b) technology does not reduce energy use, and (c) insufficient data available demonstrating benefit of the technology.

4.2.1 Improved Resistivity of Insulation

Past research has demonstrated that the resistivity of polyurethane (PU) foam insulation can be improved through the use of additives that reduce the thermal conductivity of the foam.

Research conducted in 1996 demonstrated that adding carbon black provides a means of improving the thermal insulation properties of PU foam using both HCFC-141b or cyclopentane blowing agents.[1] However, DOE is not aware that this process has been adopted by any supplier of PU foam insulation or any refrigerator manufacturer. Manufacturers have reported that it darkens the interior of a refrigerator lined with white plastic, and it stains anything it contacts.

Discussion with PU foam insulation vendors indicates that there is work ongoing which may lead to improvement in insulation performance but that any such technology would not likely be ready for introduction to the market by 2014. Discussion with manufacturers has confirmed that there are no available options for improvement in PU foam insulation performance (other than reverting to use of banned blowing agents). Due to the lack of available information and predictions that there is no significant benefit to be expected from PU foam improvements, DOE has eliminated this option from consideration in the engineering analysis.

Stakeholders at the preliminary analysis public meeting indicated that DOE should consider in the analysis a trend away from use of HFC blowing agents, in response to concerns about their global warming potential (GWP), and the possibility that climate change legislation may be enacted that would limit use of HFCs. DOE has put an analytic structure in place to allow for the rapid evaluation of efficiency improvement and trial standard levels for products using alternative foam insulation materials, if legislation banning HFCs should be enacted.

4.2.2 Gas-Filled Panels

Investigation of the status of gas-filled panels suggests that there has been some evaluation of this technology by manufacturers of residential refrigeration equipment, but that no manufacturers are using it in their products. The costs are reported to be as high as for vacuum insulation panels (VIPs), with less reduction in thermal load. DOE has not been able to identify a credible supplier that would provide gas filled panel products to the refrigeration industry. DOE has eliminated this technology from further consideration.

4.2.3 Improved Gaskets, Double Gaskets, Improved Door Face Frame

Past investigation on reduction of heat load in the gasket and door face frame area has focused on (1) limiting the conduction of heat through metal casing material passing underneath the gasket magnet on the cabinet side or in the region of the gasket clip on the door side into the cabinet interior, (2) using a gasket which provides additional cover of frame surfaces towards the interior of the magnet to prevent cold air from reaching the high-conductivity metal casing near the gasket magnet, and (3) providing a long thin "throat" area between the gasket and the interior to limit convection heat transfer. Most current designs are effective in addressing these issues.

Limited information is publicly available which would allow quantification of additional improvement potential for the door frame/gasket area of refrigerators. Some manufacturers use extra-strong gasket magnets to limit infiltration and thermal loss, but it is unclear whether significant thermal improvement is possible with such systems. Manufacturers indicated during technical discussions that properly designed and installed gasket systems provide a tight seal and that there isn't any further reduction in air leakage that could be achieved with improvements in the gasket system such as increasing the magnetic force. In addition, consumer safety laws preclude use of excessive door sealing force.

Based on information drawn from DOE's 1995 TSD, double door gaskets were not adopted by many manufacturers in the mid-1990s because of performance problems and cost. Ice has a tendency to form between the gaskets, greatly reducing their effectiveness. In addition, the gaskets tend to be visually unattractive and they make it more difficult to meet the consumer safety regulations for minimum door-opening force.

It is expected that incremental improvement may be possible for some products, however, the lack of good quantified information on general improvement potential in this area makes this technology option unsuitable for consideration as a design option.

4.2.4 Reduced Heat Load for TTD Feature

During technical discussions, manufacturers indicated that there is little or no reduction in load which can be achieved through redesign of TTD features. DOE inspected the TTD system of a side-by-side refrigerator and concluded that the load impact of this feature is modest. The door insulation thickness is maintained behind the recess except within an inch or two of the chute opening, and low-conductivity plastic is used on all surfaces. The chute door closes reliably. A calculation of the thermal load suggests that it is on the order of 3W (10 Btu/hr). The reverse engineering of this feature shows that a 2W electric anti-sweat heater is used to prevent condensation of the exterior surfaces nearest the ice chute opening. Manufacturers indicated that these load levels are typical for TTD features. Even if the chute door was insulated with ½-inch of insulation (which would likely interfere with chute door operation), the load impact would be minimal, due to the very low surface area of this door. Based on the very low potential for improvement, DOE has eliminated reduced heat load TTD features as an option for further analysis.

4.2.5 Warm Liquid or Hot Gas Refrigerant Anti-Sweat Heating

Although some refrigerators do still use electric anti-sweat heating, the typical anti-sweat heater for baseline units, according to the reverse engineering work and discussion with manufacturers, is warm liquid refrigerant. A possible exception is French door refrigerators. In these products, providing heat to the gasket surfaces which seal between the French doors (or to the flip-mullion used in some designs for sealing in this region) is not possible using warm refrigerant liquid or hot gas. French door refrigerators may use electric anti-sweat heaters in this region, but for these products conversion to refrigerant line anti-sweat is impractical. Due to the current use of refrigerant-line anti-sweat in situations where it can be used, DOE has eliminated this option from further consideration.

4.2.6 Electric Anti-Sweat Heater Sizing

Because the baseline products considered in the engineering analysis predominantly use warm liquid anti-sweat, the consideration of adjustment of the sizing of electric anti-sweat heaters is not relevant.

4.2.7 Linear Compressors

While promising potential has been reported for linear compressors, there is very little information available for commercialized linear compressors that allows confident prediction of performance and cost impacts of this technology. Information for some LG linear compressors has been reported at "LG Reference Conditions," which are significantly different than the standard ASHRAE rating conditions. Under ASHRAE conditions, compressors are rated at -10 ºF (-23.3 ºC) evaporating temperature and 130 ºF (54.4 ºC) condensing temperature. The "LG Reference Conditions" are based on -14.8 ºF (-26 ºC) evaporating and 100.4 ºF (38 ºC) condensing temperatures. It is not clear what the liquid and suction vapor temperatures for the LG conditions are—these temperatures also impact capacity and power input. The performance of some of LG's linear compressors at the LG conditions is presented in Table 4.2.1 below. At the same evaporating and condensing temperatures and with liquid and suction vapor conditions consistent with the ASHRAE test conditions, a high efficiency rotating-shaft reciprocating compressor such as the Embraco EGX70HLC would have an operating EER of about 6.9 Btu/hr-W. Hence, the LG linear compressor may be about 9% more efficient than the best current-technology rotating-shaft reciprocating compressors.

Table 4.2.1 LG Linear Compressor Performance Data

Model	Capacity Range*		Efficiency*	
	W	*Btu/hr*	*COP*	*EER*
DLF81LACT	310	1058	2.14	7.3
FA81LACT	293	1000	2.20	7.5
FA72LACT	276	941	2.20	7.5
FA63LACT	241	823	2.20	7.5
FA54LACT	207	706	2.20	7.5

Source: LG, 2007.
* Performance based on 'LG Reference' rating conditions. Models utilize refrigerant R-134a.

In the trade press, LG has expressed willingness to license the linear compressor technology to competitors.[2] However, because the LG design is proprietary, the widespread use of linear compressors is highly uncertain. Use of linear compressors in LG refrigerators is less explicit in LG product data than it was a few years ago, so it is unclear how many products are actually using these compressors. Other compressor manufacturers who have indicated that they have investigated linear technology have stated that linear compressor technology does not provide a clear path to improved efficiency, and some have indicated that they are no longer actively pursuing this technology. Hence, availability of linear compressor technology as an option for improved efficiency is uncertain. Further, DOE was not able to obtain cost estimates for linear compressors. Recently, Embraco announced the development of an oil-free linear compressor technology that was developed with Fisher & Paykel.[3] However, it is not clear when this compressor will be released for use in commercialized products, and DOE was not able to obtain any technical information regarding performance, cost, size, etc. for this technology. Furthermore, all indications are that the technology is proprietary and will not be generally available for use by all refrigeration product manufacturers. For these reasons, DOE has eliminated linear compressors from further consideration in the analyses.

4.2.8 Improved Evaporator Heat Exchange

Improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes. These types of fin and tube enhancements are common in air-conditioning applications where slit and louvered designs are used to enhance the fin surface and different types of internally-grooved surfaces are used to enhance the tubing. Application of similar enhancements in refrigerator evaporators is complicated by frost accumulation on the evaporators. Effectiveness of the fine slit and louver features for refrigerator evaporators is dubious because they would be blocked quickly with frost. In order to avoid the energy use associated with frequent defrost, fin spacing in refrigerator evaporators is comparatively sparse. This allows the evaporator to work effectively without blocking airflow with a considerable accumulation of frost. During defrost, the typical flat fin design of these evaporators assures that the frost slides rapidly off the fins and doesn't get stuck on fin enhancement features. During discussions with manufacturers, little indication was provided that efficiency could significantly be enhanced through the use of fin or tube enhancements. DOE has eliminated this option from consideration in subsequent analysis.

4.2.9 Improved Condenser Heat Exchange

Use of heat exchanger enhancements for the condenser is complicated by the need for adequate performance when the heat exchanger has not been cleaned. Most refrigerator condensers (other than hot wall condensers integrated into the outer shells of the products) are made of steel tubes and steel wire fins. These condensers have a very open construction which allows dust to flow through easily and which reduces blockage of air flow if dust does collect on the condenser surfaces. Flat fin condensers used in refrigerators are known to require more careful attention to cleaning. Use of high fin densities is more accepted in air-conditioning applications because periodic maintenance is expected and because size would get enormous if aggressive fin spacing wasn't employed, whereas cleaning of refrigerator condensers occurs infrequently or never, and the loads are small enough so that maximizing use of space is not critical. DOE has eliminated this option from consideration in subsequent analysis.

4.2.10 Fan Blade Improvements

Refrigerator fan blades use an axial design. They are typically injection molded plastic with a three-dimensional shape for improved performance as compared with older stamped sheet metal designs. One source of inefficiency for axial fans lies in their tendency to throw air outward, necessitating a shroud to collect and redirect airflow along the axis as intended. The Pax Group™ has developed a fan (PAX fan) that employs streamlined blades with patented geometrical shapes derived from a naturalistic design approach, providing better airflow direction and improved efficiency. Tests performed when replacing existing motor combinations with A.O.Smith motors and PAX fan blades show power input reductions in the range of roughly 10% to 35%.[4] It is impossible to tell how much of this benefit is associated with the fan blade and how much with the motor. Also, because the PAX fan is proprietary, the widespread use of the design is highly uncertain. There is in general little data available to quantify the energy benefit possible with improvement in fan blade design in today's refrigeration products. Fan performance is highly dependent on details of integration with the system: orifice geometry, tolerance of blade/orifice gap, match of system flow impedance to fan performance, etc. Hence, making credible estimates of energy savings potential through fan blade replacement requires testing fan blade swaps in baseline products. The cost of fabrication of improved fan blade geometries should be low, so most of the cost increase associated with this technology option would be associated with paying for the blade development and/or licensing fees. It is very difficult to predict what these costs would be unless specific vendors of high efficiency fan blades can be identified who provide complete information. During discussions with manufacturers, no information was provided which would allow credible calculation of savings and costs associated with improved fan blades. Hence, DOE has eliminated this option from further consideration.

4.2.11 Improved Expansion Valve

Residential refrigeration products exclusively use capillary tubes for refrigerant flow metering. These tubes are inexpensive and they lend themselves easily to low-cost fabrication of suction line heat exchangers by brazing the capillary to the suction line. Automatic, adjustable thermostatic or electronic expansion valves are available, but they generally are oversized for residential refrigeration. Furthermore, it is unclear whether there is any potential for energy savings using alternative expansion devices. The DOE Energy test is conducted with a single set of standardized temperatures for the ambient air (90 °F) and for the compartments. A capillary tube can be designed to provide optimized performance for this set of temperatures. Systems are generally designed to operate with evaporator exit conditions having little or no superheat during energy testing, thus maximizing use of the evaporator. In the lower ambient temperature typical in homes, the pressure available to move refrigerant through the capillary tube is lower, thus possibly leading to increased superheat and less than optimum performance. An automatic valve could provide optimum performance for a wider range of operating conditions, but such improvement is not reflected in current energy testing. DOE has eliminated this option from further consideration.

4.2.12 Off-Cycle Valve

Off-cycle refrigerant migration reduces a refrigeration product's efficiency by allowing warm and/or vapor-phase refrigerant to pass into the cabinet. A fluid control or solenoid valve installed after the condenser to effectively isolate the evaporator from the condenser during the off-cycle can be used to prevent refrigerant migration. Research has demonstrated that solenoid valves can yield substantial energy savings.[5] Such a solenoid valve represents a possible reliability issue, although many wine storage products use similar solenoid valves to allow control of multiple compartments with a single compressor. Also, operation with an off-cycle valve requires that the compressor motor can start up against a substantial pressure difference. The starting windings of compressors that can do this reliably over the life of a refrigerator draw more power and hence reduce the compressor's steady-state efficiency. The different efficiency levels of commercial refrigeration compressors designed for instant restart versus restart after pressure equalization have EER ratings which differ by 10% or more. Such a difference would be expected for residential compressors operating with an off cycle valve, and this difference would more than neutralize any benefit accrued from using the off-cycle valve. Hence, DOE has eliminated this option from further consideration.

4.2.13 Reduced Energy for Automatic Defrost

In some cases, the defrost heat supplied is more than required. Thus, energy savings can be achieved by reducing the defrost heat by either using smaller heaters, reducing the heater on-time, reducing the frequency of defrost, or a combination of these. In its 1995 TSD, DOE found that most manufacturers had already significantly reduced the electric heat for auto defrost in order to comply with the energy efficiency standards that became effective in 1993.[6] The percent of energy represented by defrost for the refrigerator-freezers tested as part of this rulemaking ranged from 4% to 5% for products without adaptive defrost and from 1% to 5% for products with adaptive defrost. It is unlikely that significant energy savings are achievable by further reducing the energy for automatic defrost without compromising defrost performance, except through use of adaptive defrost.

4.2.14 Condenser Hot Gas Defrost

Another method of reducing the energy required for defrost is to eliminate the need for electric heaters by substituting condenser hot gas in their place. In a condenser hot gas defrost system, the compressor continues to run and a valve opens allowing hot compressed refrigerant to flow to the evaporator. Many frost-free refrigerator-freezers in the 1960s and 1970s used a condenser hot gas defrost system. In its 1995 TSD, DOE was not able to identify data that demonstrated that the condenser hot gas method was more cost-effective than adaptive defrost. Therefore, DOE dropped the condenser gas defrost as a technology option in favor of adaptive defrost. [7] Hot gas defrost would potentially save energy because a large portion of the heat for defrost could be provided by heat generated by the compressor motor during the on-cycle rather than from new electricity use. The compressor is at an elevated temperature with respect to ambient during the on-cycle and is certainly much warmer than freezing temperature. The heat would be transported to the evaporator with circulating refrigerant during the defrost cycle. However, in spite of this potential reduction in use of electricity to provide defrost heat, the energy savings potential is not well documented. Also, there are concerns regarding reliability of the required valve.

4.2.15 Electronic Temperature Control

DOE has not identified any relevant information showing the energy benefit of electronic temperature control. Potential benefits of electronic control when operating with single-speed compressors are fine-tuning of the run times and fine-tuning of the cut-in and cut-out temperatures. While there may be potential for incremental improvement associated with such fine-tuning, the lack of data supporting claims for energy savings make it difficult to properly analyze this option.

4.2.16 Air-Distribution Control

Air temperature distribution in refrigeration products with fan-forced evaporator air flow is generally good, in contrast with some products with cold wall or roll bond evaporators. Hence, it is not clear that improvements in air distribution will provide significant reduction in energy use. Redirection of air flows in a cabinet could potentially provide a false indication of efficient operation, for instance if the coldest air from the evaporator discharge is directed at the locations used for the energy test thermocouples. It is conceivable that valid reduction in energy use could occur if the air flow distribution keeps cold air away from the walls of the cabinet. However, there is insufficient information regarding the designs of air flow distribution systems to quantify potential energy savings.

4.2.17 Alternative Refrigerants

DOE eliminated alternative refrigerants as a design option for most product classes because the available alternatives are either banned, have lower thermodynamic efficiencies, or, as in the case of hydrocarbons, are only allowed in limited quantities due to safety regulations. Isobutane is the most logical alternative to HFC-134a, the refrigerant currently used in U.S. residential refrigeration products. Isobutane is a hydrocarbon refrigerant with a higher theoretical efficiency than that of HFC-134a. It has been used for many years in refrigeration products in Europe and other foreign countries. The U.S. refrigeration industry has not adopted hydrocarbon refrigerants (likewise for the U.S. air conditioning industry) due to concerns regarding flammability.

UL Standard 250, "Household Refrigerators and Freezers", includes requirements for use of hydrocarbon refrigerants in residential refrigeration products, including a limit of 50 g that can be released in case of a breach of the sealed refrigeration system.[8] Isobutane has not yet been placed on EPA's Significant New Alternatives Program (SNAP) list of allowed alternative refrigerants. However, EPA recently published a notice proposing inclusion of isobutane on this list. 75 FR 25799 (May 10, 2010) The proposal limits the total charge of isobutane to 57 g. This quantity is nearly equivalent to the current UL 250 requirement, which specifies maximum leaked charge—some of the refrigerant remains in the system, thus accounting for the higher total charge specified in the EPA proposal. DOE estimated that the 57 g limit is sufficient to allow use in compact refrigerators, but use of heat exchangers with reduced internal volume would be required for this limit to be sufficient for the other product classes analyzed. Hence, DOE considered conversion to isobutane as a design option, but only for compact refrigerators.

4.2.18 Component Location

Locating the compressor at the top of the refrigerator was noted as a potential technology option. However, this change would increase structural requirement for the refrigerator cabinet, increase risk of product tip-over, and provide much less practical use of space from the consumer perspective. It also makes design for re-evaporation of defrost water more challenging. It is unlikely that the savings would justify all of these drawbacks.

Another option is to locate the evaporator fan motor outside the cabinet to reduce internal loads from the heat loss of the motor. Evaporator fan motor input wattages are now in the range 3W to 7W, with fan blade efficiency in the range 20% to 30% and motor efficiency in the range 20% to 50%. Hence, load reduction, associated with moving the motor loss outside the cabinet, is only in the range 1W to 5W for the typically less than 50% of the time that the evaporator fan is in operation. The loss associated with the added infiltration and conduction is likely to be comparable to this level. Additional issues with this approach include reliability, reduced design flexibility, and the fact that reduction of motor losses (by using more efficient fan motors) may be a more effective approach to reducing the impact of the fan motor power input.

No options for relocation of components have been identified which merit further consideration in the engineering analysis.

4.2.19 Lorenz-Meutzner Cycle

Research on Lorenz-Meutzner cycles reported in the literature involve binary mixtures HCFC-22/CFC-11, HCFC-22/HCFC-123, propane/n-pentane, and propane/n-butane. These systems achieved efficiency levels from 15 to 20 percent better than the baseline systems with which they were compared.[9,10] Because the industry settled on the use of HFC-134a to replace CFC-12, interest in the Lorenz-Meutzner cycle as an alternative to conventional refrigeration cycles declined. All of the refrigerant combinations discussed above have specific problems, the first two with phaseout of constituent refrigerants CFC-11 and HCFC-22, and the last two with flammability of the hydrocarbon blends involved. While it is possible that HFC mixtures could be developed to create a viable Lorenz-Meutzner cycle refrigerator, DOE is not aware that such a prototype has been built and tested successfully. Hence, DOE has not considered this technology in the engineering analysis.

4.2.20 Dual-Loop System

Dual-loop systems have difficulty achieving their theoretical improvement potential due to the significantly reduced efficiency for smaller-capacity compressors. If the two compressors of a dual-loop system serving a refrigerator-freezer were sized appropriately for their respective loads, the freezer compressor capacity would nominally be roughly half that of a single-system compressor. A fresh food compressor typically operates at a capacity significantly higher than its nominal capacity because of the higher evaporating temperature when cooling just the fresh food compartment. Hence, the nominal capacity of a fresh food compartment compressor serving a dual-loop system is generally 30 to 40 percent that of the single-system compressor. Even with the efficiency improvement associated with higher evaporating temperature operation of the fresh food compartment compressor, this compressor still would not operate at an efficiency level better than that of the single-system compressor for freezer conditions. Hence, with the efficiency characteristics of available compressors, it is not clear that the dual-loop architecture will provide any energy savings. Hence, DOE has not considered this technology in the engineering analysis.

4.2.21 Two-Stage System

In practice, a two-stage system would suffer the same disadvantages associated with a dual-loop system. Furthermore, it is not clear that a suitable compressor is available for the lower stage of such a system. DOE is not aware of any prototypes of such a system using compressors which their manufacturers would warrantee for such a product. Hence, DOE has not considered this technology in the engineering analysis.

4.2.22 Control Valve System and Tandem System

There are many patents covering dual-evaporator refrigerator designs. It is not clear how many of these were developed to improve system efficiency, since one of the benefits of using dual evaporators is avoiding excessively low humidity levels in the fresh food compartment. While there is research involving laboratory testing which shows that these technology options can save energy, DOE is not aware of any commercialized refrigerators using either of these approaches. In discussions with manufacturers none identified these options as being interesting approaches for energy use reduction. Further, due to the extensive patent literature discussing dual-evaporator systems, it is likely that products requiring dual evaporator designs would be restricted to the patentholders. Hence, DOE has not considered this technology in the engineering analysis.

4.2.23 Ejector Refrigerator

Energy savings have been reported for use of an ejector system in laboratory testing. In discussions with manufacturers there was limited familiarity with this concept and no acknowledgement that it has been proven through prototype testing and/or that it is an interesting concept for improving efficiency. Hence, DOE has not considered this technology in the engineering analysis.

4.2.24 Stirling Cycle

In principle, the efficiency of Stirling cycles could be higher than for vapor compression systems, but there are various technical difficulties that have so far limited the use of Stirling-cycle cooling to small prototype domestic refrigerators. There is no circulating refrigerant fluid and the hot and cold end areas are very small, which creates heat exchange difficulties. Heat pipes may be required to transfer heat to and from the system. A comparison of the performance of Stirling cycle with vapor compression compressors is shown in Figure 4.2.1 below. The Stirling cycle data was obtained from the Global Cooling website[11] and from data presented at the Purdue Refrigeration Conference in 2002.[12] The figure shows that Stirling technology is not currently ready to improve upon the efficiency of conventional technology. Hence, DOE has not considered this technology in the engineering analysis.

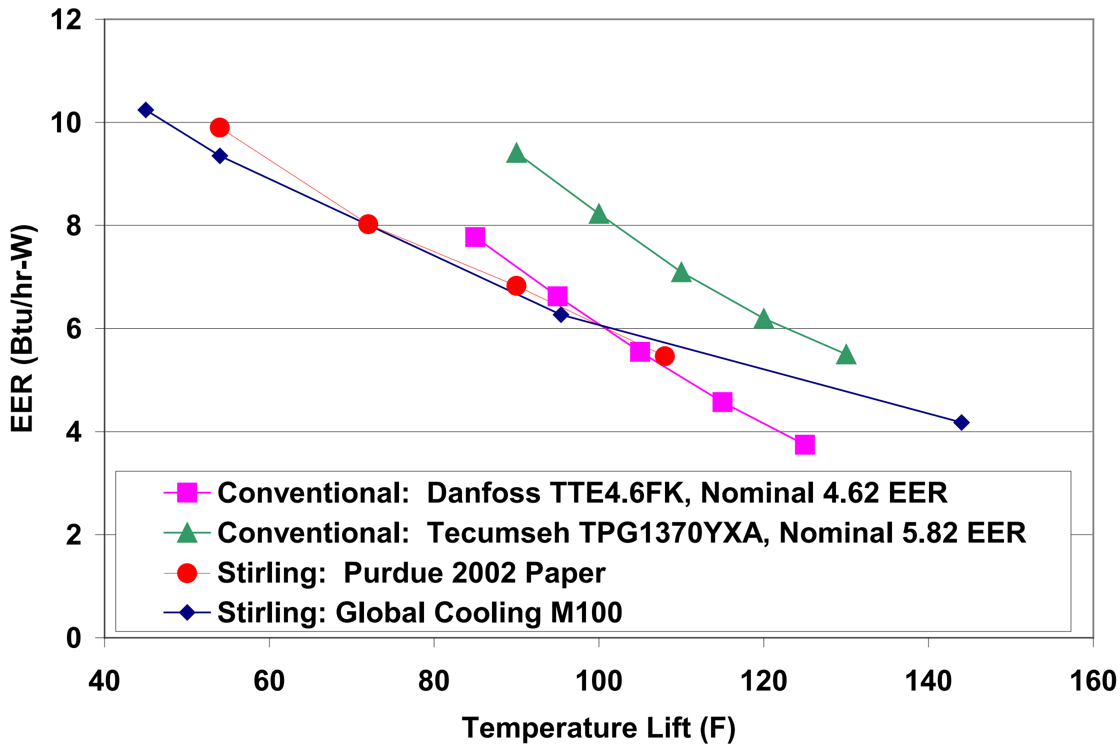

Figure 4.2.1 Comparison of Stirling and Vapor Compression Technologies

4.2.25 Thermoelectric

Thermoelectric cooling technologies currently do not achieve efficiency levels which make them attractive as a design option for improving residential refrigeration energy efficiency. As an example, DOE tested a thermoelectric refrigerator as part of the reverse engineering effort of this rulemaking. This refrigerator was a Haier model HRT02WNC, a 1.7 cubic foot all-refrigerator. In an 80 °F ambient with the system operating at full power, this unit was able to cool the interior to 47 °F while drawing 50W total. The fans serving the inside and outside heat sinks of the thermoelectric unit are rated at a voltage of 12 Volts and currents of 0.13 Amps and 0.16 Amps respectively, and a control board power input of 1W is assumed. The thermal load for the cabinet was estimated as 12 W. Hence the thermoelectric module EER was 0.9 at a temperature lift of at most 33 °F, an order of magnitude less than is achieved by conventional technology. Hence, DOE has not considered this technology in the engineering analysis.

4.2.26 Thermoacoustic

While research suggests that thermoacoustic cooling systems could achieve respectable efficiencies, the technology has not reached a level of maturity sufficient for serious consideration as the basis for efficiency improvement in residential refrigeration products. Hence, DOE has not considered this technology in the engineering analysis.

4.3 REMAINING TECHNOLOGIES

After eliminating those technologies that have no effect or do not increase EER and screening out those technologies that that do not meet the requirements of sections 4(a)(4) and 5(b) of the Process Rule, DOE is considering the technologies in the following list.

- Increased Insulation Thickness
- Vacuum Insulation Panels (VIPs)
- Variable Anti-sweat Heating
- Improved Compressor Efficiency
- Variable Speed Compressors
- Increased heat exchanger area (extension of surface area or addition of coil rows).
- Use of forced convection condenser (for upright freezers)
- Improved efficiency fan motors (brushless DC)
- Adaptive Defrost

During the preliminary analysis public meeting, stakeholders commented on several aspects of VIP technology, suggesting that this technology should be screened out. DOE's investigation of one of these issues, uncertainty of VIP supply, is presented in appendix 4-A.

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CHAPTER 5: ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The engineering analysis establishes the relationship between manufacturer production cost and energy consumption for the refrigerators, refrigerator-freezers, and freezers covered in this rulemaking. The "cost-efficiency" relationship serves as the basis for cost-benefit calculations in terms of individual customers, manufacturers, and the Nation, from which the most economically-justified, technically feasible standard level is ultimately determined.

The inputs into the engineering analysis include baseline characteristics for each product class addressed in the market and technology assessment (chapter 3), the design options from the screening analysis (chapter 4), as well as cost and energy use data collected from manufacturers, component vendors, reverse-engineering, and energy testing. The output of the engineering analysis is the cost-efficiency relationship for each product class independent of cabinet volume, which will be used in the life-cycle and payback period analyses (chapter 8).

This chapter covers the product classes DOE analyzed, and the methodology used by DOE to develop manufacturing costs, energy consumption, and extend the analysis to low-volume product classes, as well as the results of these analyses.

5.2 PRODUCT CLASSES ANALYZED

In the preliminary engineering analysis, DOE directly analyzed the first seven product classes listed in Table 5.2.1. DOE considers these classes to be representative of products currently shipped by the residential refrigerator, freezer, and refrigerator-freezer industry based on total shipments. These product classes represent close to 90% of the shipments of refrigerators, refrigerator-freezers, and freezers. DOE did not directly analyze all covered product classes in order to carry out the analysis as efficiently as possible. The analysis of the directly analyzed classes are intended to be representative of similar product classes. For instance, the analysis for product class 7 (refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service) represents the cost-efficiency characteristics of product class 4 (refrigerator-freezers—automatic defrost with side-mounted freezer without through-the-door ice service). DOE extrapolated energy standards to the remaining product classes as described in section 2.15 of chapter 2 of the preliminary TSD.

DOE also added four product classes of built-in products to the analysis. DOE selected one representative built-in product for direct analysis for each of these product classes. DOE judged the representativeness of these product selections based on discussions with manufacturers regarding design option groupings required to meet key efficiency levels with built-in products.

Table 5.2.1 Product Classes Directly Analyzed in Engineering Analysis

Product Class	Equipment Description
3	Refrigerator-freezers—automatic defrost with top-mounted freezer without through-the-door ice service
5	Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service
7	Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service
9	Upright freezers with automatic defrost
10	Chest freezers and all other freezers except compact freezers
11	Compact refrigerators and refrigerator-freezers with manual defrost
18	Compact chest freezers
3A-BI	Built-in all-refrigerators—automatic defrost
5-BI	Built-in refrigerator-freezers—automatic defrost with bottom-mounted freezer without an automatic icemaker
7-BI	Built-in refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service
9-BI	Built-in upright freezers with automatic defrost without an automatic icemaker

Note: Product class structure, including identification numbers and descriptions, have been changed during this rulemaking. The new structure takes effect in 2014 with the new energy conservation standards. The TSD may refer to product classes using their current numbers and descriptors, or the new numbers and descriptors, which take effect in 2014, depending on the context. In this table, product classes are primarily identified according to their pre-2014 status, except for the built-in status of the built-in product classes identified.

5.3 METHODOLOGY OVERVIEW

This section describes the analytical methodology DOE used in the engineering analysis. In this rulemaking, DOE has adopted a combined efficiency level/design option/reverse engineering approach to developing cost-efficiency curves. DOE established efficiency levels defined as percent energy use lower than that of baseline efficiency products, considering just the energy use that is not associated with production of ice. DOE took this approach in order to allow comparison of information developed from different sources. However, DOE's analysis is based on the efficiency improvements associated with groups of design options. Also, DOE developed manufacturing cost models based heavily on reverse engineering of products to calculate some of the incremental costs associated with improvement of efficiency.

Figure 5.3.1 presents the steps in the analysis and illustrates how they contributed to developing the cost-efficiency curves. The process began with data collection and ended with the incremental cost curve results.

As input to the analysis, DOE requested incremental cost-efficiency data from the industry. The Association of Home Appliance Manufacturers (AHAM) provided aggregated incremental cost data for a number of the product classes under analysis. Questions about the collection and aggregation process for this data arose during the preliminary analysis public meeting and comment period, thus increasing the emphasis for use of the DOE analysis results for the downstream rulemaking analyses. The DOE engineering analysis consisted of analytically-derived cost-efficiency curves for the product classes listed in Table 5.2.1.

To develop the analytically-derived cost-efficiency curves, DOE collected information from various sources on the manufacturing cost and energy use reduction characteristics of each of the design options. DOE reviewed product literature, conducted reverse-engineering of current products, and interviewed component vendors of compressors, fan motors, insulation, and heat exchangers. For the built-in product classes analyzed, DOE obtained detailed design data and specifications for the products analyzed from their manufacturer rather than conducting reverse engineering on purchased products. DOE also conducted interviews with manufacturers, the first during the preliminary analysis and the second in conjunction with the manufacturer impact analysis interviews. The engineering questionnaires associated with both of these sets of discussions are reproduced in the appendices (the preliminary analysis questionnaire in appendix 5-A and the NOPR phase questionnaire in appendix 12-A).

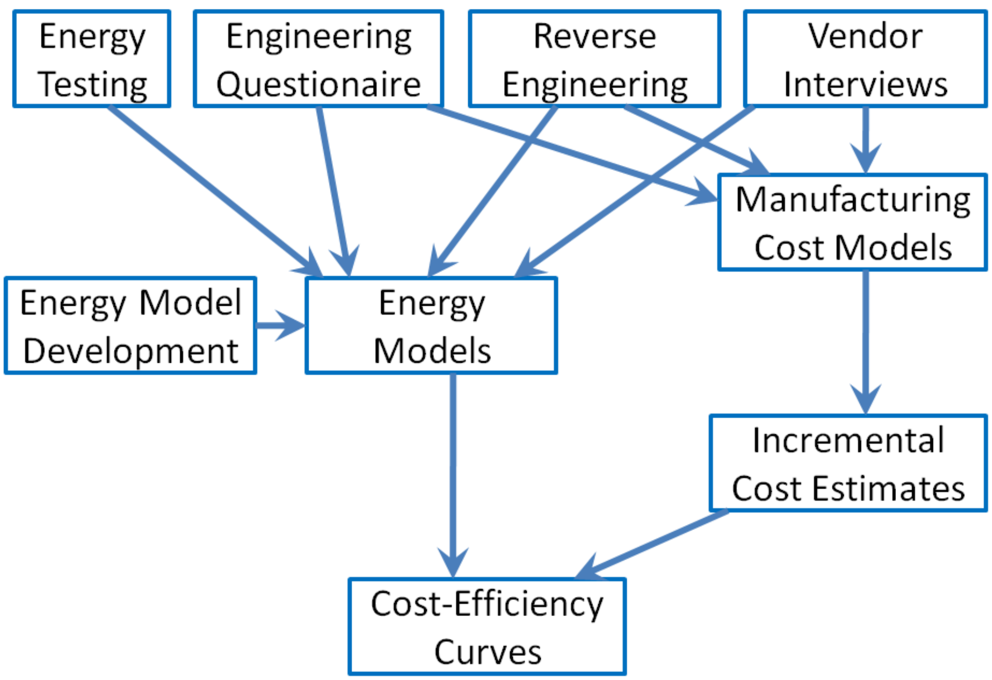

Figure 5.3.1 Flow Diagram of Engineering Analysis Methodology

Cost information from the vendor interviews and engineering questionnaires provided input to the manufacturing cost model. Incremental costs associated with specific design options were calculated using the cost model. Energy use reduction was modeled with a modified version of the established EPA Refrigerator Analysis (ERA) program which was used in the previous refrigerator rulemaking. The reverse engineering, vendor interviews, and manufacturer interviews provided input for the energy analysis. The incremental cost estimates and the energy modeling results together constitute the energy efficiency curves presented in this chapter.

5.4 EFFICIENCY LEVELS

5.4.1 Baseline Units based on the Current Test Procedure

DOE selected baseline units as reference points for all of the product classes, against which DOE determined changes resulting from use of energy saving design options. The baseline unit in each product class represents the basic characteristics of equipment in that class. A baseline unit is a unit that just meets current required energy conservation standards and provides basic consumer utility.

As discussed in chapter 3, DOE has revised the energy test procedure for refrigerators, refrigerator-freezers, and freezers. Some of the changes to the test procedure such as changes in compartment temperatures result in changes in the measured energy consumption. The new test procedure changes also affect the measured size of the refrigerators, expressed as adjusted volume. Since the maximum energy use for residential refrigeration products is expressed as a function of adjusted volume, the change in adjusted volume also would affect the definition of baseline products. This section discusses definitions of baseline units for the engineering analysis based on the current test procedure, while the next section discusses modified definitions for baseline refrigeration products based on the revised test procedure.

For this rulemaking, DOE chose baseline efficiency levels represented by the current federal energy conservation standards, expressed as maximum annual energy consumption as a function of the product's adjusted volume, as shown in Table 5.4.1. These definitions are based on testing according to the current energy test procedure. The table does not show all of the product classes established for this rulemaking. The baseline energy use characteristics for the new product classes that DOE separated from their current product classes (all-refrigerators, built-in products, and products with automatic icemakers) cannot be distinguished from other products of their current product classes because there is no baseline energy difference under the current test procedure.

Table 5.4.1 Refrigeration Product Current Energy Conservation Standards (Baseline Energy Use under Current Test Procedure)

Product Class	Equations for Maximum Energy Use (kWh/yr)
1. Refrigerators and refrigerator-freezers with manual defrost.	8.82AV + 248.4 0.31av + 248.4
2. Refrigerator-freezer—partial automatic defrost.	8.82AV + 248.4 0.31av + 248.4
3. Refrigerator-freezer—automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerator—automatic defrost.	9.80AV + 276.0 0.35av + 276.0
4. Refrigerator-freezers—automatic defrost with side-mounted freezer without through-the-door ice service.	4.91AV + 507.5 0.17av + 507.5
5. Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service.	4.60AV + 459.0 0.16av + 459.0
6. Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service.	10.20AV + 356.0 0.36av + 356.0
7. Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service.	10.10AV + 406.0 0.36av + 406.0
8. Upright freezers with manual defrost.	7.55AV + 258.3 0.27av + 258.3
9. Upright freezers with automatic defrost.	12.43AV + 326.1 0.44av + 326.1
10. Chest freezers and all other freezers except compact freezers.	9.88AV + 143.7 0.35av + 143.7
11.Compact refrigerators and refrigerator-freezers with manual defrost.	10.70AV + 299.0 0.38av + 299.0
12. Compact refrigerator-freezer—partial automatic defrost.	7.00AV + 398.0 0.25av + 398.0
13. Compact refrigerator-freezers—automatic defrost with top-mounted freezer and compact all-refrigerator—automatic defrost.	12.70AV + 355.0 0.45av + 355.0
14. Compact refrigerator-freezers—automatic defrost with side-mounted freezer.	7.60AV + 501.0 0.27av + 501.0
15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.	13.10AV + 367.0 0.46av + 367.0
16. Compact upright freezers with manual defrost.	9.78AV + 250.8 0.35av + 250.8
17. Compact upright freezers with automatic defrost.	11.40AV + 391.0 0.40av + 391.0
18. Compact chest freezers.	10.45AV + 152.0 0.37av + 152.0
5A. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service.	5.0AV + 539.0 0.18av + 539.0
10A. Chest freezers with automatic defrost.	14.76AV + 211.5 0.52av + 211.5

AV= adjusted volume in cubic feet; av = adjusted volume in liters; Refrigerator-Freezers: AV = fresh food internal volume + 1.63 * freezer internal volume: Freezers: AV = 1.73 * freezer internal volume; Refrigerators (single-door): AV = fresh food internal volume + 1.44 * freezer internal volume
All-Refrigerators: AV = internal volume

5.4.2 Baseline Efficiency Definitions Based on the New Test Procedure

As discussed in chapter 3, DOE has revised the energy test procedure. Two key changes in the test procedure include (1) harmonizing with expected test temperatures under consideration for IEC test procedure 62552 and (2) simplifying the calculation of refrigerated volumes. The new test temperatures are summarized in Table 5.4.2 below.

Table 5.4.2 Cabinet Temperature Changes for the DOE Test Procedure

Equipment Type	Fresh Food Compartment Temperature °F		Freezer Compartment Temperature °F	
	Current	New	Current	New
Refrigerator-Freezer	45	39	5	0
All-Refrigerator*	38	39	Not Applicable	
Basic Refrigerator*	45	39	15	15 (No Change)
Freezer	Not Applicable		0	0 (No Change)

*An all-refrigerator is a refrigerator with either no freezer compartment or with a freezer compartment smaller than 0.5 cubic feet in size. A basic refrigerator has a freezer compartment of 0.5 cubic feet or larger capacity.

The temperature changes also impact the volume adjustment factor used to determine the adjusted volume. This factor is multiplied by the freezer compartment volume in the adjusted volume calculation. Current and new volume adjustment factors are summarized in Table 5.4.4 below.

Table 5.4.3 Volume Adjustment Factors

Product	Current Test Procedure	New Test Procedure Revisions
Refrigerator-Freezer	1.63	1.76
Basic Refrigerator*	1.44	1.47
Freezer	1.73	1.76
All-Refrigerator**	1.00	1.00

The key changes in the volume measurement calculation between the current test procedure (which references the volume calculation procedure in AHAM standard HRF-1-1979) and the new revised test procedure (which references the new procedure in AHAM standard HRF-1-2008) are summarized in Table 5.4.4 below. Adjusted volume would be impacted both by the change in the volume adjustment factor discussed above and the change in the volume measurement.

Table 5.4.4 Compartment Volume Calculation Changes

Item	AHAM HRF-1-1979	AHAM HRF-1-2008	Expected Effect on Volume
Automatic Ice Maker Storage Bin	Included (4.2.1.1a)	Would be included under "removable containers" but dispenser MAY NOT be included	None*
Ice Makers	Included (4.2.1.1a)	No Mention	None*
Water Coolers	Included (4.2.1.1a)	No Mention	None*
Door Shelf Fronts and Bottoms	Included (4.2.1.1b)	Shelves molded into the inner door panel NOT included (4.2.2)	Decrease
Volume between the Deductible Door Dikes and Cabinet Breaker Strips or Adjacent Liner Wall	Not Included (4.2.1.2d)	No mention of exclusion, so probably included.	Increase
Shelf Hangers & Shelf and Pan Rails	Not included for fixed projections if collective volume is >0.05 ft^3 (4.2.1.2e)	Could be interpreted as part of shelving and would thus be included.	Increase

*AHAM HRF-1-2008 doesn't mention this item or is not fully clear regarding its treatment for the volume calculation, but it is expected that manufacturers would use the AHAM HRF-1-1979 approach. The new test procedure revision explicitly includes the automatic icemaker and storage bin in the volume calculation.

5.4.2.1 Data Illustrating the Impact of Key Test Procedure Changes

The different compartment temperatures of the new revised energy test procedure would change test energy use for refrigerators and refrigerator-freezers. In addition, both the impact of the modified temperatures on the adjusted volume and the modified volume calculation method would change adjusted volumes. For these reasons, it is necessary to establish modified relationships between energy use and adjusted volume to define baseline products. AHAM provided data for a number of the product classes, presented in Table 5.4.7 through Table 5.4.10 below (this is referred to as the AHAM TP Change data).

The data illustrates the impact of the compartment temperature changes and the volume calculation method changes of the new test procedure, but does not consider energy use associated with production of ice, which has been integrated with the new test procedure energy use metric, nor the impact of other test procedure changes, some of which may alter measured energy use.

The AHAM TP Change data for product classes 11 and 13 both show energy use reductions, indicating that the products represented by these data are primarily all-refrigerators. AHAM was not able to separately provide data for the all-refrigerators and the basic refrigerators of these product classes, because insufficient data was provided by manufacturers for separate aggregation.

Additional data sources which provide indication of the impacts of the test temperature changes for standard-size refrigerator-freezers include (1) energy test measurements for the refrigerator-freezers tested as part of this rulemaking, and (2) calculation of the energy impacts using ERA, the energy modeling tool used for this rulemaking. The energy use impacts indicated by these sources are shown in Table 5.4.8. DOE conducted these energy tests and calculations for three products of each of the seven product classes analyzed during the preliminary analysis (see Section 5.5.3.1 for discussion on selection of products for reverse engineering and energy testing).

Table 5.4.5 Compartment Temperature and Adjusted Volume Change Data provided by AHAM—Current Test

Product Class		Fresh Food Volume	Freezer Volume	Adjusted Volume	Energy Use
3 (R-F)	Average	12.82	5.02	20.92	420
	Standard Deviation	3.54	1.82	6.53	55
	Number of Samples	19	19	19	19
3A (AR)	Average	19.26	Not Applicable	19.26	374
	Standard Deviation	3.4		3.4	54
	Number of Samples	11		11	11
5	Average	14.21	5.15	22.62	493
	Standard Deviation	1.85	1.02	3	55
	Number of Samples	18	18	18	18
7	Average	15.77	9.32	30.95	617
	Standard Deviation	1.61	0.87	2.53	68
	Number of Samples	24	24	24	24
9	Average	Not Applicable	16.85	29.14	603
	Standard Deviation		4.88	8.45	136
	Number of Samples		18	18	18
11	Average	4.38	Not Provided	4.65	334
	Standard Deviation	1.38		1.38	44
	Number of Samples	13		13	13
13	Average	4.75	Not Provided	4.77	296
	Standard Deviation	1.18		1.15	77
	Number of Samples	12		12	12

Note: **R-F** refers to refrigerator-freezers; **AR** refers to all-refrigerators.

Table 5.4.6 Compartment Temperature and Adjusted Volume Change Data provided by AHAM--New Compartment Temperatures and Volume Calculation Method

Product Class		Fresh Food Volume	Freezer Volume	Adjusted Volume	Energy Use
3 (R-F)	Average	12.79	4.96	21.44	472
	Standard Deviation	3.51	1.78	6.59	53
	Number of Samples	19	19	19	18
3A (AR)	Average	19.51	Not Applicable	19.51	364
	Standard Deviation	3.51		3.51	53
	Number of Samples	11		11	11
5	Average	14.42	5.25	23.12	582
	Standard Deviation	1.88	1	3.01	68
	Number of Samples	18	18	18	18
7	Average	15.95	9.01	31.45	702
	Standard Deviation	1.79	0.75	2.49	82
	Number of Samples	24	24	24	24
9	Average	Not Applicable	16.84	29.47	603
	Standard Deviation		5.04	8.73	136
	Number of Samples		18	18	18
11	Average	4.34	Not Provided	4.61	324
	Standard Deviation	1.36		1.36	48
	Number of Samples	13		13	13
13	Average	4.8	Not Provided	4.83	285
	Standard Deviation	1.23		1.2	73
	Number of Samples	12		12	12

Note: **R-F** refers to refrigerator-freezers; **AR** refers to all-refrigerators.

Table 5.4.7 Compartment Temperature and Adjusted Volume Change Data provided by AHAM—Impact

Product Class		Fresh Food Volume	Freezer Volume	Adjusted Volume	Energy Use
3 (R-F)	Average	-0.1%	-1.1%	2.8%	12.4%
	Standard Deviation	0.6%	0.9%	2.3%	6.9%
	Number of Samples	19	19	19	18
3A (AR)	Average	1.2%	Not Applicable	1.2%	-2.6%
	Standard Deviation	1.0%		1.0%	1.1%
	Number of Samples	11		11	11
5	Average	1.5%	2.2%	2.2%	18.2%
	Standard Deviation	1.2%	2.2%	1.2%	3.7%
	Number of Samples	18	18	18	18
7	Average	1.0%	-3.1%	1.6%	14.0%
	Standard Deviation	2.0%	4.6%	2.0%	6.7%
	Number of Samples	24	24	24	24
9	Average	Not Applicable	-0.4%	0.9%	0.0%
	Standard Deviation		2.5%	2.2%	0.0%
	Number of Samples		18	18	18
11	Average	-0.7%	Not Provided	-0.6%	-3.1%
	Standard Deviation	1.9%		1.6%	1.4%
	Number of Samples	13		13	13
13	Average	0.9%	Not Provided	1.0%	-3.6%
	Standard Deviation	1.6%		1.4%	0.8%
	Number of Samples	12		12	12

Note: **R-F** refers to refrigerator-freezers; **AR** refers to all-refrigerators.

Table 5.4.8 Energy Use Impact of Compartment Temperature Changes: Data Developed by DOE

Product Class	Product Description	Impact based on energy measurements	Impact based on ERA modeling
3	16 ft^3 Top-Mount R-F	19.1%	14.2%
	21 ft^3 Top-Mount R-F	27.7%	15.5%
	21 ft^3 E* Top-Mount R-F	26.6%	14.1%
5	18.5 ft^3 E* Bottom-Mount R-F	12.5%	13.6%
	25 ft^3 E* Bottom-Mount R-F 1	27.6%	13.8%
	25 ft^3 E* Bottom-Mount R-F 2	17.3%	14.4%
4	22 ft^3 Side-Mount R-F†	17.7%	12.5%
7	26 ft^3 Side-Mount R-F	24.5%	12.9%
	26 ft^3 E* Side-Mount R-F	25.0%	12.2%
11	1.7 ft^3 Compact Refrigerator	-4.5%	-2.3%
	4.0 ft^3 Compact Refrigerator	Not Tested	13.7%

†This product was thought to be product class 7 when purchased.

The AHAM TP Change data shows reasonable agreement with the DOE modeled energy use impacts. However, the DOE energy measurements indicate a higher sensitivity to the temperature change of the new test procedure. The AHAM data shows that there can be significant variation in the sensitivity of different refrigerator-freezer products to the test temperature changes, particularly for product classes 3 and 7. The two compact refrigerators of Table 5.4.8 exhibit different responses to the compartment temperature change because the 1.7 ft^3 refrigerator has a freezer compartment smaller than 0.5 ft^3 and is tested as an all-refrigerator, while the 4.0 ft^3 refrigerator has a freezer compartment just larger than 0.5 ft^3, requiring that it be tested as a basic refrigerator.

5.4.2.2 Establishment of Baseline Energy—Adjusted Volume Relationships Based on the New Test Procedure Temperature and Volume Changes

The available data to inform the establishment of baseline energy versus adjusted volume relationships based on the temperature and volume changes of the new revised test procedure is discussed in Section 5.4.2.1. While this data does not address every product class, DOE has used it as the basis for establishing the baseline relationships. The approach DOE used to develop these relationships for all the product classes is summarized in Table 5.4.9 below. Note that product classes 1, 3, 11, and 13 are split because, while the all-refrigerators have reduced energy use with the new test procedure, the products which include freezers have significantly higher energy use. This applies to many products of product class 11 and some of product class 1 that have freezer compartments smaller than 0.5 ft^3, which allows them to be classified and tested as all-refrigerators rather than basic refrigerators. The test procedure impact of this classification is that the refrigerator compartment temperature would be raised for all-refrigerators, while it would be reduced for basic refrigerators under the new test procedure.

Table 5.4.9 Approach for Establishing Baseline Energy--Adjusted Volume Relationships

Product Class	Approach
1	Use modeling with ERA for temperature, assume negligible adjusted volume impact based on AHAM data for PC11.
1A (All-Refrigerators)	Use AHAM TP Change aggregated data of product class 3 all-refrigerators.
3 (Refrigerator-Freezers)	Use AHAM TP Change aggregated data.
3A (All-Refrigerators)	Use AHAM TP Change aggregated data.
4	Use AHAM TP Change aggregated data of product class 7. **
5	Use AHAM TP Change aggregated data. **
5A	Use AHAM TP Change aggregated data of product class 5. **
6	Use AHAM TP Change aggregated data of product class 3 refrigerator-freezers.
7	Use AHAM TP Change aggregated data.
8 (volume only)	Assume negligible volume impact due to simplicity of manual defrost freezer interior.
9 (volume only)	Use AHAM TP Change aggregated data.
10 (volume only)	Assume negligible impact due to simplicity of manual defrost freezer interior.
10A (volume only)	Use AHAM TP Change aggregated data for PC9.
11	Use modeling with ERA for temperature, assume negligible adjusted volume impact based on AHAM data.*
11A (All-Refrigerators)	Use modeling with ERA for temperature, assume negligible adjusted volume impact based on AHAM data.*
13 (Refrigerator-Freezers)	Use AHAM TP Change aggregated data of product class 3 refrigerator-freezers.*
13A (All-Refrigerators)	Use AHAM TP Change aggregated data of product class 3 all-refrigerators.*
14	Use AHAM TP Change aggregated data of product class 7.
15	Use AHAM TP Change aggregated data of product class 5.
16 (volume only)	Assume negligible volume impact due to simplicity of manual defrost freezer interior.
17 (volume only)	Use AHAM TP Change aggregated data for PC9.
18 (volume only)	Assume negligible volume impact due to simplicity of manual defrost freezer interior.

*The AHAM energy use increase data cannot be used for this product class, because it is not known how many of the products represented by the AHAM data are all-refrigerators.
**DOE subsequently modified the new baseline energy use equations for these product classes to adjust their slopes (see sections 5.4.2.4 and 5.4.2.6 below).

Note: For product classes 8, 10, 16, and 18, while the volume impact is assumed to be negligible, the adjusted volume increases according to the increase in the volume adjustment factor.

The methodology for determining new baseline energy—adjusted volume curves given the data indicating the impacts on the energy use and adjusted volume for a given product class is as follows. The new energy use and the current energy use for a product are represented as being proportional using an Energy Standard Adjustment Factor (ESAF).

$$BEC_{NEWTP} = ESAF \times BEC_{CURTP}$$ **Equation 5.4.1**

Where:
BEC_{NEWTP} = Baseline energy consumption using the new test procedure;
BEC_{CURTP} = Baseline energy consumption using the current test procedure.

The ESAF is considered to be a function only of product class. Dependence on adjusted volume or efficiency level cannot be determined based on the available data.

Similarly, the adjusted volume for a product under the new test procedure is related to the adjusted volume under the current test procedure using a Volume Calculation Adjustment Factor (VCAF).

$$AV_{NEWTP} = VCAF \times AV_{CURTP}$$ **Equation 5.4.2**

Where:
AV_{NEWTP} = Adjusted Volume using the new test procedure;
AV_{CURTP} = Adjusted Volume using the current test procedure.

The VCAF, like the ESAF, is considered to be a function only of product class. Baseline energy use for the current test procedure is expressed as follows, where the constants A and B are a function of product class.

$$BEC_{CURTP} = A \times AV_{CURTP} + B$$ **Equation 5.4.3**

Combining Equations 5.4.1 through 5.4.3 gives the following relationship for the baseline energy consumption based on the new test procedure.

$$BEC_{NEWTP} = ESAF \times \left(A \times \frac{AV_{NEWTP}}{VCAF} + B \right) = \left(\frac{ESAF}{VCAF} \times A \right) \times AV_{NEWTP} + \left(ESAF \times B \right)$$

Hence, the baseline energy consumption for the product class for the new test procedure can be represented as a straight-line relationship based on new constants A_{NEW} and B_{NEW}, where the new constants are related to the current constants as follows.

$$A_{NEW} = \left(\frac{ESAF}{VCAF}\right) \times A; \quad B_{NEW} = ESAF \times B$$

The baseline energy use based on the new test procedure temperature and volume changes is presented in Table 5.4.10 below for each of the product classes. This baseline energy use includes energy use not associated with icemaking. A placeholder with a value of 84 kWh/year has been integrated in the new test procedure as additional energy use for production

Table 5.4.10 Preliminary Baseline Energy Consumption based on New Test Procedure Temperature and Volume Changes

Product Class	ESAF	VCAF	Current Baseline Energy Use (kWh/year)	New Test Procedure Baseline Energy Use not Including Icemaking Energy Use (kWh/year)
1	1.132	1	8.82 AV + 248.4	9.98 AV + 281.2
1A	0.974	1.012	8.82 AV + 248.4	8.49 AV + 241.9
2	1.132	1	8.82 AV + 248.4	9.98 AV + 281.2
3, 3I, 3-BI, 3I-BI	1.124	1.028	9.80 AV + 276.0	10.72 AV + 310.2
3A, 3A-BI	0.974	1.012	9.80 AV + 276.0	9.43 AV + 268.8
4, 4I, 4-BI, 4I-BI	1.14	1.016	4.91 AV + 507.5	5.51 AV + 578.6
5, 5I, 5-BI, 5I-BI	1.182	1.022	4.60 AV + 459.0	5.32 AV + 542.5
5A, 5A-BI	1.182	1.022	5.00 AV + 539.0	5.78 AV + 637.1
6	1.124	1.028	10.20 AV + 356.0	11.15 AV + 400.1
7, 7-BI	1.14	1.016	10.10 AV + 406.0	11.33 AV + 462.8
8	1	1.017	7.55 AV + 258.3	7.42 AV + 258.3
9, 9-BI	1	1.009	12.43 AV + 326.1	12.32 AV + 326.1
10	1	1.017	9.88 AV + 143.7	9.71 AV + 143.7
10A	1	1.009	14.76 AV + 211.5	14.63 AV + 211.5
11	1.125	1	10.70 AV + 299.0	12.04 AV + 336.4
11A	0.977	1	10.70 AV + 299.0	10.45 AV + 292.1
12	1.125	1	7.00 AV + 398.0	7.88 AV + 447.8
13	1.124	1.028	12.70 AV + 355.0	13.89 AV + 399.0
13A	0.974	1.012	12.70 AV + 355.0	12.22 AV + 345.8
14	1.14	1.016	7.60 AV + 501.0	8.53 AV + 571.1
15	1.182	1.022	13.10 AV + 367.0	15.15 AV + 433.8
16	1	1.017	9.78 AV + 250.8	9.61 AV + 250.8
17	1	1.009	11.40 AV + 391.0	11.30 AV + 391.0
18	1	1.017	10.45 AV + 152.0	10.27 AV + 152.0
Note: In the "Current Baseline" equations, AV is calculated using the current volume calculation method and adjustment factor, while in the "New" equations, AV is calculated using the new volume calculation method and adjustment factor (see Table 5.4.4)				

of ice. This placeholder is added to the energy curves for products with automatic icemakers (after consideration of energy use reductions associated with candidate standard levels) to obtain the total energy use of these product classes.

5.4.2.3 Preliminary Investigation of the Slope of the Energy Use Curve

During the preliminary analysis, DOE conducted calculations to confirm whether the slopes of the baseline energy use—adjusted volume curves for the product classes analyzed in depth as part of the engineering analysis are representative of the energy use of typical products. DOE conducted these analyses based on the new revised test procedure. The analysis started with an energy model of a minimally-compliant product and examined the trend in calculated energy use as the product size changes with constant insulation thickness. For the analysis of compact refrigerators, DOE considered the change in efficiency of typically available compressors sized appropriately for the product. For standard-size products, the DOE used a constant compressor efficiency in the analysis, based on observation that compressor efficiency does not vary significantly in the capacity range suitable for most standard-size products (this is discussed in greater detail in section 5.8.4). The energy—adjusted volume slopes calculated in this analysis are presented in Table 5.4.12 below. The table also shows the slopes of the new baseline energy use—adjusted volume relationships of Table 5.4.10 above. The comparison provides an indication of whether adjustment might be required to the new baseline energy use relationships, which are based on the current energy conservation standards and the expected impacts of the expected revised test procedure.

Table 5.4.11 DOE Preliminary Assessment of the Slope of the Energy Use Curve

Product Class	Calculated Energy Curve Slope from ERA Models*	Slope from Baseline Energy Use Equation (Table 5.4.10)
3	13.3	10.7
5	12.3	5.3
7	11.9	11.3
9	9.4	12.3
10	7.7	9.7
11	16.4	12.0
11A	20 to 35**	10.5
18	4.5	10.3

* Analysis was conducted for both the small and large units analyzed for product classes 3, 5, 7, 9, 10, 18. Values shown are averages of slopes for the two ERA models.

** The energy use—adjusted volume relationship is nonlinear, with higher slope at lower volumes. The slopes indicated are applicable for a range of adjusted volumes from 1.7 to 3.6 ft^3.

5.4.2.4 Energy Use Curve Slope Changes for Product Classes 4, 5, and 5A

DOE adjusted the energy equation slopes for product classes 4 (refrigerator-freezers—automatic defrost with side-mounted freezers without through-the-door ice service) and 5 (refrigerator-freezers—automatic defrost with bottom-mounted freezers without through-the-door ice service). This section describes the development of the modified baseline energy use equations for these products.

Product Class 4

DOE did not obtain data to allow determination of the appropriate slope of the energy use equation for product class 4. However, DOE decided that the slope of the baseline energy use equation for product class 7 (refrigerator-freezers—automatic defrost with side-mounted freezers with through-the-door ice service) is appropriate also for product class 4 and its variants (4, 4I, 4-BI, and 4I-BI). This slope is equal to 11.3 (see Table 5.4.10 above).

DOE observed that the range of product total volumes for these products is 20 to 30 cu. ft., (based on the database used to develop the information in TSD Chapter 3, section 3.3.3) representing a range of adjusted volume from 25.1 to 37.7 cu. ft. using the current test procedure.

DOE selected a new intercept for the baseline energy use equation for product class 4 so that the average energy use impact would be neutral. Since shipment data for the product class correlated with volume was not available, DOE selected an intercept that would result in the same average energy use for the products at the ends of the size range for the product class described above. The resulting equation is $11.3 \times AV + 395.3$. The new curve is compared with the current energy standard and with the preliminary curve in Figure 5.4.1 below.

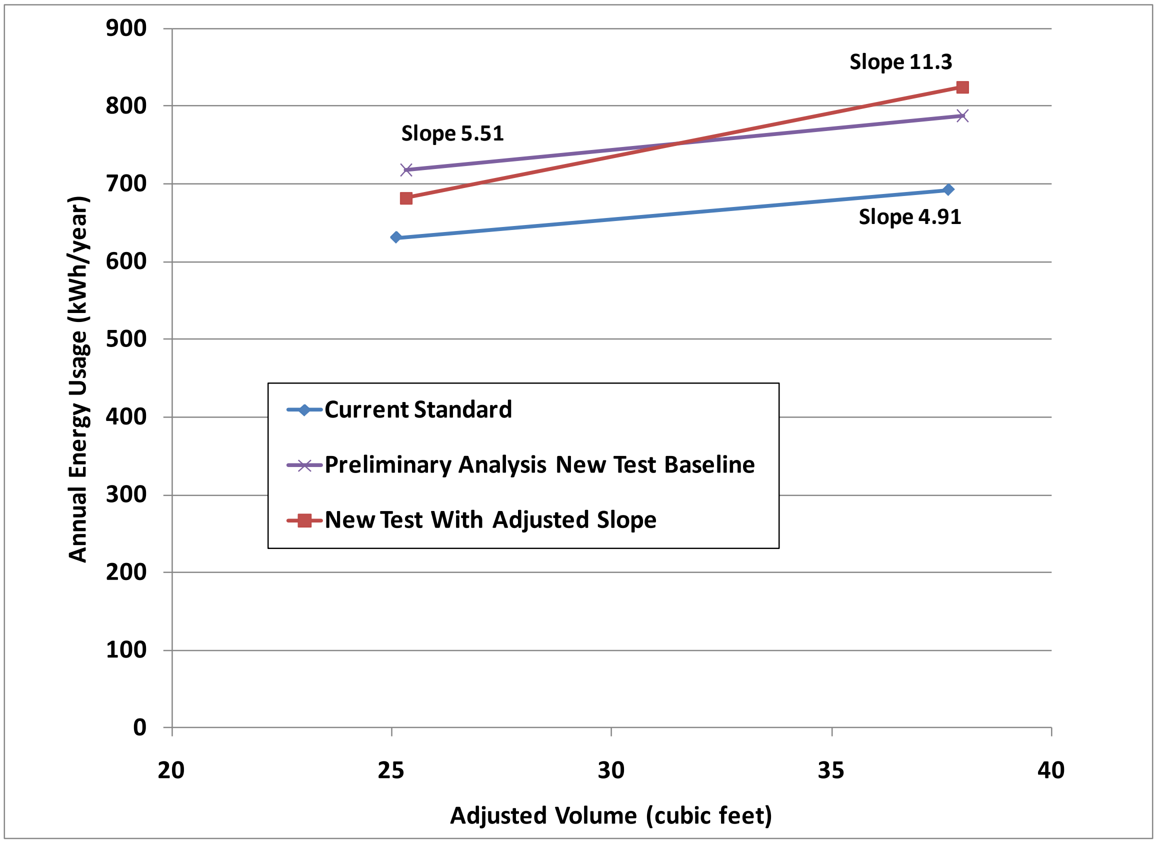

Figure 5.4.1 Comparison of Preliminary and Adjusted-Slope Energy Use Curves (Product Class 4)

Product Class 5

For this product class, DOE obtained data for two pairs of products which allowed determination of the energy/adjusted volume slope. For each of these product pairs, (1) the refrigeration system designs of the two products of the pair are identical, (2) wall thicknesses in corresponding portions of the cabinet are identical, and (3) the two products of the pair have different total and adjusted volume. The energy use slope associated with these pairs of products is compared with the current energy standard in Figure 5.4.3 below. The product data shows that the energy use dependence on adjusted volume (i.e. the appropriate slope of the baseline energy use line) is at least twice as high as expressed by the current standard.

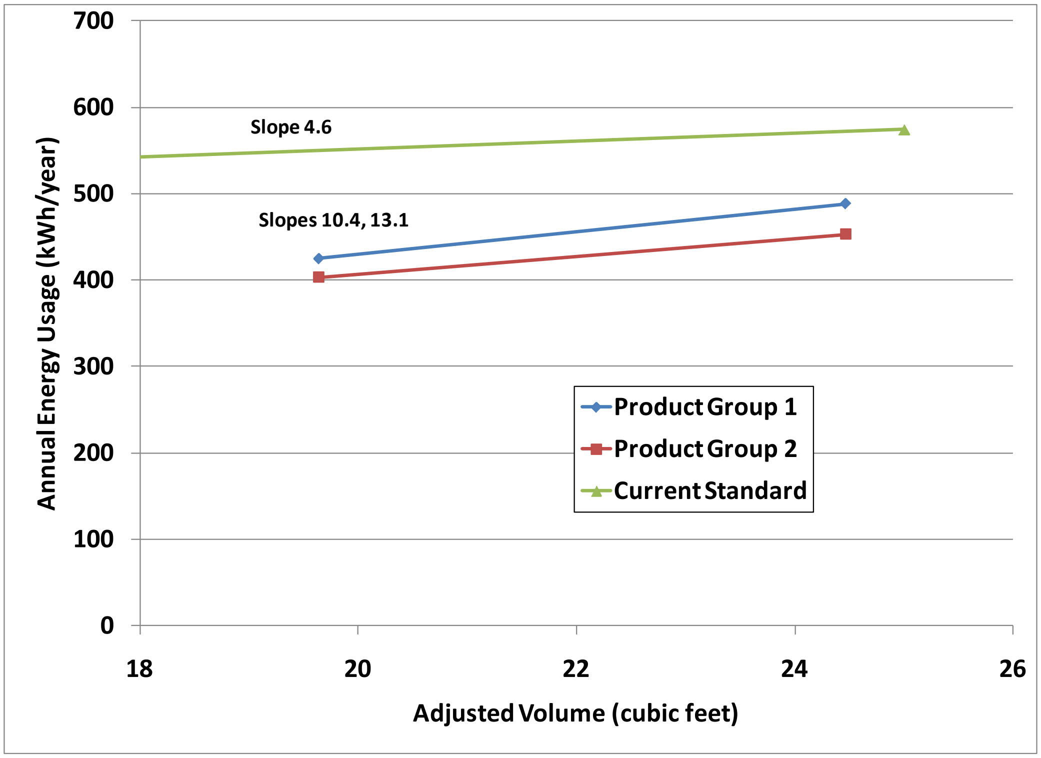

Figure 5.4.2 Product Class 5 Energy Use Equation Slope Data

When adjusted for the new test procedure, the slope of 4.6 of the current standard increases to 5.32 (see Table 5.4.10 above). In contrast, the slopes for other standard-size refrigerator-freezer product classes such as 3 (refrigerator-freezers—automatic defrost with top-mounted freezer without through-the-door ice service) and 7 (refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service) are 10.72 and 11.33. DOE has adjusted the slope of the baseline energy use equation to 11.0 for product class 5, nearly equal to the average of the slopes for these other two product classes.

DOE has also adjusted the intercept for the baseline energy use equation for product class 5 to a level that would result in neutral impact on the average energy use of products within this class. DOE does not have shipment data for every configuration of product of the class and for this reason cannot determine exactly the appropriate intercept that would provide the same shipment weighted average baseline energy use for both low-slope and adjusted-slope equations. Instead, DOE chose an intercept so that the average energy use of the two reverse engineered products for product class 5 (with total volumes 18.5 and 25 cu. ft.) was the same for the preliminary baseline curve and the new adjusted-slope curve. The adjusted-slope curve is shown in Figure 5.4.5 below. The adjusted slope equation is $11.0 \times AV + 394.2$. DOE used this baseline equation for the product class 5 variants (5, 5I, 5-BI, and 5I-BI).

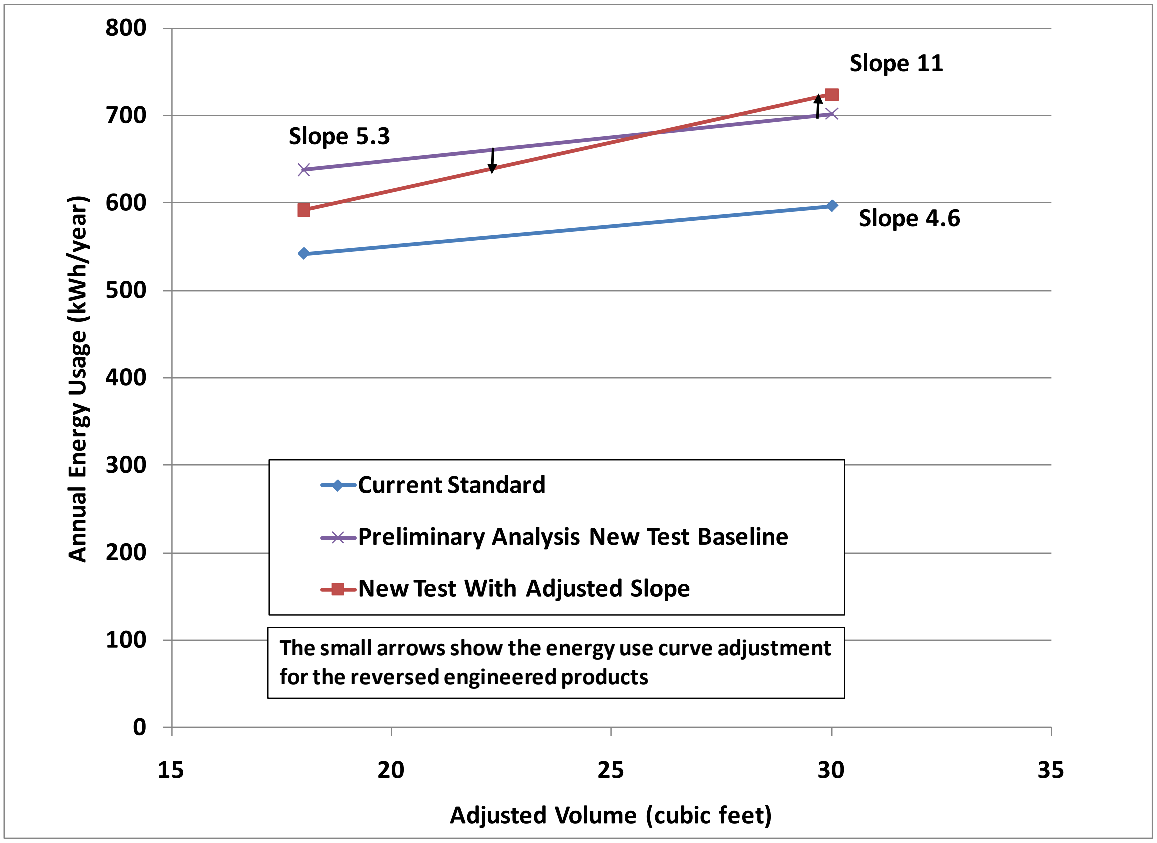

Figure 5.4.3 Comparison of Preliminary and Adjusted-Slope Energy Use Curves (Product Class 5)

Product Class 5A

DOE has adjusted of the slope for product class 5A (refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service) based on the adjusted baseline energy use equation for product class 5. DOE made this adjustment in the same way that the current energy standard for this product class was established for product class 5A through the exception relief process administered by the Office of Hearings and Appeals.[a] This adjustment involves adding to the energy use of product class 5 the difference in energy use between product classes 6 (refrigerator-freezer—automatic defrost with top-mounted freezer with through-the-door ice service) and 3 (refrigerator-freezer—automatic defrost with top-mounted freezer without through-the-door ice service). The resulting baseline energy use equation for product class 5A is 11.44 × AV + 484.1. DOE used this baseline equation for the product class 5A variants (5A and 5A-BI).

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[a] See, for example, the Decision and Order of the Office of Hearings and Appeals in case TEE-0022, Maytag Corporation, published August 11, 2005

5.4.2.5 NOPR Baseline Energy Use Equations

The adjusted baseline energy use equations presented in the NOPR TSD are summarized in Table 5.4.14 below. DOE made changes in the equations as compared with Table 5.4.10 for the following product classes.

- 4 (see discussion of slope change above)
- 5 (see discussion of slope change above)
- 5A (see discussion of slope change above)
- 16, 18 (adjustment made due to round-off errors in previous calculation)

Table 5.4.12 Adjusted Baseline Energy Use Equations--NOPR

Product Class	New Test Procedure Baseline Energy Use not Including Icemaking Energy Use (kWh/year)
1	9.98 AV + 281.2
2	9.98 AV + 281.2
1A	8.49 AV + 241.9
3, 3I, 3-BI, 3I-BI	10.72 AV + 310.2
3A, 3A-BI	9.43 AV + 268.8
4, 4I, 4-BI, 4I-BI	11.30 AV + 395.3
5, 5I, 5-BI, 5I-BI	11.00 AV + 394.2
5A, 5A-BI	11.44 AV + 484.1
6	11.15 AV + 400.1
7, 7-BI	11.33 AV + 462.8
8	7.42 AV + 258.3
9, 9-BI	12.32 AV + 326.1
10	9.71 AV + 143.7
10A	14.63 AV + 211.5
11	12.04 AV + 336.4
11A	10.45 AV + 292.1
12	7.88 AV + 447.8
13	13.89 AV + 399.0
13A	12.22 AV + 345.8
14	8.53 AV + 571.1
15	15.15 AV + 433.8
16	9.62 AV + 250.8
17	11.30 AV + 391.0
18	10.28 AV + 152.0

5.4.2.6 Additional Baseline Energy Use Equation Adjustments

DOE considered the impact on measured energy use of two additional test procedure changes, (1) modification of test procedures for special compartments that use heated temperature control, and (2) modification of the test procedure for products with long-time and/or variable defrost to capture precooling energy use. DOE developed adjustments for these changes equal to the measurement impact of the change multiplied by the percent of products expected to be affected by the change. Limited information was available to develop these adjustments. The adjustments are discussed below.

Special Compartments with Heated Temperature Control

This adjustment affects products with special compartments with separate temperature control that use heating to provide control for part of their temperature range. The current test procedure calls for testing with the temperature control in the coldest setting, while the new test procedure for such special compartments calls for averaging of tests with controls set in the coldest and warmest settings. This will increase energy use because the heater will consume energy and add thermal load when tested in the warmest setting.

This adjustment affects only standard-size refrigerator-freezers of current product classes 5, 5A, and 7). DOE identified 13 distinct products that have the heated special compartment feature, based on information that the compartment temperature range extends significantly higher than the typical fresh food compartment temperature. Manufacturers' web pages for these products are contained in "Heated Special Compartments Web Pages", document number 81 in the rulemaking docket. As described in the final rule, DOE considered the typical fresh food compartment temperature to be the default setting of the product as shipped or the recommendation for initial setting—this is generally 37 ˚F or 38 ˚F. The warmest setting for heated special compartments is generally either 41 ˚F or 42 ˚F. DOE calculated that these 13 products represent 16 basic models, because the CEC website lists two related models for each of three of the products. The number of basic models per product class and the percentage of the product classes represented by these products is presented in Table 5.4.13 below. DOE assumed in determining the total number of basic models per product class that 78% of the basic models listed in the CEC database are active. This was based on an extensive review of the listed models for product class 5A that are still being sold according to manufacturers' websites.

Table 5.4.13 Prevalence of Products with Heated Special Compartments

Product Class	Number of Products Identified	Number of Basic Models	Total Number of Basic Models	Percent of Basic Models
5	3	5	341	1.5%
5A	8	8	75	10.6%
7	2	3	436	0.7%

Information regarding the energy use associated with the heaters used for temperature control of special compartments is not publicly available, in part because there are very few products that use this feature. DOE calculated the energy use impact of the test procedure change for products having these features, as describe below.

DOE made the following assumptions for this calculation:

- The special compartment is located at the bottom of the fresh food compartment of a 25 ft^3 bottom-mount refrigerator-freezer (product class 5), with a baseline energy use of 733 kWh/yr not including icemaking energy use before consideration of the energy use impact of the test procedure change.
- The compartment has a controllable temperature range from 28 °F to 42 °F.
- The calculation is based on the standardized compartment temperatures, 0 ˚F for the freezer compartment and 39 ˚F for the fresh food compartment.
- Thermal transfer to and from the compartment is with the freezer compartment (on the bottom) and with the fresh food compartment on the top, front, rear, and sides. Although in reality there would be some isolation of the compartment from the fresh food compartment, particularly on the rear and sides, DOE has chosen to make the simplifying assumption that this isolation is negligible. This assumption increases the calculated energy use impact of the test procedure change, because, rather than undergoing some transfer through the walls of the cabinet to the ambient air (which would warm the compartment), the transfer on these surfaces is to the fresh food compartment, which, for the warmest temperature setting of the special compartment, cools the compartment.
- The thermal load on the special compartment transferred from the freezer compartment is impacted by air flow patterns within the freezer compartment. DOE assumed for the analysis that the freezer evaporator discharge air, assumed to be at -10 ˚F, is blown across the top of the freezer compartment, thus reducing the temperature of the lower surface of the mullion to this discharge air temperature for the 50% of the time that the refrigeration system operates. Hence, the average temperature of this surface is -5 °F, and the heat transfer rate is on average higher than for the other key surfaces through which heat is transferred to or from the special compartment.
- Heat transfer between the special compartment and the fresh food compartment is through one 3/16-inch plastic surface, and through air film resistance layers, on the top, sides, front, and rear of the special compartment.
- Heat transfer between the special compartment and the freezer compartment is through the mullion and one plastic compartment layer, with air film resistance in four places along this path (above and below both the mullion and the compartment layer).

These and other key assumptions for the calculation are listed below in Table 5.4.15.

Table 5.4.14: Special Compartment Energy Use Model Inputs

Description	Variable	Value	Units
Special Compartment Width	W	32	in
Special Compartment Depth	D	20	in
Special Compartment Height	H	4	in
Fresh Food Compartment Temperature	T_{FF}	39.0	°F
Special Compartment Temperature	T_{comp}	28.0 – 42.0	°F
Average Temperature beneath Mullion	T_{FZR}	-5.0	°F
Thickness of Mullion	$t_{mullion}$	1.50	in
Thickness of Special Compartment Walls	t_{comp}	0.188	in
Air Film Resistance for Most Surfaces	h_{film}	1.0	Btu/hr-sqft-°F
Air Film Resistance, Average for Freezer side of Mullion	h_{FZR}	2.0	Btu/hr-sqft-°F
Thermal Conductivity of Mullion	$k_{mullion}$	0.13	Btu-in/hr-sqft-°F
Thermal Conductivity of Special Compartment Wall	k_{comp}	0.1	Btu/hr-ft-°F

The rate of heat transfer from the special compartment to the fresh food compartment is:

$$\dot{Q}_{FF} = \left(T_{comp} - T_{FF}\right) \times A_{FF} \div \left(\frac{2}{h_{film}} + \frac{t_{comp}}{k_{comp}}\right)$$

The rate of heat transfer from the special compartment to the freezer compartment is:

$$\dot{Q}_{FZR} = \left(T_{comp} - T_{FZR}\right) \times A_{FZR} \div \left(\frac{3}{h_{film}} + \frac{t_{comp}}{k_{comp}} + \frac{t_{mullion}}{k_{mullion}} + \frac{1}{h_{FZR}}\right)$$

The total heat transfer from the compartment is equal to:

$$\dot{Q}_{total} = \dot{Q}_{FF} + \dot{Q}_{FZR}$$

A positive value for Q_{total} indicates that the special compartment loses heat to its surroundings. In this case, the electrical resistance heater supplies heat equal to Q_{total}. The energy use impact of this heater load includes energy expended by the heater in addition to energy used by the refrigeration system to remove its heat from the compartments to which it transfers heat. DOE calculated this system energy use based on assumption of a system EER equal to 5 Btu/hr-W. This is equivalent to operation with a 5.5 EER compressor with some consideration of energy use for the condenser and evaporator fans.

A negative value for Q_{total} indicates that the special compartment absorbs heat from the fresh food compartment and transfers it to the freezer compartment through the mullion. Assuming the control system provides cooling to the special compartment by diverting some evaporator discharge air to it, the required flow rate of this diverted discharge air is equal to:

$$Air\ Flow = \frac{-\dot{Q}_{total}}{\rho \times c_p \times (T_{comp} - T_{cooling\ air})}$$

where ρ is the air density, c_p is its heat capacity, and $T_{cooling\ air}$ is its temperature. The energy use impact of operating the product with a setting cold enough to require such cooling is zero, because the cooling diverted from the rest of the product to the compartment to maintain its temperature is exactly equal to the cooling provided to the rest of the product through the special compartment walls.

Energy use for the product when operating with the special compartment in its coldest setting is equal to the baseline energy use, 733 kWh per year, because the current test procedure calls for setting temperature controls for such special compartments to the coldest setting. Energy use for the product when operating with the special compartment in its warmest setting subtracts the energy use impact of operation in the coldest position and adds the energy use impact of the heater calculated for the warmest compartment temperature setting.

The energy use determined for the product with the special compartment test procedure change is equal to the average of the energy use measurements associated with the warmest and coldest settings. This is compared with the baseline energy use of 733 kWh to determine the percentage impact associated with the test procedure change. The results of the calculation are summarized in

Table 5.4.17. The calculation is based on a particular size bottom-mount refrigerator-freezer product. DOE believes that the estimate is conservative (tending to be high) for side-mount products, because there is less opportunity in side-mount products for thermal transfer from the special compartment to the freezer compartment. However, DOE has used the calculation for adjustment of all three of the product classes for which DOE identified products with heated special compartments.

Table 5.4.15: Special Compartment Energy Use Model Results

	Coldest Setting		**Warmest Setting**
T_{comp}	28 °F		42 °F
$\dot{Q}_{total}$	-3.8 W		5.8 W
$Air\ Flow$	0.32 CFM		N/A
$\dot{Q}_{heater}$	N/A		5.8 W
Added system average power	N/A		4.0 W
Total Added Power	N/A		9.8 W
Energy Use Impact	N/A		86 kWh/yr
Total Energy Use	733 kWh/yr		819 kWh/yr
Average Energy Use with Test Procedure Change	776 kWh/yr		
Percent Increase	5.9 %		
Product Class Group	5	5A	7
Percent of Products w/ Heated Special Compartment(s)	1.5%	10.6%	0.7%
Average Impact	0.088%	0.622%	0.041%

Precooling Energy Use

This adjustment affects products which use precooling of the freezer compartment and/or fresh food compartment. The new test procedure measures the energy use of the precooling cycle, whereas the current test procedure does not measure this energy use. DOE measured the energy use of 9 standard-size refrigerator freezers with automatic defrost during the engineering analysis. Two of these products used precooling, i.e. 22%. DOE has no information suggesting that this design feature is used for any products other than standard-size refrigerator-freezers. Hence, DOE has decided to use the precooling prevalence of this sample of refrigerator-freezers as the basis of the adjustment of the baseline energy use of all standard-size refrigerator-freezers.

The average impact on the energy use measurement for the two tested products was 2%. Hence, DOE calculates the shipment-weighted average impact of this test procedure change as 0.44%.

Total Impact

DOE calculated the total adjustment associated with the two test procedure changes for product classes 5, 5A, and 7 (and their variants) as illustrated below for product class 5A:

$$Adjustment\ Factor = (1 + 0.00622) \times (1 + 0.0044) = 1.0106$$

The adjustment factors applied to the NOPR-phase baseline energy use equations to obtain the final rule baseline equations are summarized in

Table 5.4.19 below.

Table 5.4.16 Additional Adjustments to Account for Test Procedure Changes

Product Classes	Special Heated Compartment Adjustment?	Precooling Adjustment?	Adjustment Factor
1, 1A, 2, 3A, 3A-BI, 8, 9, 9I, 9-BI, 9I-BI, 10, 10A, 11, 11A, 12, 13, 13A, 13I, 14, 14I, 15, 15I, 16, 17, 18	No	No	1.0000
3, 3I, 3-BI, 3I-BI, 4, 4I, 4-BI, 4I-BI, 6,	No	Yes	1.0044
5, 5I, 5-BI, 5I-BI	Yes	Yes	1.0053
5A, 5A-BI	Yes	Yes	1.0106
7, 7-BI	Yes	Yes	1.0048

5.4.2.7 Final Baseline Energy Use Equations

The adjusted baseline energy use equations are summarized in Table 5.4.21 below. The NOPR-phase equations for standard-size refrigerator-freezers with automatic defrost have been adjusted using the adjustment factor discussed in section 5.4.2.6.

Table 5.4.17 Adjusted Baseline Energy Use Equations--Final

Product Class	New Test Procedure Baseline Energy Use not Including Icemaking Energy Use (kWh/year)
1	9.98 AV + 281.2
2	9.98 AV + 281.2
1A	8.49 AV + 241.9
3, 3I, 3-BI, 3I-BI	10.76 AV + 311.6
3A, 3A-BI	9.43 AV + 268.8
4, 4I, 4-BI, 4I-BI	11.35 AV + 397.1
5, 5I, 5-BI, 5I-BI	11.06 AV + 396.3
5A, 5A-BI	11.56 AV + 489.3
6	11.20 AV + 401.9
7, 7-BI	11.39 AV + 465.1
8	7.42 AV + 258.3
9, 9I, 9-BI, 9I-BI	12.32 AV + 326.1
10	9.71 AV + 143.7
10A	14.63 AV + 211.5
11	12.04 AV + 336.4
11A	10.45 AV + 292.1
12	7.88 AV + 447.8
13, 13I	13.89 AV + 399.0
13A	12.22 AV + 345.8
14, 14I	8.53 AV + 571.1
15, 15I	15.15 AV + 433.8
16	9.62 AV + 250.8
17	11.30 AV + 391.0
18	10.28 AV + 152.0

5.4.3 Incremental Efficiency Levels

DOE established a series of incremental efficiency levels, for which it has developed incremental cost data and quantified the cost-efficiency relationship for each of the seven analyzed product classes. The incremental efficiency levels for freestanding products are shown in Table 5.4.21 below. The energy use reductions indicated in this table represent reductions only in the energy use not associated with icemaking. The levels for built-in products are shown in Table 5.4.23 below. Maximum available efficiency levels for the analyzed product classes, which are based on a survey of product databases and manufacturer websites, are tabulated in Table 5.4.25 below. Maximum technology levels, which are based on DOE energy modeling using all applicable design options, are discussed in Section 5.4.4.

Table 5.4.18 Incremental Efficiency Levels for Freestanding Products (% Energy Use Less than Baseline)

Level	Standard-Size Refrigerator-Freezers			Standard-Size Freezers		Compact Refrigerators and Freezers	
	PC3	PC5	PC7	PC9	PC10	PC11	PC18
1	10%			10% (Current ENERGY STAR)		10%	
2	15% (Former ENERGY STAR)			15%		15%	
3	20% (Current ENERGY STAR *)			20%		20% (Current ENERGY STAR *)	
4	25% (CEE Tier 2)			25%		25% (CEE Tier 2)	
5	30% (CEE Tier 3)			30%		30% (CEE Tier 3)	
6	36%		33%	35%		35%	
7				40%	41%	40%	42%
8				44%		45%	
9						50%	
10						59%	

*Current ENERGY STAR is equivalent to CEE Tier 1 for standard-size refrigerators and refrigerator-freezers and for all compact products.

Table 5.4.19 Incremental Efficiency Levels for Built-In Products

	Product Class			
Level	3A-BI All-Refrigerator	5-BI Bottom-Mount Refrigerator-Freezer	7-BI Side-Mount Refrigerator-Freezer	9-BI Upright Freezer
1	10%	10%	10%	10% (Current ENERGY STAR)
2	15%	15%	15%	15%
3	20% (Current ENERGY STAR)	20% (Current ENERGY STAR)	20% (Current ENERGY STAR)	20%
4	25%	25%	22%	25%
5	29%	27%		27%

Table 5.4.20 Maximum Available Levels (%Energy Use Less than Baseline)

Product Class	Maximum Available Level		
	Percent	Volume (ft^3)	Brand & Model Number
3	30%	18	Frigidaire LGUI1849L*
5	33%	21	LG LFC21776**
7	32%	26	Whirlpool GSS26C4XX*0*
9, 9-BI	27%	9	Gaggenau RF411700
10	15%	11	Summit CF11ES
11	27%	3	Avanti RM3251B-1
18	23%	7	Haier ESCM071EA
3A-BI	31%	13	Thermador T24BR70***
5-BI	27%	17	Sub-Zero BI30US*
7-BI	21%	22	Fisher & Paykel RX216*T*XV2
Sources: ENERGY STAR Refrigerator & Freezer Database (7/29/2010), ENERGY STAR Freezer Database (7/19/2010), CEE Database (7/15/2010), CEC Database (4/28/2010), Manufacturer websites			

5.4.4 Maximum Technology Level

DOE defines a maximum technology level to represent the theoretical maximum possible efficiency if all available design options are incorporated. The maximum technology level is not to be confused with the maximum available level, which is the highest efficiency unit currently available on the market. In many cases the maximum technology level is not commercially available because it is not economically feasible. Figure 5.4.7 below shows the maximum available efficiency levels, based on the ENERGY STAR databases from 7/19/10 (freezers) and 7/29/10 (refrigerators and freezers), with adjustments including deleting products which are no longer for sale based on the CEC database and manufacturers' and retailers' websites.

As mentioned, the maximum technology level may not represent available products because they may not be economically feasible. DOE determined maximum technology levels using energy modeling. The energy models for the maximum technology levels were based on use of all design options applicable for the specific product classes. While these product configurations have not likely been tested as prototypes, all of the individual design options have been incorporated in available products. The maximum technology efficiency levels for the analyzed product classes are presented in Table 5.4.21 below. These efficiency levels are in some cases higher than the maximum available products. The costs of the maximum technology efficiency level designs are also quite high, being based on extensive use of high-cost design options such as vacuum insulating panels as well as all applicable lower-cost design options. Table 5.4.21 indicates which design options were used for each of the product classes.

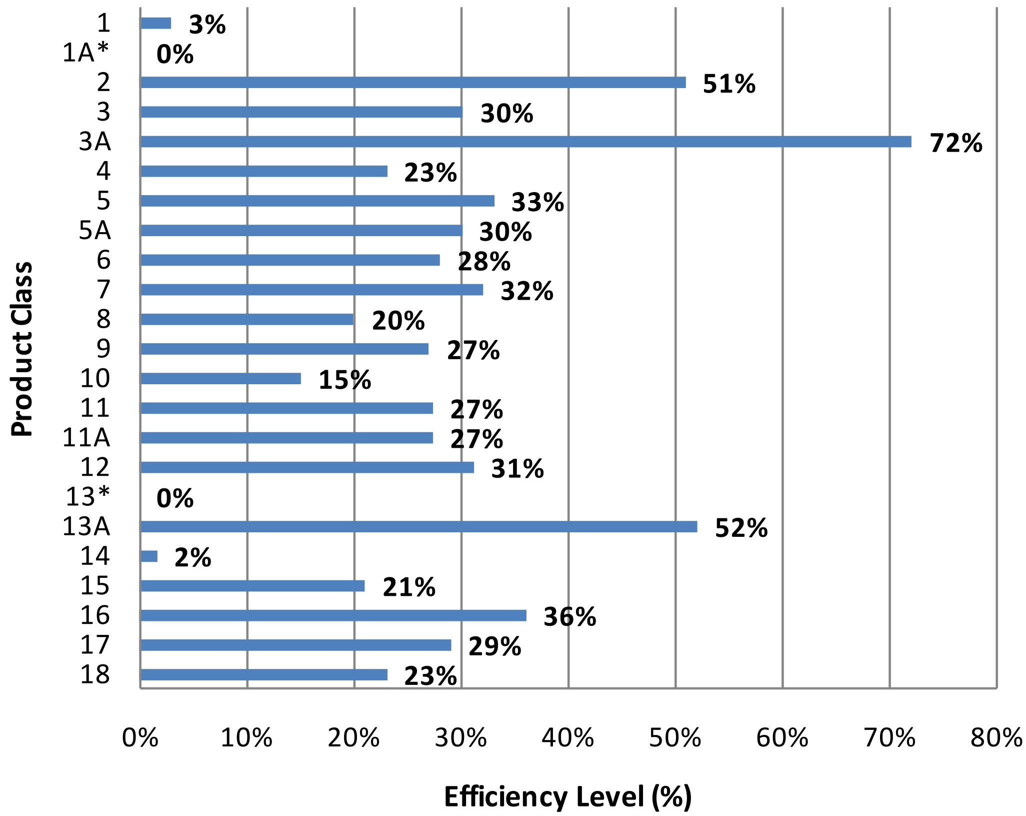

Figure 5.4.4 Maximum Efficiency Levels Available by Product Class
*No active model available with better than baseline efficiency

Table 5.4.21 Maximum Technology Levels and Design Options

Product Class	% Lower Energy	Design Options Used									
		Brushless DC Fans	Forced Convection Condenser	Larger Evaporator	Larger Condenser	Thicker Insulation	VIPs	Variable Speed Compressor	Adaptive Defrost	Variable Anti-Sweat	Isobutane Refrigerant
3	36%	✓		✓	✓		✓	✓	✓		
5	36%	✓		✓	✓		✓	✓	✓	✓	
7	33%	✓		✓	✓		✓	✓	✓	✓	
9	44%	✓	✓	✓		✓	✓	✓	✓		
10	41%			✓	✓	✓	✓	✓			
11	59%			✓	✓	✓	✓	✓			✓
18	42%					✓	✓	✓			
3A-BI	29%	✓			✓		✓	✓			
5-BI	27%	✓			✓		✓	✓	✓		
7-BI	22%	✓			✓		✓	✓	✓	✓	
9-BI	27%	✓			✓		✓	✓	✓		

Note: Levels indicated are the average of the levels determined for the two products of each product class analyzed in detail for product classes 3, 5, 7, 9, 10, 11, and 18.

5.5 DATA COLLECTION

DOE collected data from a number of sources to support the engineering analysis. The key sources include the following.

- AHAM
- Component Vendors
- Reverse-Engineering of Products
- Manufacturer Interviews
- Energy Tests

The data collection process is described in greater detail in the following sections.

5.5.1 Manufacturer-Submitted Shipment and Cost Data from AHAM

DOE included draft data requests sheets to support the engineering and other DOE analyses in the framework document as Tables A1 through A10 of that document. Some of these tables were revised based on comments received during the framework comment period. For example, incremental cost data was provided for up to 35% efficiency level, and included a 10% efficiency level, which replaced the 15% efficiency level of the draft tables. Other requests DOE made to AHAM in addition to the requests made in the framework document include the following.

- Historical shipment data for Wine Coolers, broken out by key types: manual defrost/auto defrost.
- Historical shipment data for Built-in Refrigerators, disaggregated by product class.
- Recent shipment data for products incorporating a wine cooler compartment with either (1) a fresh food compartment, (2) a freezer compartment, or (3) both a fresh food and a freezer compartment.
- Recent shipment data for French Door refrigerators broken out between products with and without through-the-door (TTD) ice service.
- Recent shipment data for convertible-bottom-drawer refrigerators (products with three doors configured as a side-by-side arrangement on top with a single drawer below, and for which the upper compartments are freezer and fresh food compartments and the drawer is convertible).
- Percent of refrigerator-freezers shipped with ice makers for applicable product classes (3, 4, 5, 13, 14, 15), historical data if possible.
- Total shipments of ice makers (any breakdown by (a) installed at factory, (b) installed by dealer, (c) installed by homeowner?), historical data if possible.
- For as many refrigerator, refrigerator-freezer, and freezer models as practical, data on the impact of the new changes in compartment temperature and volume calculation method:
- Compartment Volumes: volumes calculated according to the current procedure and according to the new procedure, with indication of product class.
- Energy use (for refrigerators and refrigerator-freezers only): Annual energy use measurements for units tested for both temperatures (i.e. not Energy Label data—this should be energy test values calculated based on test data for the old temperatures and the new temperatures for sequential tests of the same unit. This will typically require three tests to make sure that both sets of temperatures are bracketed.
- It is anticipated that data for product classes 3 and 13 would be separated according to whether the product is a refrigerator-freezer or all-refrigerator.

AHAM supported the rulemaking by supplying much of this data. AHAM supplied DOE with aggregated shipment-weighted average data for many of the submittals in order to avoid divulging data submitted by individual manufacturers.

5.5.2 Component Vendor Data

DOE directly contacted major suppliers of key refrigerator and freezer components to obtain performance and cost data to support its design option analysis. The data received from vendors was compared with information received from manufacturers during the manufacturer interviews in order to develop input values for performance and cost parameters for the energy modeling and manufacturing cost modeling. This vendor solicitation effort consisted of phone interviews, email correspondence, and in-person interviews. Table 5.5.1 lists the vendors contacted.

DOE also obtained from the compressor vendors or their websites complete performance data for compressors used in many of the energy analyses, including analyses for baseline and improved-efficiency configurations.

Table 5.5.1 Component Vendors Contacted by DOE during Engineering Analysis

Component Type	Vendors
Compressors	Embraco Tecumseh Matsushita Danfoss LG Huayi ACC (ZEL) Jiangsu Baixue Electric Appliances Co.,Ltd
Fan Motors	Matsushita
VIPs	va-Q-tec Matsushita Porextherm ThermoCor NanoPore Insulation LLC Glacier Bay Thermal Visions
Foam Insulation	BASF Foam Supplies, Inc.
Aerogel Insulation	Aspen Aerogels
Heat Exchangers	Brazeway

5.5.3 Reverse Engineering

DOE purchased a number of representative refrigerators and freezers as part of the engineering analysis in order to examine design and fabrication details. This reverse-engineering included detailed measurement of dimensions, system and component-level power measurements, measurement of air flows for products with forced convection heat exchangers, and physical teardowns. The results of the reverse engineering process were used as input to the manufacturing cost modeling and the energy use modeling. This section describes the selection of products for reverse-engineering as well as some of the measurements made to support subsequent modeling. Section 5.6 provides a more thorough description of the physical teardown process used to support manufacturing cost modeling.

5.5.3.1 Selection of Products for Reverse Engineering

Table 5.5.3 below lists descriptions of the products selected for reverse engineering and indicates for which products DOE conducted energy tests (see Section 5.5.5 for more on energy testing). DOE performed reverse engineering on units rated at baseline and improved (i.e., ENERGY

STAR) energy consumption levels for the seven analyzed product classes. DOE chose at least one representative small-size and one large-size unit to cover the range of volumes within each product class. In order to best examine the design choices associated with efficiency improvements, DOE selected baseline

Table 5.5.2 Selected Units for Reverse-Engineering and Energy Testing

PC	Product Description	Energy % Less than Baseline	Energy Test	Physical Teardown	Energy Use Model
3	16 ft^3 Top-Mount R-F	0%	✓	✓	✓
	21 ft^3 Top-Mount R-F	0%	✓	✓	✓
	21 ft^3 E* Top-Mount R-F	20%	✓	✓	✓
4	22 ft^3 Side-Mount R-F†	0%	✓	✓	✓
5	18.5 ft^3 E* Bottom-Mount R-F	15%*	✓	✓	✓
	25 ft^3 E* Bottom-Mount R-F 1	20%	✓	✓	✓
	25 ft^3 E* Bottom-Mount R-F 2	20%	✓	✓	✓
5A	25 ft^3 French Door E* Bottom-Mount R-F	20%			✓
	26 ft^3 French Door E* Bottom-Mount R-F	20%			
7	26 ft^3 Side-Mount R-F	0%	✓	✓	✓
	26 ft^3 E* Side-Mount R-F	20%	✓	✓	✓
9	14 ft^3 Upright Freezer	0%		✓	✓
	20 ft^3 Upright Freezer	2%	✓	✓	✓
	20 ft^3 E* Upright Freezer 1	12%		✓	✓
	20 ft^3 E* Upright Freezer 2	10%			
10	15 ft^3 Chest Freezer	1%	✓	✓	✓
	15 ft^3 E* Chest Freezer	11%		✓	✓
	20 ft^3 Chest Freezer	0%		✓	✓
11	1.7 ft^3 Compact Refrigerator	7%	✓	✓	✓
	4 ft^3 Compact Refrigerator	2%		✓	✓
	4 ft^3 E* Compact Refrigerator	22%		✓	✓
18	3.4 ft^3 Compact Chest Freezer	0%		✓	✓
	7 ft^3 Compact Chest Freezer 1	1%		✓	✓
	7 ft^3 Compact Chest Freezer 2	1%		✓	✓

*Exact efficiency level is not known because product literature did not include indication of separate compartment volumes.
†This product was thought to be product class 7 when purchased.

efficiency/ENERGY STAR product pairs if possible, for which the two products were identical other than the differences necessary for the ENERGY STAR-rated product to achieve higher efficiency. Such product pairs included the 21 ft^3 Top-Mount refrigerator-freezers, the 26 ft^3 Side-Mount refrigerator-freezers, the 20 ft^3 upright freezers, and the 4 ft^3 compact refrigerators.

5.5.3.2 Collection of Energy Modeling Data

DOE examined each unit prior to teardown to record details to be used as input for the energy modeling. The key measurements are described in this section.

The rated refrigerated volumes for each product's compartments and its rated energy use were based on product literature or the ENERGY GUIDE. In the case of the 3.4 ft^3 chest freezer, the product literature did not provide an indication of energy use, and the product did not arrive with an ENERGY GUIDE. For this product, DOE assumed that energy use was exactly equal to maximum allowable energy use for the product class.

Power input for the product was measured for a period of 24 or more hours. This measurement was not intended to be an energy test, but provided useful information regarding the product controls, including off-cycle wattage, defrost heater on-time, and defrost interval (or indication of variable defrost). The power measurements for the products were made in the reverse engineering test laboratory, whose ambient temperature may have covered a broad range from 65 ˚F to 85 ˚F during the time that these measurements were carried out. Also, careful attention was not paid to the temperature set points for this measurement—the set points generally were left in the as-shipped positions.

Component-level power measurements were carried out for fans, defrost heaters, and manual defrost controls for the products which had these components. Power was also measured for some products' anti-sweat heaters.

Air flow measurements were made for all forced-convection heat exchangers. These measurements were made with a hot wire anemometer. The location of these measurements varied depending on the heat exchanger type and configuration. The determination of air flows based on these measurements is not very reliable, so this measurement was used as an indication of air flow trends more than exact indication of air flow for the various products.

Details of the cabinet size and insulation thickness were based on direct physical measurements. Most of these measurements were made prior to the teardown, but measurements of some parameters, such as outer shell thickness, inner liner thickness, and insulation thickness, were made during the teardown process. Use of insulation other than polyurethane foam was noted as part of the teardown process. Frame area details including gasket details were observed, and recorded with pictures as part of the teardown process.

Heat exchanger details were recorded, including type, configuration, numbers of tubes and fins, dimensions, etc. For cold wall and hot wall heat exchangers this data was recorded during the product teardown process. The details of anti-sweat heaters were also determined during the teardown process, including the layout for refrigerant anti-sweat loops. The details of suction line heat exchangers were similarly determined during teardown.

Component manufacturer and model data were recorded for key components such as compressors, fans, and controls.

Design data for the analyzed built-in products were obtained directly from a built-in product manufacturer.

The energy modeling data for the teardown products are presented in detail in appendix 5-A.

5.5.4 Manufacturer Interviews

DOE's contractor discussed engineering issues with manufacturers during the preliminary analysis interviews. The engineering questions were consolidated into an engineering questionnaire, which guided the interview process for all of these discussions. The engineering questionnaire is shown in appendix 5-A. Key technical topics addressed during these discussions include the following:

- Typical characteristics of components and typical design details (i.e. such as insulation thicknesses) used for key product classes.
- Typical design differences between baseline and ENERGY STAR products.
- Differences in design pathways and incremental costs across different product classes
- Viability of technology options, and their typical costs.

All of these interviews were conducted under non-disclosure agreements with the manufacturers. Hence, none of the individual responses can be reported. However, values for many of the parameters and costs used in the engineering analysis were based on aggregated input from these discussions.

After the preliminary analysis comment period, DOE's contractor again visited manufacturers and discussed engineering issues. Some of this discussion responded directly to comments made during the preliminary analysis public meeting and in written submittals from stakeholders. Some of the technical data discussed during the preliminary analysis discussions was revisited. Much of the discussion also addressed differences between DOE's preliminary analysis results and the manufacturers' information regarding the design changes required to achieve higher efficiency levels, including the 30% efficiency levels achieved by some standard-size refrigerator-freezer products. These discussions were also conducted under non-disclosure agreements and hence the findings cannot be reported in detail. However, DOE adjusted many of its engineering analysis model inputs for better consistency with the information obtained during these interviews.

5.5.5 Energy testing

DOE conducted energy testing to verify energy use of many of the products obtained for reverse engineering, to provide refrigeration system data to support energy use modeling, and to evaluate the difference in energy use between current energy test compartment temperatures and the new temperatures associated with the expected revised test procedure.

Twelve of the 24 units were tested, as indicated in Table 5.5.3, including all of the refrigerator-freezer models and one each of the upright freezers, chest freezers, and compact refrigerators. No compact chest freezers were tested.

Energy testing was carried out by an independent test lab according to the DOE Energy Test Procedure as described in 10 CFR Part 430 Subpart B, Appendix A1 or B1, with reference to AHAM Standard HRF-1-1979 as applicable. In addition to the standard energy test results, DOE requested specific temperature measurements to be taken in various locations during the test to better understand the refrigeration system operating characteristics. Specifically, low-mass thermocouples were mounted in good thermal contact with the surface of refrigerant tubing, insulated externally from local ambient air. Table 5.5.3 lists the additional measurements.

Table 5.5.3 Additional Thermocouple Locations for Preliminary Analysis Energy Tests

Thermocouple Location	Refrigerator-Freezers	Upright Freezer	Chest Freezer	Compact Refrigerator
Discharge 4" from shell	✓	✓	✓	✓
Condenser Inlet	✓			
Condenser Mid	✓			
Condenser Outlet	✓	✓	✓	✓
Evaporator Inlet	✓	✓	✓	
Evaporator Outlet	✓	✓	✓	✓
Suction 4" from shell	✓	✓	✓	✓
Condenser Air Inlet	✓			
Pan Heater In		✓		
Pan Heater Out		✓		
Hot Wall Condenser Surface		✓	✓	✓
Compressor Compartment Air		✓	✓	✓
Cold Wall Evaporator Surface			✓	✓

Note: Two units of the 1.7 ft^3 compact refrigerator were tested because the first of these was not able to hold proper internal temperatures.

During the NOPR phase of the work, DOE also arranged for testing of some products having efficiency levels at or near the max available. These tests, conducted only according to the current test procedure and not incorporating the additional measurements described in Table 5.5.5, confirmed that most of these products achieved their rated efficiency levels. The results of the tests are summarized in Table 5.5.6 below.

Table 5.5.4 High-Efficiency Refrigeration Product Test Results

Product Class	Total Volume (cu. ft.)	Adjusted Volume [1] (cu. ft.)	Rated Energy (kWh/year)	Rated Percent Below Standard	Measured Energy Use (kWh/year)
3	18.89	22.04	343	30%	336
5	18.51	22.03	392	30%	371
7	22.11	26.66	473	30%	431
3A	16.14	16.14	204	53%	309
[1] As measured during test.					

5.6 MANUFACTURING COST MODELING

5.6.1 Generation of Bills of Materials

The end result of each teardown is a structured bill of materials (BOM). DOE developed structured BOMs for each of the physical teardowns. Structured BOMs describe each product part and its relationship to the other parts in the estimated order in which manufacturers assembled them. The BOMs describe each fabrication and assembly operation in detail, including the type of equipment needed (e.g., presses, drills), the process cycle times, and the labor associated with each manufacturing step. The result is a thorough and explicit model of the production process, which includes space, conveyor, and equipment requirements by planned production level.

The BOMs incorporate all materials, components, and fasteners classified as either raw materials or purchased parts and assemblies. The classifications into raw materials or purchased parts were based on DOE's previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs). DOE also visited manufacturing plants to reinforce its understanding of the industry's current manufacturing practices for each of the three product categories.

For purchased parts, the purchase price is estimated based on volume-variable price quotations and detailed discussions with manufacturers and component suppliers. For fabricated parts, the prices of "raw" metals (e.g., tube, sheet metal) are estimated on the basis of 5-year averages (see Section 5.6.4.4) while all other materials and purchased parts reflect current market costs. The cost of transforming the intermediate materials into finished parts is estimated based on current industry pricing. DOE shared major estimates with manufacturers during the engineering manufacturer interviews to gain feedback on the analysis, its methodology, and preliminary results.

5.6.2 Cost Structure of the Spreadsheet Models

The manufacturing cost assessment methodology used is a detailed, component-focused technique for calculating the manufacturing cost of a product (direct materials, direct labor, and the overhead costs associated with production). The first step in the manufacturing cost assessment was the creation of a complete and structured BOM from the disassembly of the units selected for teardown. The units were dismantled, and each part was characterized according to weight, manufacturing processes used, dimensions, material, and quantity. The BOM incorporates all materials, components, and fasters with estimates of raw material costs and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication were based on industry experience, information in trade publications, and discussions with manufacturers. Interview and plant visits were conducted with manufacturers to add industry experience on the methodology and pricing.

The last step was to convert this information into dollar values. To perform this task, DOE collected information on labor rates, tooling costs, raw material prices, and other factors. DOE assumed values for these parameters using internal expertise and confidential information available to DOE contractors. Although most of the assumptions are manufacturer specific and cannot be revealed, Section 5.6.4.3 provides a discussion of the values used for each assumption.

In summary, DOE assigned costs of labor, materials, and overhead to each part whether purchased or produced in-house. DOE then aggregated single-part costs into major assemblies (e.g., door assembly, heat exchanger assembly, shelving, packaging, controls, bottom components assembly, wiring harnesses, inner/outer wrapper assembly, etc.) and summarized these costs in a worksheet. During engineering interviews with manufacturers, DOE showed key estimates from the cost model and asked for feedback. DOE considered any information manufacturers gave that was relevant to the cost model and incorporated it into the analysis, if appropriate.

5.6.3 Cost Model and Definitions

Once DOE disassembled selected units, gathered information from manufacturer catalogs on additional products, and identified technologies, DOE created an appropriate manufacturing cost model that could translate physical information into manufacturer production costs (MPCs). The cost model is based on production activities and divides factory costs into the following categories:

- Materials: Purchased parts (i.e. compressor, fan motors, control boards, door handles, shelf frames, etc.), raw materials (i.e., cold rolled steel, copper tube, etc.), and indirect materials that are used for processing and fabrication.

- Labor: Fabrication, assembly, indirect, and supervisor labor. Fabrication and assembly labor cost are burdened with benefits and supervisory costs.
- Overhead: Equipment, tooling, and building depreciation, as well as utilities, equipment and tooling maintenance, insurance, and property taxes.

5.6.3.1 Cost Definitions

Because there are many different accounting systems and methods to monitor costs, DOE defined the above terms as follows:

- Direct material: Purchased parts (out-sourced) plus manufactured parts (made in-house from raw materials).
- Indirect material: Material used during manufacturing (e.g., welding rods, adhesives).
- Fabrication labor: Labor associated with in-house piece manufacturing.
- Assembly labor: Labor associated with final assembly.
- Indirect labor: Labor costs that scaled with fabrication and assembly labor. This included the cost of technicians, manufacturing engineering support, stocking, etc. that were assigned on a span basis.
- Equipment and plant depreciation: Money allocated to pay for initial equipment installation and replacement as the production equipment wears out.
- Tooling depreciation: Cost for initial tooling (including nonrecurring engineering and debugging of the tools) and tooling replacement as it wears out.
- Building depreciation: Money allocated to pay for the building space and the conveyors that feed and/or make up the assembly line.
- Utilities: Electricity, gas, telephones, etc.
- Maintenance: Annual money spent on maintaining tooling and equipment.
- Insurance: Appropriated as a function of unit cost.
- Property Tax: Appropriated as a function as unit cost.

5.6.4 Cost Model Assumptions Overview

As discussed in the previous section, assumptions about manufacturer practices and cost structure played an important role in estimating the final product cost. Some assumptions were different for specific manufacturers, depending on their market position, manufacturing practices, and size.

In converting physical information about the product into cost information, DOE reconstructed manufacturing processes for each component using internal expertise and knowledge of the methods used by the industry. DOE used assumptions regarding the manufacturing process parameters (e.g., equipment use, labor rates, tooling depreciation, and cost of purchased raw materials) to determine the value of each component. DOE then summed the values of the components into assembly costs and, finally, the total product cost. The product cost included the material, labor, and overhead costs associated with the manufacturing facility. The material costs included both direct and indirect materials. The labor costs included fabrication, assembly, indirect, direct, and supervisor labor rates, including the associated overhead.

The labor costs included assembly, fabrication, supervisor, and indirect labor. Overhead costs included equipment depreciation, tooling depreciation, building depreciation, utilities, equipment, tooling maintenance, insurance, property, and taxes.

DOE used the information gathered from manufacturer interviews to make updates to the cost model. These changes involved updating component and material pricing.

The next sections discuss specific assumptions about outsourcing, factory parameters, production volumes, and material prices. When the assumptions are manufacturer-specific, they are presented as industry averages to prevent disclosure of confidential information.

5.6.4.1 Fabrication Estimates

DOE characterized parts based on whether manufacturers purchased them from outside suppliers or fabricated them in-house. For purchased parts, DOE estimated the purchase price. For fabricated parts, DOE estimated the price of raw materials (e.g., tube, sheet metal) and the cost of transforming them into finished parts. Whenever possible, DOE obtained price quotes directly from the manufacturers' suppliers.

DOE based the manufacturing operations assumptions on internal expertise, interviews with manufacturers, and manufacturing facilities site visits. The major manufacturer processes identified and developed for the spreadsheet model are listed in Table 5.6.1. Fabrication process cycle times were estimated and entered into the BOM.

Table 5.6.1 Cost Model In-House Manufacturing Operation Assumptions

Fabrication	Finishing	Assembly/Joining	Quality Control
Fixturing Stamping/Pressing Turret Punch Tube Forming Brake Forming Cutting & Shearing Insulating & Insulation Injection Tube/Wire Bending Brazing Vacuum Forming Blow Molding	Washing Painting Powder Coating De-burring Polishing Refrigerant Charging	Adhesive Bonding Spot Welding Seam Welding Packaging	Inspecting & Testing

5.6.4.2 Production Volumes Assumptions

A manufacturer's production volumes vary depending on several factors, including market share, the type of product produced (i.e., standard- size refrigerator-freezer, compact refrigerator-freezer, etc.), and if the manufacturer produces other similar products. DOE based production volume assumptions for these residential refrigeration products on shipment data, industry knowledge, and engineering manufacturer interviews. The manufacturing plant annual production capacities used for the analyses differ by product class as follows.

- Product Classes 3 and 6: 1.5 million
- Product Classes 5 and 5A: 0.5 million
- Product Classes 4 and 7: 1 million
- Product Class 9: 150,000
- Product Class 10: 100,000
- Product Class 11: 0.5 million
- Product Class 18: 100,000

5.6.4.3 Factory Parameters Assumptions

DOE used information gathered from publicly available literature, manufacturer interviews, and analysis of common industry practices to formulate factory parameters for each type of manufacturer. DOE first made assumptions about a set of preliminary factory parameters before the manufacturer interviews. DOE then revised the assumptions using comments and information gathered during the interviews. Table 5.6.3 lists DOE's assumptions for refrigerator manufacturers.

Table 5.6.2 Refrigerator & Freezer Factory Parameter Assumptions

Parameter	Assumption
Plant Capacity (units/yr)	see section 5.6.4.2
Actual Annual Production Volume (units/yr)	5/6 of plant capacity
Fabrication Labor Wages ($/hr)	16.00
Fringe Benefits Ratio	50%

5.6.4.4 Material Cost Assumptions

DOE determined the cost of raw materials using publicly available information such as the American Metals Market[b], interviews with manufacturers, and direct discussions with material suppliers. Common metals used in the fabrication of residential refrigerator products include plain cold rolled steel (CRS), copper tubing, and aluminum. There have been large fluctuations in metal prices over the last few years. To account for these fluctuations, DOE used a 5-year

[b] American Metals Market. Last accessed November 2008. <http://www.amm.com>.

average of metal prices from the Bureau of Labor Statistics Producer Price Indices (PPIs) spanning 2003 to 2008 with an adjustment to 2008$.[c] DOE used the PPIs for copper rolling, drawing, and extruding and steel mill products, and made the adjustments to 2008$ using the gross domestic product implicit price deflator.[d] For resins used in the fabrication of these refrigeration products, DOE used current resin prices gathered from industry research, publications such as Plastics News,[e] and interviews with manufacturers.

5.6.5 Manufacturing Production Cost

Once the cost estimate for each teardown unit was finalized, a detailed summary was prepared for relevant components, subassemblies, and processes. The BOM thus details all aspects of product costs. DOE totaled the cost of materials, labor, and direct overhead used to manufacture a product in order to calculate the manufacturing production cost.[f] Figure 5.6.1 shows the

[c] U.S. Department of Labor, Bureau of Labor Statistics, Producer Price Indices. Last accessed November 2008. <http://www.bls.gov/ppi>.

[d] U.S. Department of Commerce, Bureau Economic Analysis, Gross Domestic Product Implicit Price Deflator. Last accessed November 2008. <https://bea.gov/bea/dn/nipaweb/TableView.asp#Mid>.

[e] Plastic News, Resin Pricing. Last accessed March 21, 2008. <http://www.plasticsnews.com/subscriber/headlines.phtml>.

[f] When viewed from the companywide perspective, the sum of all material, labor, and overhead costs equals the company's sales cost, also referred to as the cost of goods sold (COGS).

general breakdown of costs associated with manufacturing a product.

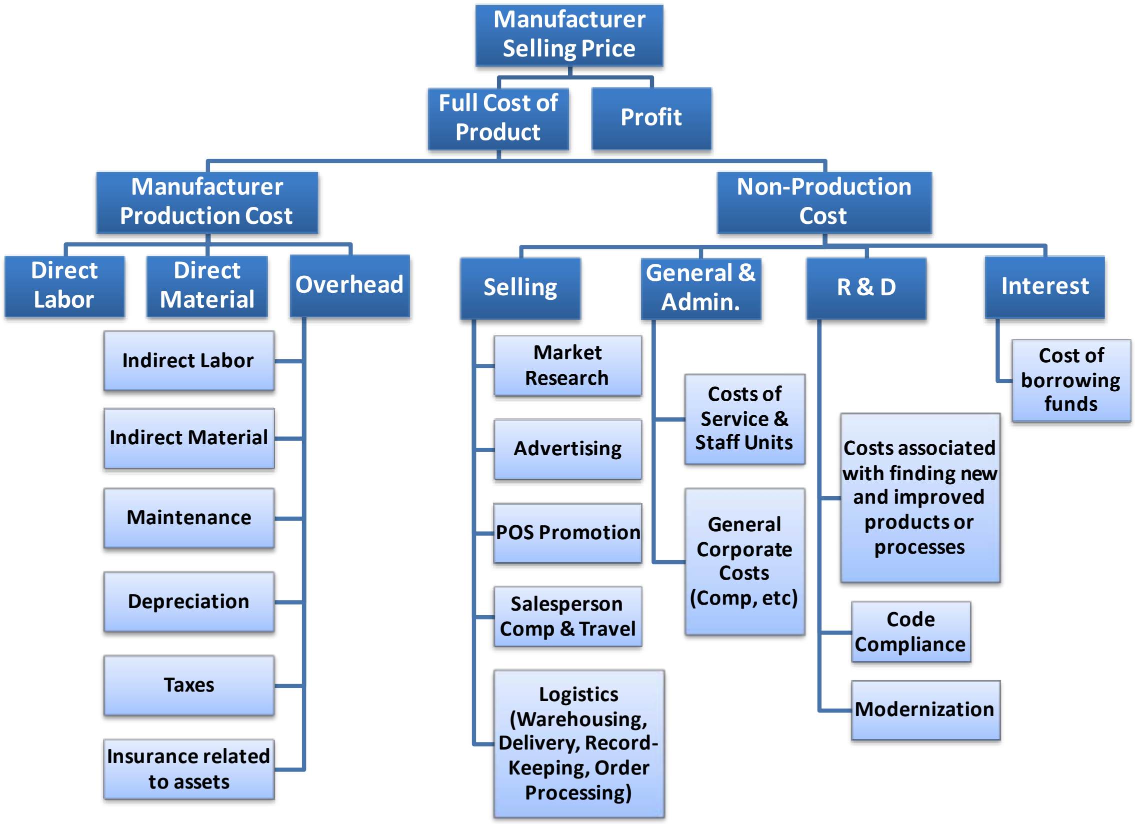

Figure 5.6.1 Full Production Costs

The full cost of product is broken down into two main costs, the full production cost or MPC, and the non-production cost. The non-production cost is equal to the manufacturer markup minus profits.

Technologies used in the units subject to teardown are noted in the summary sheet of each cost model and are cost-estimated individually. Thus, various implementations of technologies can be accommodated, ranging from assemblies that are entirely purchased to units that are entirely from raw materials. Hybrid assemblies, consisting of purchased parts and parts made on site are thus also accommodated.

5.6.6 Incremental Cost Estimates

Incremental costs were determined for design options applied to the baseline-efficiency refrigerator models. The approach for estimating the incremental costs varied depending on the design option. Details in this calculation which are specific to individual design options are discussed in Section 5.8, which discusses design options. Aspects of the incremental cost calculation which were generally applied to multiple design options are discussed in this section.

Many of the design options involve replacement of a current component with a higher-efficiency component. For these design options, the increased price paid by the OEM for the new component represents the manufacturing cost increase—other elements of product cost such as overhead and capital expenditures would be insignificantly affected by these design changes. The appropriate price increases are discussed in Section 5.8 by design option.

For some design changes, calculating the cost impact of the design change required direct use of the manufacturing cost model to determine changes to a number of parts. The baseline manufacturing cost was subtracted from the manufacturing cost of the modified design to determine the incremental cost of the design option. This approach was used in particular for insulation thickness increases and heat exchanger size increases for cold wall and hot wall heat exchangers.

5.6.6.1 Overhead and Depreciation Costs

Some design options involve costs in addition to the price increase associated with a new component. For such options, there may be overhead and capital expenses which must be added to the direct costs associated with the design option. Estimates of typical additional costs associated with overhead and depreciation for manufacture of refrigeration products were made for the reverse-engineering models, using estimates of these costs provided by the manufacturing cost model. These calculations were carried out based on typical production plant capacities, with actual production volumes estimated to be 5/6 of plant capacities. The annual plant capacities for the product classes used in these calculations are as indicated in section 5.6.4.2.

The additional costs are presented as percentage of direct material and labor costs in Table 5.6.5 below. The averages for the listed product class categories were used to increase direct material and labor costs for some design options for which this adjustment was necessary. DOE initially conducted this calculation during the preliminary analysis. As a result of changes to the manufacturing cost model during the NOPR phase, some of the numbers changed slightly. However, the overall average percent cost ratios did not change significantly. DOE continued use of the values calculated for these parameters during the preliminary analysis.

Table 5.6.3 Preliminary Analysis Overhead and Depreciation Cost Ratios

Product Class Group	Product Class	Product	Percent Cost Ratio	Average Percent Cost Ratio for Product Class Group
Standard-Size Refrigerator-Freezers	3	16 ft^3 Top-Mount R-F	31.2%	23.4%
		21 ft^3 Top-Mount R-F	23.2%	
		21 ft^3 E* Top-Mount R-F	23.2%	
	4	22 ft^3 Side-Mount R-F†	22.0%	
	5	19 ft^3 E* Bottom-Mount R-F	23.5%	
		25 ft^3 E* Bottom-Mount R-F 1	20.9%	

		25 ft^3 E* Bottom-Mount R-F 2	23.3%	
	7	26 ft^3 Side-Mount R-F	20.7%	
		26 ft^3 E* Side-Mount R-F	22.5%	
Standard-Size Freezers	9	14 ft^3 Upright Freezer	28.6%	28.5%
		20 ft^3 Upright Freezer	26.2%	
		20 ft^3 E* Upright Freezer 1	25.0%	
	10	15 ft^3 Chest Freezer	35.5%	
		15 ft^3 E* Chest Freezer	33.2%	
		20 ft^3 Chest Freezer	22.5%	
Compact Refrigerators, Refrigerator-Freezers, and Freezers	11	1.7 ft^3 Compact Refrigerator	40.2%	39.2%
		4 ft^3 Compact Refrigerator	35.6%	
		4 ft^3 E* Compact Refrigerator	36.5%	
	18	3.4 ft^3 Compact Chest Freezer	42.3%	
		7 ft^3 Compact Chest Freezer 1	36.6%	
		7 ft^3 Compact Chest Freezer 2	44.2%	

The manufacturing cost model estimates are consistent with overall industry trends. Census data shows that the average value of this cost adder for NAICS code 335222 (Household Refrigerator and Home Freezer Manufacturing) is 27.7%.

5.6.6.2 Depreciation Costs for Insulation Thickness Increases

DOE considered that increases in cabinet wall and door thicknesses would require redesign of the entire refrigerator or freezer platform and would likely lead to the building of a new production plant. This conservative approach to the analysis was based on input from manufacturers. For such design changes, the difference in Greenfield costs[g] of two designs would not capture the depreciation costs which would be incurred by the manufacturer and which would add to the product cost after such a platform conversion. DOE conservatively used the Greenfield depreciation costs per product determined by the manufacturing cost model as an additional cost for wall thickness increases. The calculation of manufacturing costs for all of the teardown products based on typical plant capacities described above was used as the basis for the determination of Greenfield depreciation costs per product. The results of the calculations are summarized in

[g] Greenfield costs are defined as the costs associated with building a new manufacturing facility, to be distinguished from the costs required to upgrade or modify a facility.

Table 5.6.7 below. Average depreciation costs were applied in the engineering analyses for all of the analyzed products of a product class. The depreciation costs also were separately allocated to the cabinet or door, as indicated in the table.

Table 5.6.4 Greenfield Depreciation Costs per Product

Product Class	Product	Depreciation Cost			
		Total	Average	Average Cabinet	Average Door(s)
9	14 ft^3 Upright Freezer	$29.48	$30	$23	$7
	20 ft^3 Upright Freezer	$31.40			
	20 ft^3 E* Upright Freezer 1	$30.44			
10	15 ft^3 Chest Freezer	$32.70	$33	$26	$7
	15 ft^3 E* Chest Freezer	$34.12			
	20 ft^3 Chest Freezer	$30.73			
18	3.4 ft^3 Compact Chest Freezer	$35.99	$32	$26	$6
	7 ft^3 Compact Chest Freezer 1	$30.99			
	7 ft^3 Compact Chest Freezer 2	$29.68			
11	1.7 ft^3 Compact Refrigerator	$11.95	$13	$10	$3
	4 ft^3 Compact Refrigerator	$13.27			
	4 ft^3 E* Compact Refrigerator	$13.27			

5.6.6.3 G&A and Profit

DOE estimated the further addition to the manufacturer selling price associated with G&A and profit for the appliance industry as 26% of manufacturer production cost. This adder was applied to all of the MPC estimates in order to determine manufacturer selling price (MSP) numbers. This markup is described in more detail in chapter 6.

5.7 ENERGY MODELING

DOE carried out detailed energy modeling of representative baseline and ENERGY STAR refrigeration products, and on design variations of these products that included one or more of the design options considered for the engineering analysis. This energy modeling work served as the basis of estimates of energy savings potential associated with the design options. The products selected for reverse engineering provided the basis for the energy modeling. Energy model input was determined for these products from the data collected during the reverse engineering work, described in Section 5.5.3. Additional data, used both as input, and for calibration of individual product energy models, was provided by energy testing as described in Section 5.5.5. Using the energy modeling results and manufacturing cost modeling results for these designs allowed DOE to develop incremental cost estimates for multiple efficiency levels based on each of the baseline products analyzed.

DOE carried out energy modeling during this rulemaking using an improved version of the EPA Refrigerator Analysis (ERA) program, earlier versions of which have been used in previous refrigerator rulemakings. Section 5.7.1 describes the ERA model development briefly. A more detailed description of the program and its recent development is presented in appendix 5-B.

5.7.1 Energy Model development

ERA is a steady-state energy model that calculates heat leakage into a cabinet and determines the energy needed by the refrigeration system to maintain the interior temperatures as specified by the user. Total energy used includes the energy from the compressor, fan motors, defrost heater, electronic control, and anti-sweat heaters, if applicable. See appendix 5-B for a detailed explanation of the ERA model.

The DOS version of ERA was developed initially under EPA-sponsorship during the late 1980s. This was undertaken by the EPA as part of its involvement in the establishment of energy standards for refrigerators, refrigerator-freezers, and freezers under the National Appliance Energy Conservation Act of 1987 (NAECA). A developmental version of the program was used by the DOE as a partial basis for the energy standard established in 1989 (effective in 1993). The work also involved extensive testing of the model against manufacturer-supplied refrigeration appliance design and test data. Based on these comparisons and manufacturer review comments through its industry organization (AHAM), development of the model continued until its release in 1997.[1]

ERA combined an analysis of the refrigeration load requirements of the cabinet with a simulation of the capacity and efficiency of the refrigeration cycle. The cabinet loads module was a modest enhancement of a program developed for the DOE during the late 1970s,[2] including the consideration of door-opening effects on the load and an ability to deal with complex insulation systems. The cycle module was a derivative of the NIST CYCLE 7 program,[3] which used the CSD equation of state to represent the thermodynamic properties of pure and mixed refrigerants,[4] adapting routines for calculating refrigerant properties from REFPROP3.[5] The program, and its User's Manual, were first released to the public in 1993, and for a few years were downloadable from the EPA website.[6] Subsequent to the 1993 final rule, DOE published updated standards for refrigerators, refrigerator-freezers and freezers in 1997, becoming effective in 2001. Analysis carried out in support of the 1997 final rule involved use of the final released EPA version of ERA.[1]

The DOS version of ERA was subsequently modified as described in appendix 5-B, but these revisions were not made available to the public. During the course of this rulemaking, further development of the model was carried out in order to allow use of the model for calculation of energy use of modern residential refrigeration products and to allow a modern version of the program to be made available to stakeholders to validate DOE analysis. Key modifications made include the following.

- Enhancement of the user-interface to a Windows environment
- Employment of the most current refrigerant property routines
- Incorporation of a broad range of evaporator and condenser algorithms that correspond to the technologies now found in modern refrigerators
- Improved compressor modeling, with built-in procedures for validating supplied compressor maps
- Improvements where desirable in the cabinet loads analysis and cycle performance algorithms.
- Preparation of internal documentation of the program through extensive context-sensitive Help files.

DOE made many of the preliminary analysis phase energy model calculations described in this chapter using a DOS version of the ERA program prior to the completion of the Windows version. During the NOPR phase of this rulemaking, DOE converted all of the original energy model calculations used for development of cost-efficiency curves to the Windows version of ERA.

The development history and capabilities of the program are described in more detail in appendix 5-B.

5.7.2 Supplemental Spreadsheet Models

Spreadsheet analysis tools were developed and used as part of some of the energy model development and calculations in order to (1) calculate airside heat transfer performance of spine fin evaporators, (2) determine appropriate composite insulated wall thermal resistivity when calculating cabinet thermal performance using vacuum panel insulation, (3) adjust of ERA analysis results of vacuum panel design options, and (4) calculate the condenser fan energy consumption for condensers serving two refrigeration circuits..

Spine fin evaporator airside heat transfer performance was calculated using a spreadsheet. Equations for the model were based on the work of Holtzapple and Carranza.[7,8] The ERA heat exchanger models (the ERAEVAP program) provided heat transfer coefficients for refrigerant-side heat transfer in the two-phase and superheated regimes. Using these values, the spreadsheet model provided the overall heat transfer coefficients for the two regimes of the evaporator and the effective heat transfer area, which were the inputs for DOS version of ERA.

When modeling use of vacuum insulation panels (VIPs), the cabinet walls or door have two regions of differing thermal resistivity. Average values of resistivity were calculated and entered into ERA to model these composite insulation systems. In addition, as discussed in section 5.8.3, energy benefits reported by manufacturers using vacuum panels have generally been less than calculated in this fashion by ERA. Adjustments were made to the ERA results to compensate for this difference. This is discussed in greater detail in section 5.8.3.

For some product classes (e.g. 3A-BI, 5-BI, 7-BI), the representative products selected for energy modeling featured dual-loop refrigeration systems, i.e. two separate refrigeration circuits sharing a single dual-circuit condenser with a single fan. ERA calculates energy use for dual-loop systems, but assumes that these systems have no common components. In order to model the dual-circuit condensers of the selected products, the condenser model for each refrigeration system was based on only that portion of the condenser tubing and fins allocated to it. Because of overlap of system operation, proper calculation of condenser fan run time was not possible using ERA. Instead, the condenser fan run time and power input was calculated separately, taking into consideration the run time of each of the two systems. This calculation assumed that there was no correlation between one system's duty cycle and whether the other system was running.
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5.7.3 Development and Calibration of ERA Current Energy Test Models

ERA modeling during the engineering analysis involved the following three phases.

- Modeling of existing reverse-engineered products based on the current energy test procedure.
- Adjustment of models to represent baseline products tested under the expected revised test procedure. DOE made some adjustments in this step in product designs to adjust from the reverse-engineered product configuration to the desired configurations to represent the analyzed product classes (e.g. adjustment of efficiency level, conversion to French doors, addition of a through-the-door ice service feature).
- Iterative modeling with multiple series of adjustments to calculate the energy savings which can be achieved with different combinations of design options.

This section focuses on the first phase of the ERA modeling work, namely establishing models for the teardown products based on the current energy test procedure. These models were later adjusted to represent baseline energy use under the new test procedures, and these models were used subsequently to calculate energy savings potential. The baseline analysis results were compared with available data to assure that the models provide accurate representation of product energy use. This section discusses the creation and calibration of the ERA energy models, the metrics which were compared, and the adjustments which were made in some cases in order to improve calibration.

Input data for energy modeling was collected during the reverse engineering phase of the project. Collection of this data is discussed in Section 5.5.3.2 above. For products which DOE arranged to have energy tested, additional information was available for certain model parameters, such as defrost heater on times, compressor run time between defrosts, evaporator exit superheat, etc. Performance data was obtained from compressor vendors for the compressors used in the teardown products, as well as for compressors which could be considered as alternative options to reduce energy use.

Initial energy models were created, and the models were subsequently adjusted to provide a best match with available data for product performance. Key sources of information used for calibration of the energy models were the product EnergyGuide labels and data from energy tests carried out for a number of the reverse-engineered units (Section 5.5.5). Energy test parameters besides energy use which were examined include compressor running power input, duty cycle, evaporating temperature, and condensing temperature. Since not all ERA input parameters can be determined definitively based on available information, some of the inputs were adjusted within reasonable ranges in order to provide good matches between model results and other performance indicators. It is recognized that energy levels reported in the EnergyGuide can be conservative to provide margin for variation in the production process. Hence, it is expected that ERA results would more likely be lower than the EnergyGuide value than higher.

In some cases the directly modeled energy use was initially significantly lower than actual product energy use. In some of these cases in which the system operating parameters could be well calibrated based on test data, DOE attributed the high actual duty cycle and energy use to high actual cabinet thermal load. A number of factors could possibly explain such results, including greater impact than expected of thermal short circuits associated with wiring harnesses and other design details, excess gasket region load, and consistently lower insulation thermal performance than expected. A consistently underperforming compressor model could also explain such a discrepancy, but DOE concluded that this explanation is less likely than factors which would increase cabinet thermal load. Hence, for these cases, additional cabinet load was added to result in an energy use and compressor duty cycle which provided reasonable agreement with the available data. The side-mount refrigerator-freezers (product classes 4 and 7) were adjusted using this approach, for example.

In some cases, DOE concluded that ERA was not modeling particular heat exchangers properly. DOE adjusted the calculated effective surface area of the heat exchanger upwards or downwards to represent heat transfer performance different than modeled to achieve more reasonable match of evaporating or condensing temperatures, as measured during energy test work. DOE made similar adjustments in some cases to evaporator pressure drop to adjust for an apparent discrepancy between measured evaporator surface temperature and compressor power input.

The ERA analysis results after adjustments of the model input for the seven key product classes analyzed are compared with the EnergyGuide data and Energy test results in Figure 5.7.1 for refrigerator-freezers, in Figure 5.7.3 for standard-size freezers, and in Figure 5.7.5 for compact refrigerators and freezers. Energy testing was performed on a limited group of freezers and compact products: one upright freezer, one chest freezer, and one compact refrigerator. For these figures, the energy use of the freezers has been adjusted consistent with the energy test by applying the 0.85 correction factor for upright freezers and the 0.7 correction factor for chest freezers. The energy models are within a few percent of the EnergyGuide labeled energy.

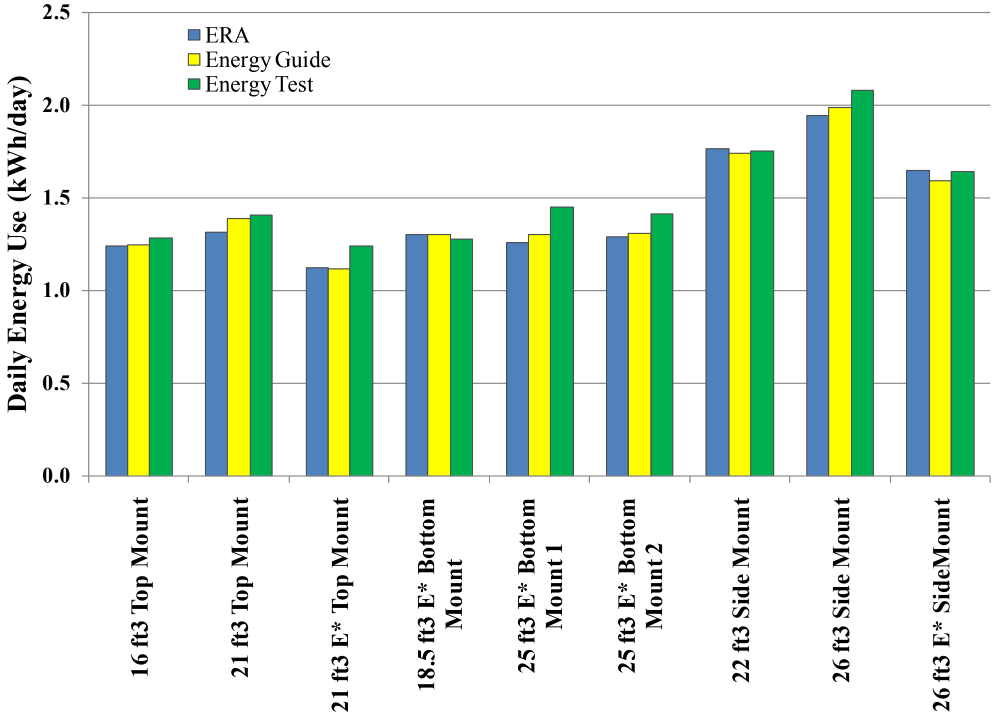

Figure 5.7.1 ERA Analysis for Refrigerator-Freezers Compared with EnergyGuide Labels and Energy Test Measurements

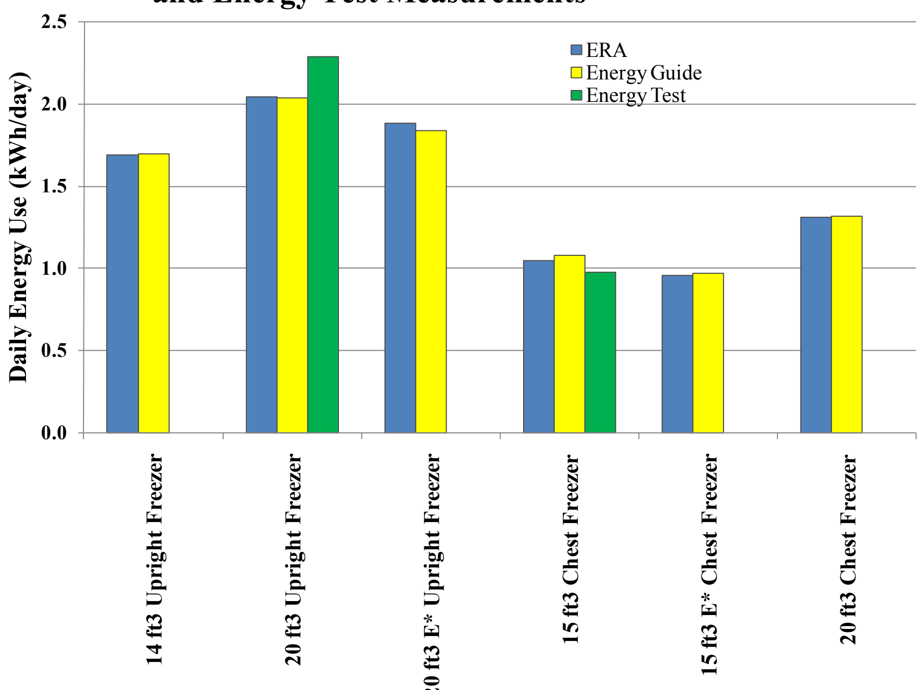

Figure 5.7.2 ERA Analysis for Freezers Compared with EnergyGuide Labels and Energy Test Measurements

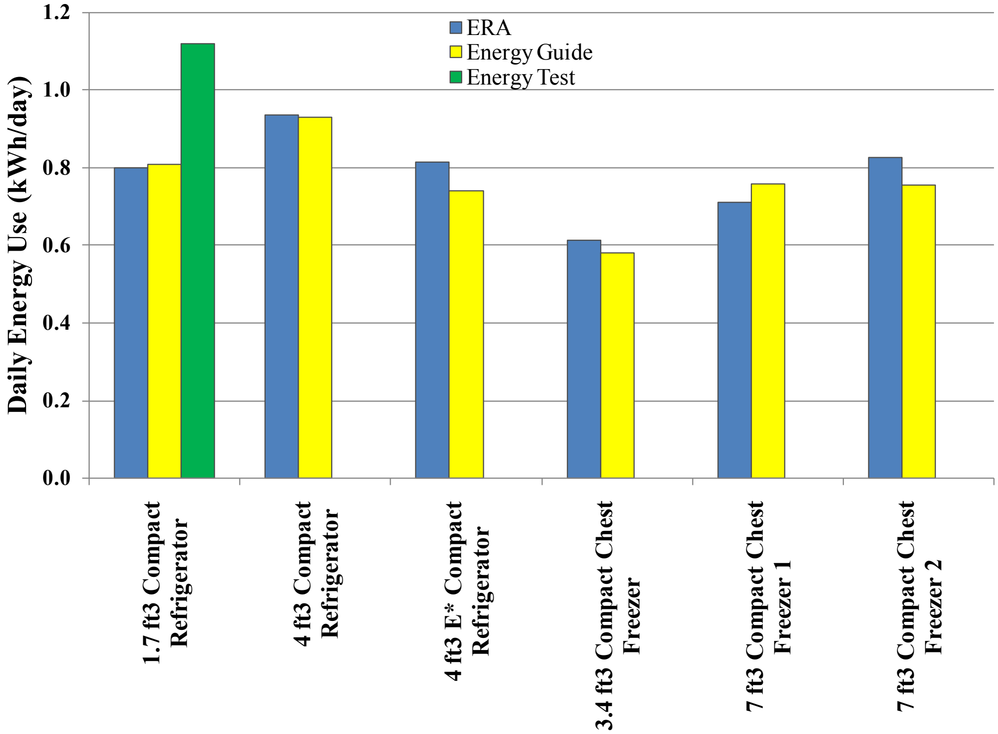

Figure 5.7.3 ERA Analysis for Compact Refrigerators and Freezers Compared with EnergyGuide Labels and Energy Test Measurements

5.7.4 Adjustments to Energy Models to Represent Baseline Products Tested Under the New Test Procedure

This section discusses adjustment of the calibrated baseline ERA models to address two issues: (1) modification of some of the modeled product designs so they represent baseline-efficiency products of the desired product classes, and (2) adjustment for the new test procedure changes.

Modifications were made to some of the modeled product designs so that they represent baseline products of the product classes of interest with appropriate typical characteristics. The changes made are discussed in the following paragraphs.

Some of the teardown products purchased were not available as baseline-efficiency products, i.e. products with energy use that is minimally compliant with the current energy standards. This was true primarily for product class 5, refrigerator-freezers with automatic defrost and bottom-mounted freezers without TTD ice service. As indicated above in Table 5.5.3, one of these products had energy use roughly 15% below the maximum allowable energy use (the former ENERGY STAR level), and the others had energy use at 20% below (the current ENERGY STAR level). In order to allow the engineering analysis to examine the cost associated with the efficiency improvement from the 0% to the 15% and 20% efficiency levels, DOE created baseline models for products which would be minimally compliant with the standards. DOE did this by carrying out the analysis in reverse, removing the less cost-effective design options first, in order to achieve calculated energy levels consistent with the baseline energy standard.

For product class 5, DOE established baseline models representing products with French Doors. Comments made at the framework meeting and submitted to DOE as part of the framework comment period addressed this issue, as discussed in chapter 2 of the preliminary TSD. Most of the teardown products were purchased prior to the framework meeting, so DOE was not able to consider this issue when selecting these products. The two French Door products (see Table 5.5.3) were purchased later, to allow investigation of the different design details for these products. However, these French Door products are not product class 5, since they have TTD ice service. During the preliminary manufacturer interviews, DOE learned that more than half the sales of product class 5 currently have French Doors. As a result, DOE used a French Door design as the basis for the engineering analysis for this product class. Because neither the products initially purchased for teardown, nor the French Door products purchased later, strictly fit the intended baseline design configuration, DOE made adjustments to establish product class 5 French Door designs for the engineering analysis. DOE did this for one of the 25 ft^3 product class 5A reverse engineered units by "removing" the TTD features, and for the 18.5 ft^3 product by "adding" French Door design features. Additional detail regarding development of the product class 5 French Door models is discussed below.

French door refrigerator-freezers generally require electric anti-sweat heaters to prevent condensation of moisture on the gaskets and/or flip-mullions which seal between the French doors, since refrigerant-line anti-sweat heating is not possible in this region. DOE set the electric anti-sweat heater average power input to 2.5 W for the 18.5 ft^3 model and 2 W for the 25 ft^3 model. These averages are based on a 10W heater load cycling with the compressor, and averaging to account for test procedure treatment of electric anti-sweat heaters (energy use is the average of tests with the anti-sweat heater on during one test and off during another). The compressor duty cycle was close to 40% for the 25 ft^3 model and close to 50% for the 18.5 ft^3 model. These loads were not present for the models representing the reverse engineered products because the 18.5 ft^3 product had a single door and because DOE understands that the 25 ft^3 product was tested with the anti-sweat heater not energized.

DOE adjusted the per-length gasket load for the fresh food compartments for the preliminary analysis energy models of product class 5 to account for the additional gasket region length associated with the French Doors. The modified Windows version of the ERA model used in the analysis did not require this adjustment, since it includes a provision to indicate that the product has French Doors.

The freezer compartment of the 25 ft^3 product class 5A teardown model had two drawers. Hence, the preliminary analysis energy model representing this product as received incorporated an increase in the freezer compartment per-length gasket load to account for the increased gasket length. The Windows version of the energy model allows indication that the freezer has a double drawer. When establishing the baseline ERA model for subsequent design option analysis, DOE readjusted the model for consistency with a single-drawer design. DOE took this step in order to establish a baseline model representing a single freezer drawer.

DOE eliminated the loads associated with the TTD ice system of the 25 ft^3 product class 5A baseline to create the 25 ft^3 product class 5 with French Doors model. This includes the loads of the ice chute penetration, as well as the loads associated with the duct which conveys cold freezer air to the ice maker compartment. Additional loads and energy use associated with heaters in the region of this duct never entered into the model, because DOE understands that the teardown product was tested in a fashion which prevented activation of these heaters.

After adjustment for the design features for consistency with the desired feature set to represent the product class, DOE selected different compressor efficiency levels and/or different fan motor types for the baseline energy models in order to achieve modeled energy use consistent with the energy conservation standard.

DOE obtained the product class 4 teardown unit (refrigerator-freezer with automatic defrost and side-mounted freezer *without* TTD ice service) with the understanding that it had TTD ice service. To address this discrepancy in the energy modeling work, the initial baseline model for the product was modified to represent product class 7 (refrigerator-freezer with automatic defrost and side-mounted freezer *with* TTD ice service). DOE did this by adding load and additional electric anti-sweat heat appropriate for the TTD feature.

DOE conducted the engineering analysis based on the expected revised energy test procedure, which includes modified cabinet temperatures as discussed in Section 5.4.2. After calibration of the ERA models with EnergyGuide and energy test data according to the current energy test procedure, and after the adjustment to the models to better represent the products under investigation as described above, DOE adjusted the ERA models to represent operation under the new energy test procedure. This adjustment did not apply to the freezers, since there are no new changes to the freezer compartment temperatures. The calculated impact of the compartment temperature changes on the energy use is discussed in Section 5.4.2.1 and is shown in Table 5.4.8 of that section. This calculated impact of the temperature changes is fairly consistent with the results provided by AHAM, although it is less than the impact measured during DOE testing of the teardown products.

5.8 DESIGN OPTIONS

After conducting the screening analysis described in chapter 4, DOE considered the remaining technologies in the design option analysis. Table 5.8.1 lists the design options DOE considered for each product classes. Some design options are only applicable to certain types of equipment. Following the table is a description of how DOE applied each of the design options during the engineering analysis. See chapter 3 for background descriptions of the technologies.

Table 5.8.1 Design Options by Product Class

Design Option	PC3	PC5	PC7	PC9	PC10	PC11	PC18
Increased Insulation Thickness				✓ 1 in	✓ 1 in	✓ 3/4 in	✓ 3/4 in
Isobutane Refrigerant						✓	
Vacuum-Insulated Panels	✓	✓	✓	✓	✓	✓	✓
Improved Compressor Efficiency	✓	✓	✓	✓	✓	✓	✓
Variable-Speed Compressor	✓	✓	✓	✓	✓	✓	✓
Increased Evaporator Surface Area	✓	✓	✓	✓	✓	✓	
Increased Condenser Surface Area	✓	✓	✓		✓	✓	
Forced Convection Condenser				✓			
Brushless DC Evaporator Fan	✓	✓	✓	✓			
Brushless DC Condenser Fan	✓	✓	✓	✓			
Adaptive Defrost	✓	✓	✓	✓			
Variable Anti-Sweat Heater Control		✓	✓				

5.8.1 Increased Insulation Thickness

Manufacturers stated during discussions that the potential for insulation thickness increases is very limited for many product classes. Greater insulation thickness would result in either decreased interior volumes, increased exterior dimensions, or some combination of both. They cited the high percentage of the market associated with replacements and the fixed sizes available for replacement refrigerators in consumers' kitchens. The 1995 TSD supporting the 1997 refrigerator energy conservation standard final rule provided information regarding the reduction in served market associated with exterior size increases.[9] Reduction in internal volume is undesirable because this is a key selling feature. As a result, DOE did not consider insulation thickness increase in the analysis for standard-size refrigerator-freezers.

There is some more flexibility in the potential to increase insulation thickness for freezers, since freezers are less likely to be placed in fixed-dimension spaces in kitchens. DOE considered insulation thickness increases of up to 1 inch for standard-size freezers, with a limitation on maximum wall thickness of 3.5 inches.

Compact refrigerators often have limitations on potential for size increase. However, many compact refrigerator products currently have insulation thickness no more than an inch. The potential energy benefit of insulation thickness increases for these products is significant. Hence, DOE considered increases of up to 3/4 inch for these products. DOE considered increase up to ¾ inch also for compact freezers.

A manufacturer's approach to implementing insulation thickness increase would likely involve a combination of reduced internal volume and increased external dimensions. DOE used just external dimension increase, to assure that the product size (represented by adjusted volume) and the associated baseline energy use for the product did not change for different groups of design options.

DOE calculated costs associated with insulation thickness increases using the manufacturing cost model. As discussed in Section 5.6.6, DOE applied a conservative treatment of depreciation costs in which it added the additional cost equal to the Greenfield depreciation cost per product in order to reflect the likely build of a new production facility. DOE assumed that the depreciation cost would be incurred for any increase in insulation thickness. However, DOE allowed for increases in the door thickness without applying depreciation costs associated with the cabinet, and vice versa. The development of these depreciation costs is discussed in section 5.6.6.2 above.

5.8.2 Isobutane Compressor

Comments received at the preliminary public meeting and during the subsequent comment period called for use of alternative refrigerants as a design option. As mentioned in Chapter 3, R-600a (isobutane) is used predominantly for residential refrigeration products in Europe, and it is also used extensively in Asia. Isobutane has the potential for higher efficiency than the HFC-134a refrigerant that is used in residential refrigeration products in the U.S. DOE did not consider isobutane as a design option in its preliminary analyses because it is a hydrocarbon, is subject to charge limits by UL, and is not currently on EPA's Significant New Alternatives Program (SNAP) list of allowed refrigerant alternatives to CFCs and HCFCs. DOE has considered isobutane in its analysis because EPA has proposed to add isobutane to the SNAP list. 75 FR 25799 (May 10, 2010). However, the EPA proposal allows use of isobutane under a charge limitation of 57 grams for residential refrigeration products. This quantity of refrigerant is not sufficient for most residential refrigeration products manufactured for the U.S. market without significant redevelopment of heat exchangers and/or use of dual systems. While such modifications are possible, information regarding low-volume heat exchanger technology demonstrating its charge reduction, energy use impacts, and reliability was not available. Further, the space required for an additional refrigeration system would reduce product interior volume or increase exterior dimensions, hence DOE did not consider use of dual systems to address the charge limitations of hydrocarbons for most product classes. DOE applied this design option only to compact refrigerators (Product Class 11).

DOE conducted a theoretical analysis across a range of evaporating and condensing temperatures to compare the performance of isobutane refrigerant with HFC-134a. DOE conducted this analysis using the REFPROP database developed by NIST[10], with the following assumptions.

- Equal compressor efficiencies for both refrigerants (ratio of power input for adiabatic isentropic compression to actual power input).
- Liquid and return gas temperatures both 90 ˚F.

The results are shown in Figure 5.8.1 below.

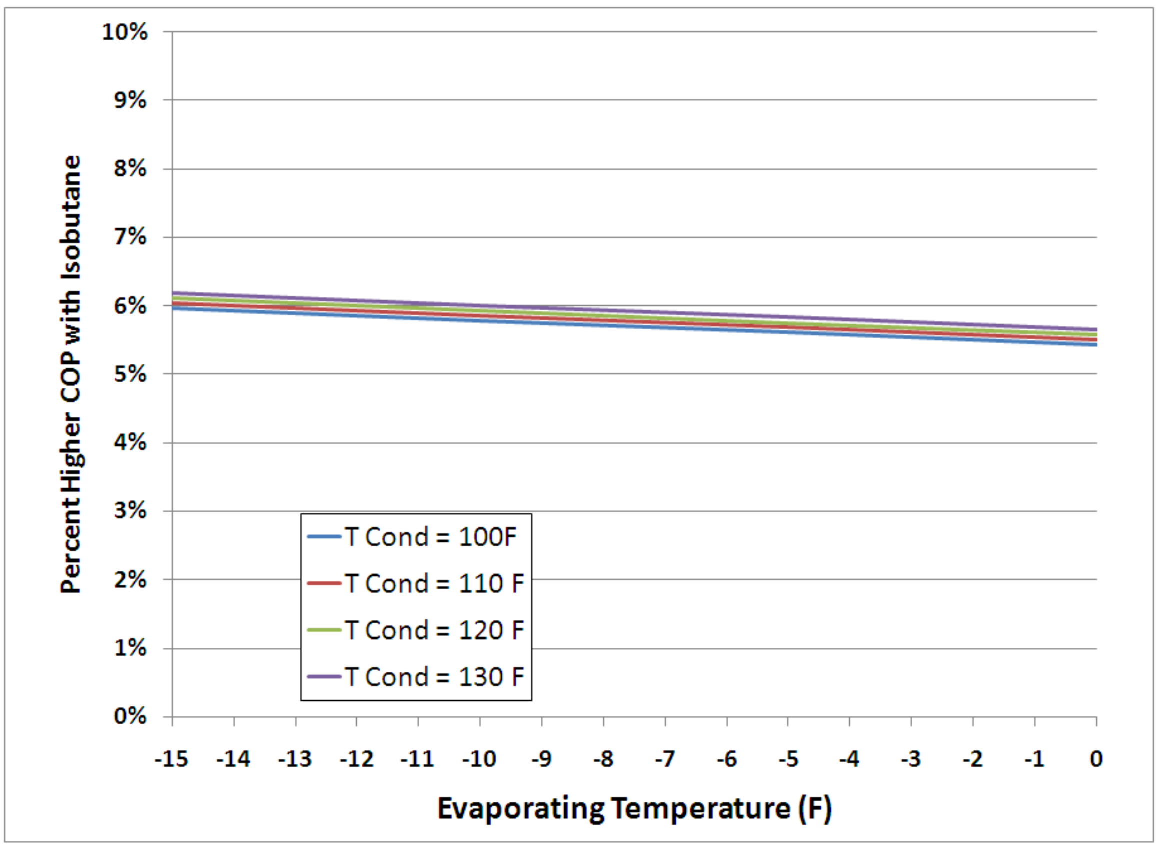

Figure 5.8.1 Energy Benefit of Isobutane Compared with HFC-134a

DOE also obtained information regarding the efficiency improvement potential using isobutane from compressor vendors and manufacturer discussions. Based on the results of its theoretical analysis and the additional information received, DOE assigned a five percent energy benefit to the conversion to isobutane compressors. DOE implemented this in the ERA analysis by reducing the compressor power multiplier from 1.0 to 0.95 for the HFC-134a compressor model.

Based on discussions with compressor vendors, DOE concluded that the cost impact associated with use of isobutane compressors is negligible. Further, DOE concluded that the cost impact on the remainder of the sealed system is also negligible. DOE considered a cost increase of $1 per product for this design option associated with plant and equipment modifications to allow safe charging of isobutane refrigerant. DOE also considered cost increases for use of sealed electrical components in order to safeguard against electrical sparks within the electrical components providing an ignition source in case of a refrigerant leak. DOE used in its analysis cost increases of $4 per product for the baseline simple thermostatic control and an additional $4 to address additional electrical content if a variable-speed compressor system is used in the product.

5.8.3 Vacuum-Insulated Panels

Vacuum-insulated panels (VIPs) increase efficiency by significantly increasing the thermal resistivity of the cabinet walls, and therefore decreasing heat penetration into the cabinet. DOE considered the addition of ½-inch thick VIPs to the walls and doors of the cabinet for all product classes, and the remainder of the insulation thickness was filled with PU foam. Data for VIP thermal characteristics and costs were provided by va-Q-tec, a VIP manufacturer. The cost information was confirmed through discussions with manufacturers. In these discussions, manufacturers pointed out that edge effects can result in actual performance significantly less than predicted. However, DOE considers that thermal performance estimates based on the va-Q-tec technology are more accurate than for other VIP options because this technology has a more modest mid-panel thermal resistance and a significantly thinner metallic layer than other options. The mid-panel conductivity of this VIP technology is 3.5 mW/m-C (0.024 Btu-in/sqft-hr-˚F).[11] In contrast, the conductivity of PU foam is in the range 0.13 to 0.14 Btu-in/sqft-hr-˚F.

As mentioned in Section 5.7.2, DOE modeled the thermal performance of composite walls including VIPs using composite wall average thermal resistivities. The composite wall resistivity R_w was calculated as follows.

$$R_w = \frac{\left(R_{VIP} t_{VIP} + R_{PU} t_{PU}\right)}{\left(t_{VIP} + t_{PU}\right)}$$

Where R_{VIP} and R_{PU} are the thermal resistivities of the VIP and the PU foam, and t_{VIP} and t_{PU} are the thicknesses of the VIP and PU foam layers. The thermal resistivities for the materials are the inverses of the conductivities.

DOE analysis using ERA of cabinet load reduction achievable through the use of VIPs using this analysis approach is consistent with analysis carried out by va-Q-tec and also consistent with prototype testing using VIP technology. The reduction in cabinet load possible using VIPs for a refrigerator-freezer with typical wall thickness is roughly 30%, which is consistent with results reported by Electrolux for use of vacuum insulation in freezers.[12] However, during NOPR phase discussions with manufacturers, DOE learned that different manufacturers have had widely varying levels of success in applying VIPs to refrigeration products. The levels of performance benefit reported by manufacturers ranged roughly from 0 to 100 percent of the levels predicted by the ERA analysis. DOE used a performance degradation factor of 50% in its analysis to account for this variation in experience.

The quantity of VIP that can be added to the cabinet is limited by the structural design requirements. Based on discussions with manufacturers, DOE applied a limit of 50% of the cabinet surface area in its analysis. DOE allowed full (100%) coverage of door surface area.

The following cost information, which va-Q-tec provided and/or which DOE developed based on subsequent discussions, formed the basis of the applied costs for VIPs.

- Average panel cost $\$3.08/ft^2$ at 1.2 cm thickness.
- Fill cost as a percent of panel cost 60%.
- Added glue cost for adhering the panel to cabinet surfaces 5% of panel cost.
- Cost savings associated with displaced PU foam 2.5% of panel cost.

In order to allow calculation of costs for other VIP thicknesses, DOE considered the fill cost to be proportional to the thickness, and the remaining cost per square foot to be constant. In addition, DOE calculated direct labor cost associated with application of the panel to cabinet and door surfaces based on the $24/hr wage rate (including fringe benefits) discussed in section 5.6, and time for application of 10 minutes for a compartment and 1 minute for a door. The direct material and labor costs associated with use of the VIP must be adjusted to account for capital expenses and overhead associated with incorporation of VIPs into the production process. Because the material cost of VIPs is currently high in relation to the costs of other materials used in the manufacture of refrigerators and freezers, the cost adders for overhead and depreciation discussed in Section 5.6.6.1 and shown in Table 5.6.5 were divided by two in order to provide more reasonable representation of these costs for this technology. Hence, DOE used the following percent additions: 11.7% for standard-size refrigerator-freezers, 14.2% for standard-size freezers, and 19.6% for compact refrigerators.

See appendix 4-A for information developed in response to preliminary analysis phase comments questioning the ability of VIP suppliers to meet the demand for VIPs that might be required by potential DOE standards.

5.8.4 Improved Compressor Efficiency

DOE considered the substitution of higher efficiency compressors for all product classes. DOE often applied this design option in two stages if there was a large gap between the baseline energy efficiency ratio (EER) and the maximum available EER for a given compressor capacity. DOE acquired compressor performance data from compressor vendors for use in the energy analysis, including capacity and power input for the applicable range of combinations of suction and discharge pressure conditions. As an example of the potential for improvement, standard-size baseline refrigerator-freezers typically use compressors with a rated EER of 5.0 to 5.5 Btu/h-W. DOE considered improved EERs of 5.75 through 6.25 Btu/h-W.

DOE considered improved-efficiency compressors with EERs up to roughly 6.25 Btu/h-W for standard- size refrigerator-freezers. The range of available compressor efficiencies is illustrated in Figure 5.8.3 below.

The peak available efficiency level does not vary significantly for the range of capacities typical for standard-size refrigerator-freezers (600 to 800 Btu/h). However, efficiency level drops off considerably for smaller capacity compressors that are generally used in compact refrigerators and freezers.

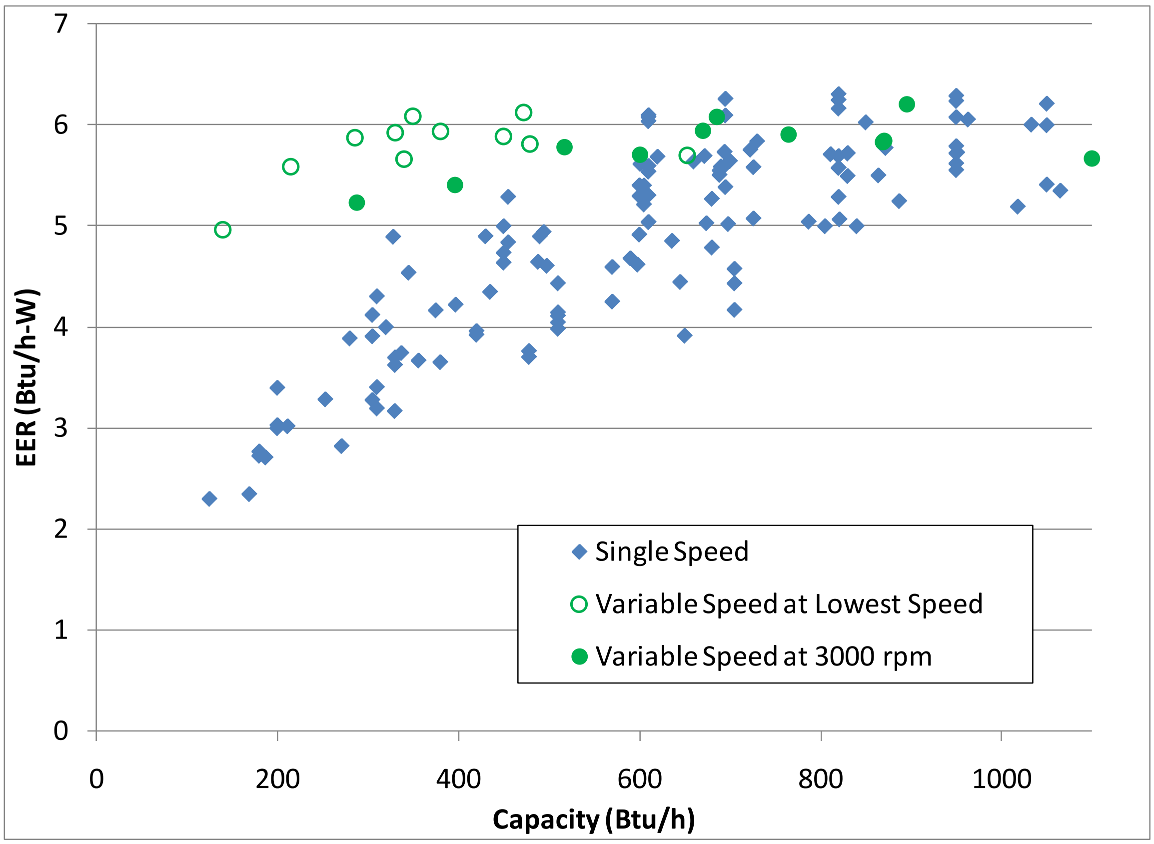

Figure 5.8.2 Compressor Efficiency Data

DOE received estimates for increased cost of higher-efficiency compressors used for standard-size refrigerator-freezers and standard-size freezers from compressor vendors. These estimates were also discussed with manufacturers. Based on this information, DOE developed a curve for the cost premium associated with higher efficiency compressors. This curve is shown in Figure 5.8.5 below.

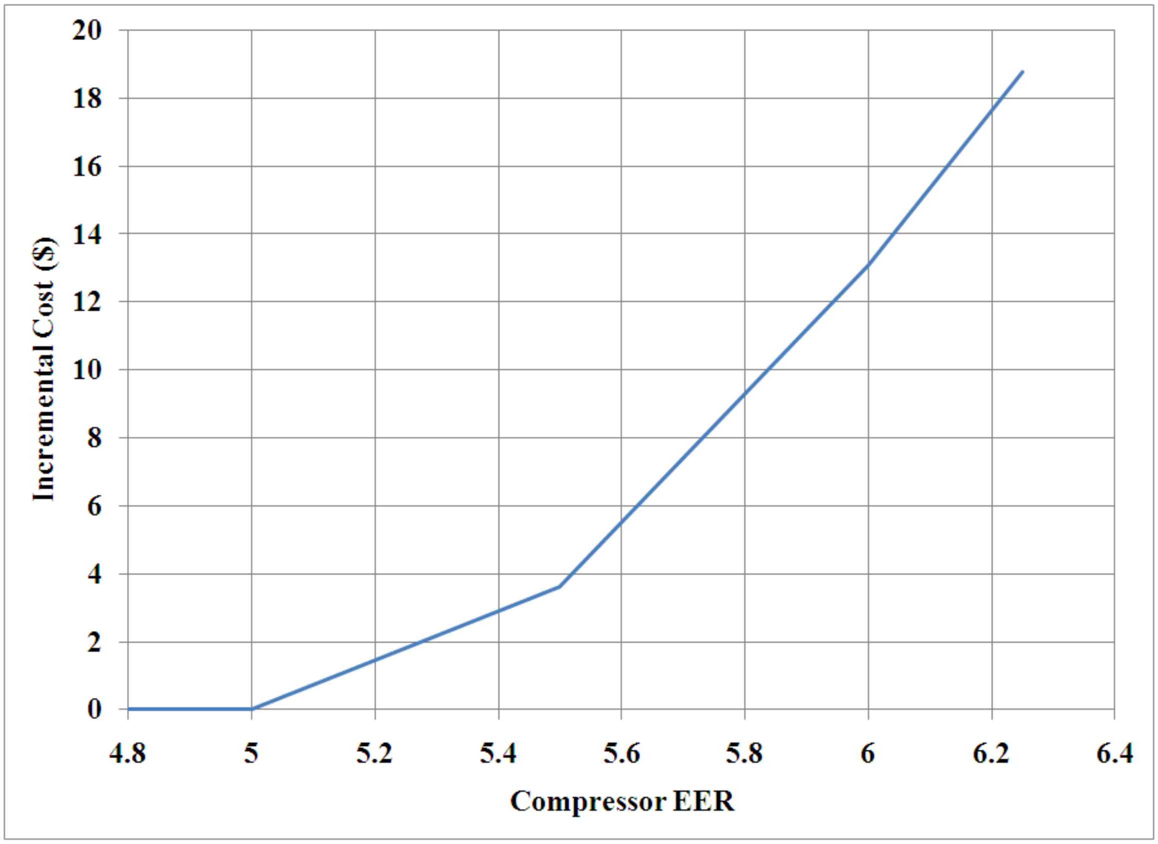

Figure 5.8.3 Incremental Cost for Single-Speed Compressors for Standard-Size Products

When considering compressor efficiency improvement for standard-size products, DOE used the performance data of specific higher-efficiency compressors in the energy analysis. DOE selected the alternative compressors to have nearly the same capacity as the baseline compressors, in order to assure nearly identical performance except for compressor power input.

In the analysis of compressor efficiency improvements for compact products, DOE used an approach that addressed the reduction of compressor efficiency as the capacity is reduced. DOE developed a curve roughly representing the maximum available EER for smaller compressors. This curve is compared in Figure 5.8.4 below with the data for commercially available compressors.

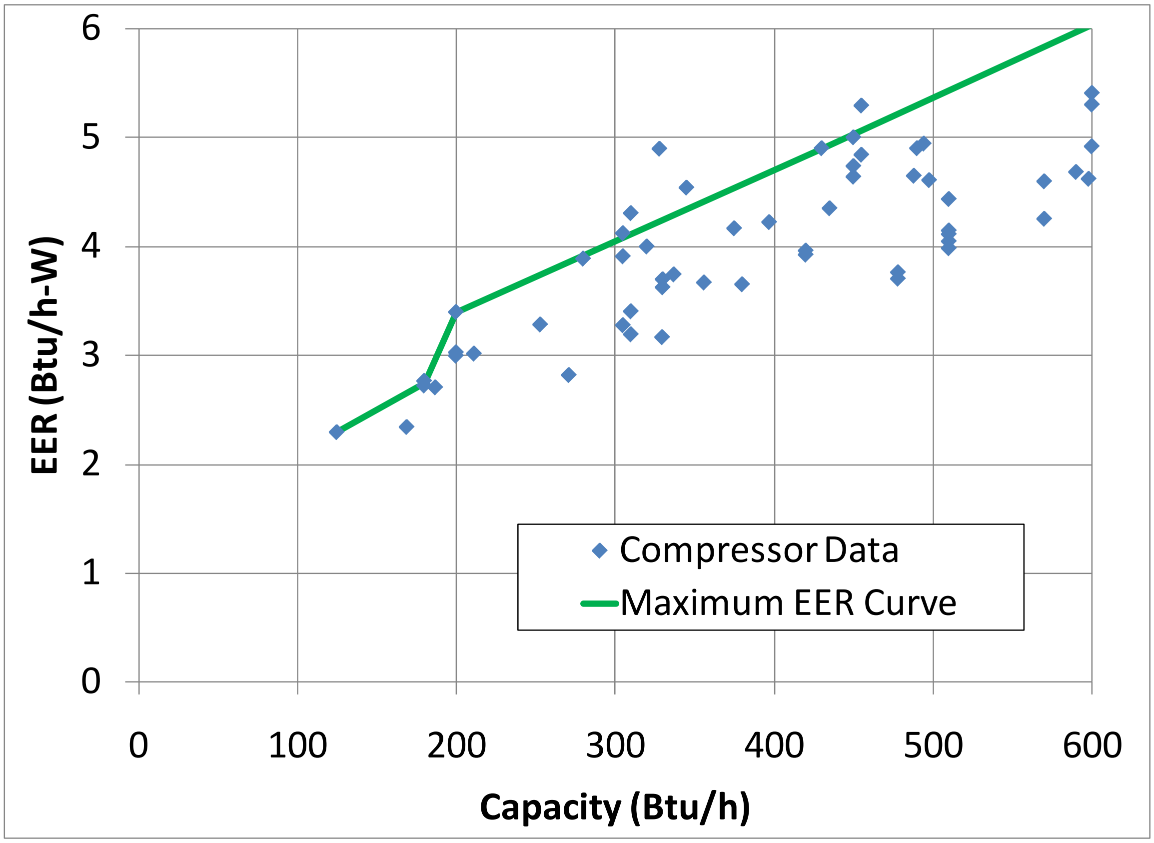

Figure 5.8.4 Efficiency Curve for Low Capacity Compressors

To model energy use of higher efficiency low-capacity compressors, DOE reduced the power input data for the baseline compressor by a selected factor so that the rated EER matches the maximum EER of the above curve. The baseline compressors of the products analyzed had EERs typically 0.5 to 1 Btu/h-W lower than the maximum curve shown in the figure above.

DOE received vendor cost estimates for efficiency improvements for low-capacity compressors. DOE also received information on the typical cost increase during discussions with manufacturers of products which use these compressors. A representative cost estimate of $10 per 1.0 Btu/h-W efficiency improvement was used in the analysis.

5.8.5 Variable-Speed Compressor

Variable speed compressors (VSCs) operate at multiple speeds to allow variation of compressor capacity. They also generally use permanent magnet motors, which can be more efficient than induction motors for the power level required for residential refrigerator compressors. They improve efficiency by (1) use of the higher-efficiency motor technology, (2) increasing the operating effectiveness of heat exchangers because there is lower mass flow being cooled or warmed by a fixed-size heat exchanger, and (3) reducing cycling losses by reducing the number of cycles. VSC technology has been available for many years and a number of refrigerator-freezer products currently use the technology. Currently nearly all of these products use Embraco VSCs. DOE obtained compressor performance data for the range of sizes of Embraco VSCs. This information was used in the energy analysis. DOE selected VSCs so that the VSC capacity when operating at 3,000 rpm nearly matched the capacity of the replaced single speed compressor. The lowest available speed for the Embraco VSCs is 1,600 rpm. The compressor typically cycles at the low speed to maintain internal set points for energy test conditions. DOE primarily used the performance data for 1,600 rpm in the energy analyses. The performance of VSCs at the lowest speed and at 3,000 rpm is shown in Figure 5.8.3 above.

In order to maximize the energy benefit of a VSC, a design needs to address the potential increase in energy use associated with longer fan run time. The increase in fan energy use can negate much of the reduction in compressor energy use. As a result, it is often necessary to use brushless DC fan motors. In addition, brushless DC fan motors can operate at different speeds, depending on the design configuration. DOE is not aware of brushless DC fan motors designed for 120 VAC power input at representative capacities for refrigerator duty that allow adjustment of fan speed, although such a design should be viable. Most designs incorporating fan speed control use DC-input power for the fans and require a control system which can provide the DC power and vary it to adjust fan speed. DOE's analysis did not involve optimization of fan speed and power with the variable speed compressor system. Instead, DOE selected a fan speed to achieve roughly 50% power input, using the cube law for fan power to calculate power input (The cube law states that for a given fan and air flow system geometry, air flow is proportional to fan speed and power input is proportional to the cube of fan speed).

DOE obtained estimates of the cost increase for switching to VSCs from Embraco, and from discussions with manufacturers. An average of the estimates of this cost increase provided by the manufacturers weighted by manufacturer market share is near $56. This includes the compressor and its motor controller, but does not include additional changes which might be required to implement a variable speed system. DOE used the $56 cost increase in the analyses. Additional costs associated with conversion of a refrigeration system to variable speed operation are associated with a switch to brushless DC fan motors and the use of a control system sophisticated enough to provide adequate or optimized control. The Embraco VSC design includes a control system that can be used with a conventional mechanical thermostat. This system has been implemented in a commercially available freezer.[13] The Embraco control adjusts speed based on the response of the mechanical thermostat. DOE considers that this approach is suitable for products with manual defrost. For products with automatic defrost and especially adaptive defrost, it is not reasonable to expect that the Embraco system alone would be suitable. DOE included in cost estimates an additional $30 for addition of an electronic control system for products with automatic defrost. For product classes for which a significant portion of current models already have electronic control (product classes 5 and 7), analysis was conducted for an electronic control unit and a mechanical control unit. DOE also considered use of brushless DC fan motors necessary when switching to VSCs. However, the DOE analysis incorporated switch to brushless DC fan motors as a design option earlier than VSCs in the progressive layering of design options, because brushless DC fan motors are more cost effective than a full conversion to variable speed.

DOE also considered the additional standby power consumption associated with the electronic control board required for conversions to variable speed operation. DOE attributed 1.5 W of standby power to electronic controls. Use of electronic controls with a VSC makes dedicated controllers for adaptive defrost and variable anti-sweat unnecessary. In cases where a VSC was added after either the adaptive defrost or variable anti-sweat design options were utilized, DOE removed the 0.5 W of standby power assumed for each of these self-contained controllers. The costs of the self-contained controllers were then also removed, assuming these design options preceded implementation of VSCs in the analysis.

DOE also adjusted the compressor run time between defrosts when applying a VSC. Since the compressor duty cycle typically increases significantly when switching to a VSC, the appropriate compressor run time between defrosts should increase to maintain equivalent defrost performance. DOE increased this parameter in the ERA model to achieve the same defrost frequency when applying the VSC design option.

5.8.6 Increased Evaporator Surface Area

The evaporator is necessary for transferring heat from the cabinet to the refrigerant. Larger surface area allows the heat transfer to occur more efficiently. DOE considered an increase in evaporator surface area for all products analyzed. In some cases the size increase was limited by available space. This was true especially for the chest freezers and compact refrigerators. DOE reviewed the space available in the teardown products that served as the basis for the energy modeling to determine how much size increase would be possible without requiring significant modifications to the cabinet design. In some cases, DOE determined that no size increase was possible.

In the preliminary analyses, evaporator size increases were implemented in the energy analysis for forced convection evaporators through the use of adjustment factors applied to the overall UA factor (heat transfer coefficient times surface area) and to the refrigerant side pressure drop. These factors were proportional to the intended heat exchanger surface area increases. DOE modified this methodology in the NOPR stage, using instead direct adjustment of the input parameters describing the evaporator geometry. DOE increased either the number or length of tube rows as appropriate for the space available for size increase. In cases where DOE increased the length of the evaporator in the direction of airflow, it also increased the fan power input by a factor equal to half the evaporator size increase (this reflects evaporator pressure drop increase proportional to the size increase and an assumption that the evaporator pressure drop represents half of the system airside pressure drop).

Treatment of the cost of the evaporator size increase depended on the evaporator type. For forced convention and roll bond evaporators, DOE adjusted the baseline costs of the evaporators upwards by the size increase factor. For cold wall evaporators, DOE directly calculated the cost increase using the manufacturing cost model by increasing the tube lengths and materials associated with providing good tube/liner thermal contact.

5.8.7 Increased Condenser Surface Area

The condenser transfers heat from the refrigerant to the ambient air. Larger surface area allows the heat transfer to occur more efficiently. DOE considered increase in condenser surface area for all products analyzed. In some cases the size increase was limited by available space. This was true especially for hot wall or static condensers. DOE reviewed the space available in the teardown products that served as the basis for the energy modeling to determine how much size increase would be possible without requiring significant modifications to the cabinet design. In some cases, DOE determined that no size increase was possible.

In the preliminary analyses, condenser size increases were implemented in the energy analysis for forced convection condensers through the use of adjustment factors applied to the overall UA factor (heat transfer coefficient times surface areas) and to the refrigerant side pressure drop. These factors were proportional to the intended heat exchanger surface area increases. DOE modified this methodology in the NOPR stage, using instead direct adjustment of the input parameters describing the condenser geometry. DOE increased either the number or length of tube rows as appropriate for the space available for size increase. In cases where DOE increased the length of the condenser in the direction of airflow, it also increased the fan power input by a factor equal to the condenser size increase (this reflects condenser pressure drop increase proportional to the size increase and an assumption that the condenser pressure drop represents all of the system airside pressure drop).

Treatment of the cost of the condenser size increase depended on the condenser type. For forced convention and static condensers, DOE adjusted the baseline costs of the condensers upwards by the size increase factor. For hot wall condensers, DOE directly calculated the cost increase using the manufacturing cost model by increasing the tube lengths and materials associated with providing good tube/shell thermal contact.

5.8.8 Brushless DC Fan Motors

Brushless DC fan motors are more efficient than the shaded pole motors which are often used in baseline model refrigerators.

For the 1997 refrigerator energy conservation standard final rule, DOE analysis included reduction of motor power input from initial values in a range from 8 to 12 W for shaded pole fan motors to 4.5 W for brushless DC motors.[9] This is a reduction in power ranging from 44 to 57%.

The fan power input measured for the teardown products are summarized in Table 5.8.2 below. For the baseline/ENERGY STAR product pairs, the table presents power input for both sets of each applicable fan. The fan motor power reduction associated with the switch to brushless DC motors based on this data is in the range 60% to 65%.

Table 5.8.2 Teardown Product Fan Power Input

Product	Evaporator Fans		Condenser Fans	
	Shaded Pole	**Brushless DC**	**Shaded Pole**	**Brushless DC**
21 ft^3 Top-Mount**	5.7, 6.1	NA	9.4	3.3
26 ft^3 Side-Mount**	5.6, 5.8	NA	8.5	3.4
25 ft^3 Bottom Mount 1	6.5	NA	NA	3.7
18.5 ft^3 Bottom Mount	6.2	NA	NA	3.8
25 ft^3 Bottom Mount 2	NA	3.25*	NA	2.2*
22 ft^3 Side-Mount	NA	3.25*	9.1	NA
20 ft^3 Upright Freezer**	11.5	4.5	NA	NA
14 ft^3 Upright Freezer	7.4	NA	NA	NA

*DC-input fan. The listed wattage is nominal.
**Data provided for a baseline/ENERGY STAR product pair.

DOE also obtained information on typical fan motor power reduction associated with a switch to brushless DC motors during discussions with manufacturers. The responses indicated that the reductions would be more modest than suggested by the 1995 TSD values or the measurements of teardown products. DOE selected a compromise power reduction of 50% when the possible reduction was not already clearly illustrated by the measurements of the baseline/ENERGY STAR teardown product pairs under analysis.

DOE obtained incremental cost estimates for the switch to brushless DC motors through discussion with Matsushita, a key vendor supplying these motors, and through discussions with manufacturers. DOE used incremental cost estimates of $4.30 for condenser fans and $4.10 for evaporator fans.

5.8.9 Adaptive Defrost

An adaptive defrost system adjusts the time interval between defrosts based on some indication of the need for defrost. A common indicator is the length of time required to complete the previous defrost. Other indicators could include the number of door openings or a measurement of ambient humidity. DOE considered this design option for product classes which have automatic defrost (product classes 3, 5, 7, and 9). The ERA model allows input of compressor run time between defrost. To model this option, DOE increased the compressor run time between defrosts to 24 hours, as compared to the typical range for baseline products of 10-15 hours. For the preliminary analyses, DOE used a compressor run time between defrosts of 38 hours. The 38 hours is the default time interval specified by the test procedure assuming default values of the minimum and maximum compressor run intervals of 12 and 84 hours, allowed if an algorithm does not have specific values of these parameters. Manufacturer interviews conducted during the NOPR stage suggested that minimum and maximum intervals of 6 and 96 hours are more reflective of adaptive defrost systems. Using these minimum and maximum compressor run values in the test procedure yields the 24 hours used in the final analyses.

In cases in which DOE applied adaptive defrost in the analysis to a product that did not already have electronic controls, DOE assumed use of a standalone adaptive defrost controller. DOE used a standby power consumption of 0.5 W for this type of controller. Based on discussions with manufacturers, DOE used an incremental cost of $8 in the energy analysis for adaptive defrost, if a standalone adaptive defrost controller was used. Refrigerators which already have electronic control can implement adaptive defrost with programming changes which incur no per-unit cost.

In cases where both adaptive defrost and variable speed compressor design options were analyzed, the cost of the adaptive defrost was eliminated, because the introduction of electronic controls would make use of a standalone adaptive defrost controller unnecessary.

5.8.10 Variable Anti-Sweat Heater Control

Variable anti-sweat heater control adjusts the time-average wattage of an electric anti-sweat heater based on ambient temperature and humidity conditions so that all surfaces are just above the ambient dew point. DOE considered this option for bottom-mount French-door refrigerator-freezers (product class 5) and for side-mount refrigerator-freezers with TTD ice (product class 7). French-door products generally use electric anti-sweat heaters in the region of the seal between the two fresh food doors to control condensation because warm liquid anti-sweat heating cannot easily be applied in this region. Similarly, products with TTD ice generally use electric anti-sweat heaters in the region around the ice dispenser opening. Most modern refrigeration products use warm liquid anti-sweat heating in most regions susceptible to condensation of moisture (i.e. the door gaskets and nearby door frame areas). However, the French Door and TTD dispenser regions mentioned above are typical exceptions. To model the energy use reduction associated with this design option, DOE established a curve representing the heater power input as a function of ambient humidity. DOE then calculated annual average electric anti-sweat heater wattage based on the frequency distribution of humidity levels established in the GE waiver describing a test procedure for this control scheme.[14] The selected DOE curves are based on power levels of 0W at 50% RH and 9W at 100% RH for product class 5 and 0W at 50% RH and 2W at 100% RH for product class 7.

Implementation of variable anti-sweat heater control requires use of a humidity sensor and an electronic controller which can adjust the time-average heater wattage appropriately. For products which already have electronic control, DOE used the cost just of a humidity sensor. DOE used a cost of $9.48 for a Honeywell humidity sensor based on high-quantity pricing.[15] No product currently exists which provides standalone variable anti-sweat heater control. However, DOE considers the $8 example of the standalone adaptive defrost controller to be representative of the incremental cost of such a product. DOE also considered standby power consumption for this design option in the revised analysis: 0.2 W of standby power consumption for the humidity sensor, and 0.5 W of standby power consumption for a self-contained electronic controller. For the case of a product already having electronic controls, DOE added just the 0.2 W standby power load associated with the sensor.

5.8.11 Forced Convection Condenser

A forced convection condenser can be more efficient than a hot wall condenser, because it enables more effective heat transfer from the refrigerant to the ambient air. DOE considered this option for upright freezers only (product class 9). This conversion involves the addition of a typical wire-tube condenser, a fan assembly, wiring to power the fan, and a warm liquid anti-sweat heating loop, and the elimination of hot wall tubing on the insulation side of the outer shell. In the case of the upright freezer products examined for the reverse engineering work, there was ample space underneath the cabinet for the condenser and fan assembly. In addition, these products incorporated hot gas condensate pan heaters. These heaters could be eliminated in a forced-convection arrangement, because the condenser heat and air flow of the forced convection arrangement would be sufficient to evaporate the condensate, as is generally done for refrigerator-freezers. DOE used a net incremental cost of $12 for this conversion, assuming use of a brushless DC fan motor—most of the cost of the added components would be saved through elimination of the hot wall condenser. DOE analyzed this design option both with shaded pole and brushless DC condenser fans. The option provided an energy benefit in combined design option analysis only when using the brushless DC fan motor.

5.9 ENGINEERING ANALYSIS RESULTS

This section shows the incremental cost curves developed by DOE.

5.9.1 DOE Cost-Efficiency Curves

DOE generated cost-efficiency curves for two product volumes in each of the seven analyzed freestanding (non-built-in) product classes based on combinations of individual design options. For the built-in product classes, DOE analyzed one product of each class. DOE normalized the curves by converting to costs at specific efficiency levels (every 5% energy use reduction up to max tech) for simplified downstream analysis.

Conversion of cost curves to the specified efficiency levels was complicated by the characteristics of the design options required to provide further efficiency improvement. Some design options can be partially applied, while others cannot. For instance, the cost for compressor efficiency improvement, illustrated in Figure 5.8.5, varies as the efficiency varies. Because intermediate efficiency level compressors are generally available, the cost to achieve a portion of the efficiency improvement calculated in the energy model would be a portion of the total design option cost. However, in some cases, such as implementation of a variable speed compressor, the design option cannot be partially implemented. For these cases, DOE applied the entire cost of the design option at the intermediate efficiency level, even though the design might overshoot the efficiency level. This causes some of the incremental cost curves to have slopes which don’t increase monotonically.

The DOE incremental MSP costs are presented in the tables below: Table 5.9.1 for standard-size refrigerator-freezers, Table 5.9.3 for standard-size freezers,

Table 5.9.5 for compact refrigeration products, and Table 5.9.7 for built-in products. DOE analyzed two sizes of each product for all but the built-in products. DOE averaged the results for each of these pairs of products to derive the final values presented in the tables.

Table 5.9.1 Incremental Manufacturer Selling Price Results for Standard-Size Refrigerator-Freezers

Efficiency Level (percent less than baseline energy use)	Product Class		
	3: Refrigerator-freezers — automatic defrost with top-mounted freezer without TTD ice service	5: Refrigerator-freezers — automatic defrost with bottom-mounted freezer without TTD ice service	7: Refrigerator-freezers — automatic defrost with side-mounted freezer with TTD ice service
10%	$11.81	$12.99	$9.90
15%	$19.73	$21.64	$19.03
20%	$73.13	$37.54	$42.45
25%	$106.73	$89.52	$94.21
30%	$180.46	$175.05	$206.85
Max Tech (% -- Cost)	36% -- $286.19	36% -- $293.47	33% -- $295.21

Table 5.9.2 Incremental Manufacturer Selling Price Results for Standard-Size Freezers

Efficiency Level (percent less than baseline energy use)	Product Class	
	9: Upright freezers with automatic defrost	10: Chest freezers and all other freezers except compact freezers
10%	$11.19	$6.44
15%	$28.46	$14.68
20%	$43.77	$24.19
25%	$67.00	$62.33
30%	$88.22	$79.17
35%	$135.70	$127.07
40%	$201.92	
Max Tech (% -- Cost)	44% -- $348.61	41% -- $223.55

Table 5.9.3 Incremental Manufacturer Selling Price Results for Compact Refrigerators and Freezers

Efficiency Level (percent less than baseline energy use)	Product Class	
	11: Compact refrigerators and refrigerator-freezers with manual defrost	18: Compact chest freezers
10%	$4.64	$5.99
15%	$8.17	$16.70
20%	$13.19	$52.73
25%	$23.22	$61.54
30%	$31.20	$87.84
35%	$53.61	$94.47
40%	$60.14	
45%	$87.47	
50%	$102.35	
Max Tech (% -- Cost)	59% -- $155.96	42% -- $157.09

Table 5.9.4 Incremental Manufacturer Selling Price Results for Built-In Refrigeration Products

Efficiency Level (percent less than baseline energy use)	Product Class			
	3A-BI: Built-In All-Refrigerators	5-BI: Built-In Bottom-Mount Refrigerator-Freezers without TTD ice service	7-BI: Built-In Side-Mount Refrigerator-Freezers with TTD ice service	9-BI: Built-In Upright Freezers
10%	$7.14	$21.47	$51.45	$15.68
15%	$18.90	$85.82	$123.47	$27.44
20%	$127.10	$165.89	$281.53	$99.23
25%	$272.09	$295.28		$211.74
Max Tech (%--cost)	29%--$381.70	27%--$370.22	22%--$371.27	27%--$297.56

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CHAPTER 6. MARKUPS FOR PRODUCT PRICE DETERMINATION

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CHAPTER 6. MARKUPS FOR PRODUCT PRICE DETERMINATION

6.1 INTRODUCTION

To carry out its analyses, DOE needed to determine the cost to the consumer of baseline products and the cost of more-efficient units. As discussed in chapter 8, DOE developed retail prices for baseline products using proprietary retail price data collected by The NPD Group. For products with higher-than-baseline efficiency, DOE estimated the consumer prices by applying appropriate markups to the incremental manufacturing costs estimated in the engineering analysis.

6.1.1 Distribution Channels

The appropriate markups for determining consumer equipment prices depend on the type of distribution channels through which products move from manufacturers to purchasers. At each point in the distribution channel, companies mark up the price of the equipment to cover their business costs and profit margin.

Data from the Association of Home Appliance Manufacturers (AHAM)[1] indicate that an overwhelming majority of residential appliances are sold through retail outlets. Because DOE is not aware of any other distribution channel that plays a significant role for residential refrigeration products, DOE assumed that all of the refrigeration products are purchased by consumers from retail outlets. DOE did not include a separate distribution channel for refrigeration products included as part of a new home, as it did not have information on the extent to which these products are "pre-installed" by builders in new homes.

6.1.2 Markup Calculation Procedure

As just discussed, at each point in the distribution channel, companies mark up the price of the equipment to cover their business costs and profit margin. In financial statements, gross margin is the difference between the company revenue and the company cost of sales or cost of goods sold (*CGS*). The gross margin includes the expenses of companies in the distribution channel—including overhead costs (sales, general, and administration); research and development (R&D) and interest expenses; depreciation, and taxes—and company profits. To cover costs and to contribute positively to company cash flow, the price of products must include a markup. Products command lower or higher markups, depending on company expenses associated with the product and the degree of market competition. In developing markups for manufacturers and retailers, DOE obtained data about the revenue, *CGS*, and expenses of firms that produce and sell the products of interest.

6.2 MANUFACTURER MARKUP

DOE uses manufacturer markups to transform a manufacturer's production costs into a manufacturer selling price. DOE used *CGS* and gross margin to calculate the manufacturer markup (MU_{MFG}) with the following equation:

$$MU_{MFG} = \frac{CGS_{MFG} + GM_{MFG}}{CGS_{MFG}}$$

where:

MU_{MFG} = Manufacturer markup,
CGS_{MFG} = Manufacturer's cost of goods sold or Manufacturer Production Cost (*MPC*), and
GM_{MFG} = Manufacturer's gross margin.

The manufacturer's *CGS* (or *MPC)* plus its *GM* equals the manufacturer selling price (*MSP*).

In developing the initial baseline manufacturer markup, DOE used the same markup as the 2009 cooking products final rule and the 2010 commercial clothes washers final rule. DOE used this baseline manufacturer markup because all publicly traded companies that manufacture residential refrigeration equipment also manufacture a number of other appliances, and because the 1.26 baseline manufacturer markup had already been vetted during the rulemakings for these other products. DOE developed this average manufacturer markup by examining the annual Securities and Exchange Commission (SEC) 10-K reports filed by four publicly-traded manufacturers primarily engaged in appliance manufacturing.[2] Because these companies are typically diversified, producing a range of different appliances, an industry average markup was assumed by DOE to be representative for the manufacture of refrigeration products. DOE evaluated markups for the years 2002-2005. Table 6.2.1 lists the average corporate gross margin during the years 2002-2005, and corresponding markups, for each of the four manufacturers.

Table 6.2.1 Major Appliance Manufacturer Markups

	Mfr A	Mfr B	Mfr C	Mfr D
Average Net Revenues (Million)	$372	$280	$4770	$12,682
Corporate Gross Margin	15%	28%	16%	22%
Markup	1.18	1.39	1.19	1.28

Source: SEC 10-K reports (2002-2005)

The average markup value based on these companies is 1.26, which is the initial value that DOE used for standard-size refrigerator-freezers, standard-size freezers, and compact refrigeration products. DOE requested manufacturer feedback on the accuracy of this estimate and other financial assumptions during DOE's confidential manufacturer impact analysis interviews and continued to use this value for the NOPR and final rule. For built-in refrigeration products, DOE used a baseline manufacturer markup of 1.40. DOE calculated the built-in refrigeration manufacturer markup using the weighted average market share of information also submitted during manufacturer interviews.

Note DOE inadvertently altered Table 6.2.1 in the NOPR TSD chapter. The Table 6.2.1 above matches the original Table 6.3.1 DOE included in the preliminary analysis TSD. However, DOE has used a 1.26 manufacturer markup for non-built-in products throughout the rulemaking that was calculated using the information above.

6.3 RETAILER MARKUP

6.3.1 Approach for Retailer Markups

DOE based the retailer markups for residential refrigeration products on financial data for Electronics and Appliance Stores from the 2002 U.S. Census Business Expenditure Survey (BES), which is the most recent available survey.[3] DOE organized the financial data into statements that break down cost components incurred by firms in this category. DOE assumes that the income statements faithfully represent the various average costs incurred by firms selling home appliances. Although Electronics and Appliance Stores handle multiple commodity lines, the data provide the most accurate available indication of expenses for selling home appliances.

The BES data provided for Electronics and Appliance Stores only contain total sales and detailed operating expenses. In order to construct a complete data set to estimate markups, DOE needed to estimate CGS and gross margin. The 1997 Business Expenses Survey provides total sales, gross margin and detailed operating expenses of Household Appliance Stores. The CGS and gross margin account for around 70% and 30% of the total sales, respectively. DOE found that gross margin as percent of sales has been roughly constant in this category from 1993 to 2007.[a] Therefore, DOE assumed that the fractions of CGS and gross margin as percent of sales in 2002 are the same as in 1997. Following this assumption, DOE calculated the CGS, gross margin and net profit for Electronics and Appliance Stores in the 2002 BES.

6.3.1.1 Baseline Retailer Markup[b]

The baseline markup relates the manufacturer sales price of baseline products to the retailer sales price. DOE considers baseline models to be equipment sold under existing market conditions (i.e., without new energy efficiency standards). DOE calculated the baseline markup (MU_{BASE}) for retailers as an average markup using the following equation:

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[a] U.S. Census, 2007 Annual Retail Trade Report: Electronics and Appliance Stores Sales and Gross Margin

[b] As described in section 6.1, the baseline retail markup was not used in the analysis for refrigeration products. DOE presents the derivation of this markup so it can be contrasted with the incremental retail markup.

$$MU_{BASE} = \frac{CGS_{RTL} + GM_{RTL}}{CGS_{RTL}}$$

where:

MU_{BASE} = Baseline retailer markup,
CGS_{RTL} = Retailer's cost of goods sold,
GM_{RTL} = Retailer's gross margin,

Table 6.3.1 shows the calculation of the baseline retailer markup.

Table 6.3.1 Data for Baseline Markup Calculation: Electronics and Appliance Stores (2002)

Kind of business item	Amount ($1,000)
Sales	$83,896,811
Cost of Goods Sold (CGS)	$57,888,800
Gross Margin (GM)	$26,008,011
Baseline Markup = (CGS+GM)/CGS	**1.45**

Source: U.S. Census, 2002 Business Expenses Survey (for Sales) and 1997 Business Expenses Survey (for CGS and GM shares)

6.3.1.2 Incremental Retailer Markup

Incremental markups are coefficients that relate the change in the manufacturer sales price of higher-efficiency models to the change in the retailer sales price. DOE considers higher-efficiency models to be equipment sold under market conditions with new efficiency standards. The incremental markup reflects a situation in which the retailer faces an increase in CGS for a particular product due to new or amended standards.

Unfortunately, empirical evidence regarding appliance retailer markup practices when a product increases in cost (due to increased efficiency or other factors) is lacking. DOE understands that real-world markup practices will vary depending on the market conditions faced by retailers, on the magnitude of the change in CGS associated with an efficiency increase and on any associated changes in retail costs. Pricing in retail stores may also involve rules of thumb that are difficult to know and to incorporate into DOE's analysis.

Given the uncertainty about actual markup practices in appliance retailing, DOE uses an approach that reflects the following key concepts:

1. Changes in the efficiency of the goods sold are not expected to increase economic profits. Thus, DOE calculates markups/gross margins to allow cost recovery for retail companies in the distribution chain (including changes in the cost of capital) without changes in company profits.

2. Efficiency improvements impact some distribution costs but not others. DOE sets markups and retail prices to cover the distribution costs expected to change with efficiency but not the distribution costs that are not expected to change with efficiency.

   The incremental markup approach is described in more detail in Dale et al. (2004).[4]

To estimate incremental retailer markups, DOE divides retailers' operating expenses into two categories: (1) Those that do not change when CGS increases due to amended efficiency standards ("fixed"), and (2) Those that increase proportionately with CGS ("variable"). DOE defines fixed costs to include labor and occupancy expenses because these costs are not likely to increase as a result of a rise in CGS due to amended efficiency standards. All other expenses, as well as the net profit, are assumed to vary in proportion to CGS. Although it is possible that some of the other expenses may not scale with CGS, DOE is inclined to take a more conservative position and include these as variable costs. (Note: Under DOE's approach, a high fixed cost component yields a low incremental markup.)

DOE calculated the incremental markup (MU_{INCR}) for retailers using the following equation:

$$MU_{INCR} = \frac{CGS_{RTL} + VC_{RTL}}{CGS_{RTL}}$$

where:

MU_{INCR} =	Incremental retailer markup,
CGS_{RTL} =	Retailer's cost of goods sold, and
VC_{RTL} =	Retailer's variable costs.

Table 6.3.2 shows the breakdown of operating expenses using the 2002 BES data. The incremental markup is calculated as 1.17.

Table 6.3.2 Data for Incremental Markup Calculation: Electronics and Appliance Stores (2002)

	Amount ($1,000)
Sales	$83,896,811
Cost of Goods Sold (CGS)	*$57,888,800*
Gross Margin (GM)	*$26,008,011*
Labor & Occupancy Expenses ("Fixed")	
Annual payroll	$10,267,605
Employer costs for fringe benefit	$1,407,970
Contract labor costs including temporary help	$160,094
Purchased utilities, total	$427,809
Cost of purchased repair and maintenance services	$308,789
Cost of purchased management consulting administrative services and other professional services	$300,548
Purchased communication services	$400,598
Lease and rental payments	$2,655,286
Taxes and license fees (mostly income taxes)	$385,538
Subtotal:	$16,314,237
Other Operating Expenses & Profit ("Variable")	
Expensed computer related supplies	$86,751
Cost of purchased packaging and containers	$41,866
Other materials and supplies not for resale	$611,361
Cost of purchased transportation, shipping and warehousing services	$500,233
Cost of purchased printing services	$285,012
Cost of purchased advertising and promotional services	$1,840,898
Cost of purchased legal services	$90,020
Cost of purchased accounting, auditing, and bookkeeping services	$86,292
Cost of purchased custom coded original software (expensed) including adaption of off-the-shelf software	$18,944
Cost of system support design and services including web design	$35,748
Cost of insurance	$393,201
Cost of data processing and other purchased computer services, except communications	$41,056
Depreciation and amortization charges	$1,229,110
Commissions paid	$106,061
Other operating expenses	$2,929,906
Cost of contract work	$21,955
Net profit before taxes	*$1,375,360*
Subtotal:	$9,693,774
Incremental Markup = (CGS+Total Other Operating Expenses and Profit)/CGS	**1.17**

Source: U.S. Census, 2002 Business Expenses Survey

By dividing expenses into fixed and variable components, the incremental markup approach envisions that retailers cover costs without changing profits. Although retailers may be able to reap higher profits for a time, DOE's approach assumes that competition in the appliance retail market, combined with relatively inelastic demand (*i.e.,* the demand is not expected to decrease significantly with a relatively small increase in price), will tend to pressure retail margins back down.

To measure the degree of competition in appliance retailing, DOE estimated the four firm concentration ratio (FFCR) of major appliance sales in three retail channels: Electronics and Appliance Stores, Building and Material and Supplies Dealers, and General Merchandise Stores. The FFCR represents the market share of the four largest firms in the relevant sector. Generally, an FFCR of less than 40% indicates that the sector is not concentrated and an FFCR of more than 70% indicates that a sector is highly concentrated.[c] [d]

The FFCR of sub-sector appliance sales within each channel is equal to the sector FFCR times the percent of total sales within each channel accounted for by major appliances. As shown in Table 6.3.3, the results indicate that appliance sales in Electronics and Appliance Stores, Household Appliance Stores, Building Material Supplies Dealers and General Merchandise Stores have a FFCR well under the 40% threshold. Moreover, the Electronics and Appliance Stores sector includes "Household Appliance Stores" as a subsector. Because there are many stores in this subsector, it has a FFCR of only 16.8%.

Table 6.3.3 Electronics and Appliance Stores, Concentration by Four Large Firms

Sector	**Four Firm Concentration Ratio** (Percent of Sector Sales)	**Percent of Sales Accounted for by Major Appliances**	**Four Firm Concentration Ratio** (Percent of Major Appliance Sales)
Electronics and Appliance Stores	43.9	39.4	17.3
Household Appliance Stores subsector	16.8	-	-
Building Material and Supplies Dealers	41.7	15.7	6.5
General Merchandise Stores	65.1	35.4	23.0

Source: U.S. Economic Census, Establishment and Firm Size: (Including Legal Form of Organization), 1997, 2002.
*Note: The assumption used here is that major appliance sales are uniformly distributed within all firms in each sector.

[c] University of Maryland University College
http://info.umuc.edu/mba/public/AMBA607/IndustryStructure.html
[d] Quick MBA
http://www.quickmba.com/econ/micro/indcon.shtml

6.4 SALES TAXES

The sales tax represents state and local sales taxes that are applied to the consumer equipment price. The sales tax is a multiplicative factor that increases the consumer equipment price.

DOE derived state and local taxes from data provided by the Sales Tax Clearinghouse.[5] DOE derived population-weighted average tax values for each Census division and large state, as shown in Table 6.4.1.

Table 6.4.1 Average Sales Tax Rates by Census Division and Large State

Census Division/State	Tax Rate
New England	6.1%
Mid Atlantic	6.6%
East North Central	6.9%
West North Central	6.9%
South Atlantic	6.6%
East South Central	7.9%
West South Central	8.4%
Mountain	6.8%
Pacific	7.5%
New York State	8.5%
California	9.2%
Texas	8.1%
Florida	6.7%

DOE then derived U.S. average tax values for each product (as shown in Table 6.4.2 below) based on the product's saturation within each Census division and large state. It determined the saturations from the DOE Energy Information Administration (EIA)'s 2005 Residential Energy Consumption Survey.[6]

Table 6.4.2 Average Sales Tax Rates by Product

Product	Tax Rate
Refrigerators (Standard-size and compact)	7.3%
Freezers (Standard-size and compact)	7.2%

6.5 SUMMARY OF MARKUPS

Table 6.5.1 summarizes the markups at each stage in the distribution channel and the average sales tax.

Table 6.5.1 Summary of Markups

Markup	Baseline	Incremental
Manufacturer	1.26	
Retailer	1.45	1.17
Sales Tax	1.073	

REFERENCES

[1] Association of Home Appliance Manufacturers. *AHAM 2003 Fact Book*, 2003. Washington, DC. p. 25.

[2] Security Exchange Commission, *SEC 10-K Reports,* Various dates, 1999-2006, Security Exchange Commission. <http://www.sec.gov/>

[3] U.S. Census Bureau. *2002 Economic Census, Business Expenses Survey, Retail Trade, Household Appliance Stores*, 2002. Washington, DC. <http://www.census.gov/csd/bes/bes97.htm>

[4] *Dale, Larry et al., "An Analysis of Price Determination and Markups in the Air-Conditioning and Heating Equipment Industry", LBNL-52791, January 2004.*

[5] Sales Tax Clearinghouse, Inc. *State sales tax rates along with combined average city and county rates*. <http://thestc.com/STrates.stm>

[6] U.S. Department of Energy-Energy Information Administration. *Residential Energy Consumption Survey, 2005Public Use Data Files*. Washington, DC. <http://www.eia.doe.gov/emeu/recs/recspubuse05/pubuse05.html>

CHAPTER 7. ENERGY USE ANALYSIS

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CHAPTER 7. ENERGY USE ANALYSIS

7.1 INTRODUCTION

To perform the life-cycle cost (LCC) and payback period (PBP) calculations described in chapter 8, the U.S. Department of Energy (DOE) determines the savings in operating cost that consumers would reap from more efficient products. DOE uses data on annual energy consumption, along with energy prices, to develop the most significant component of consumer operating cost. (Maintenance and repair costs are the other components.) This chapter describes how DOE determined the annual energy consumption of refrigeration products for the LCC and PBP analysis.

The goal of the energy use analysis is to generate a range of energy use values that reflects actual product use in American homes. The analysis uses information on use of actual products in the field to estimate the energy that would be used by new products at various efficiency levels.

The DOE test procedure produces standardized results that can be used to assess or compare the performance of products operating under specified conditions. Actual energy usage in the field often differs from that estimated by the test procedure because of variation in operating conditions, the behavior of users, and other factors. In the case of refrigerator-freezers, researchers have conducted studies that measure the field consumption and compare it to the DOE test results for the measured models. DOE's review of several such studies, which is described in appendix 7-A, confirmed that energy use measured in the field often differs considerably from the usage measured by the DOE test procedure.

7.1.1 Overview of Approach Used in the Preliminary Analysis

In its preliminary analysis, DOE treated the field energy consumption reported for households in the Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS)[1] as the actual consumption of the refrigeration product(s) in that household. RECS queries a national sample of households to collect statistical information on household consumption of and expenditures for energy, along with data on energy-related characteristics of the housing units and households. RECS provides enough information to establish the type of refrigeration product (the product class) used in each household, and provides an estimate of the household energy consumption attributable to refrigerators or freezers. DOE estimated the test energy use of the refrigerators or freezers in RECS homes, and then derived a "usage adjustment factor' (UAF) as the ratio of the reported field energy consumption for each sample household to the estimated test energy use. DOE developed such UAFs for standard-size units, but not for compact units because many of those products are used outside the residential sector, such as in college dormitories, hotels and motels, and offices.

For each considered efficiency level, DOE calculated field-adjusted annual energy consumption for each home by multiplying the tested energy consumption of a new refrigeration product, measured using the existing test procedures, by the efficiency standard adjustment factor (ESAF) and the UAF for that household.

7.1.2 Overview of Approach Used for the NOPR and Final Rule

During the preliminary analysis, stakeholders raised several concerns over the use of the field energy consumption reported in RECS to derive UAFs. Therefore, for the NOPR, DOE developed a new approach to derive UAFs for the RECS sample households. This approach involved collection of field-metered electricity use data for residential refrigeration products. The approach was retained for the Final Rule.

DOE was able to obtain data from seven studies, including about 100 data points that DOE collected itself. A total of 1,967 data points were collected that included units from all representative product classes except compact freezers, and spanned a variety of collection years, unit ages, U.S. locations and household populations, including some units used in commercial settings (e.g., offices and hotels). DOE made various adjustments to the raw data, including extrapolation to annual electricity consumption where necessary.

From identifying information about each unit, its test energy consumption was estimated and the UAF was calculated as the ratio of metered energy use to test energy use. The data were pooled into four categories: primary refrigerators, secondary refrigerators, freezers and compact refrigerators. Although DOE considered including data for compact refrigerators in the final analysis, it decided not to include those data due to concerns over data quality and representativeness.

For each category, DOE performed weighted least-squares regressions on numerous variables of potential interest in order to construct a function that predicts the UAF based on household and climate variables. DOE selected for final evaluation a small number of variables for which the regression results had sufficient statistical significance,and that could be obtained or reasonably inferred from RECS variables. Within each of the three product categories modeled, DOE used the appropriate set of regression coefficients, along with values for the relevant variables specific to each household, to generate UAF estimates for each RECS household. For compact refrigeration products, a UAF of 1 was used.

Using the UAF derived for each RECS household, DOE determined the field energy consumption in each household of a new refrigeration product at each considered efficiency level using the following equation:

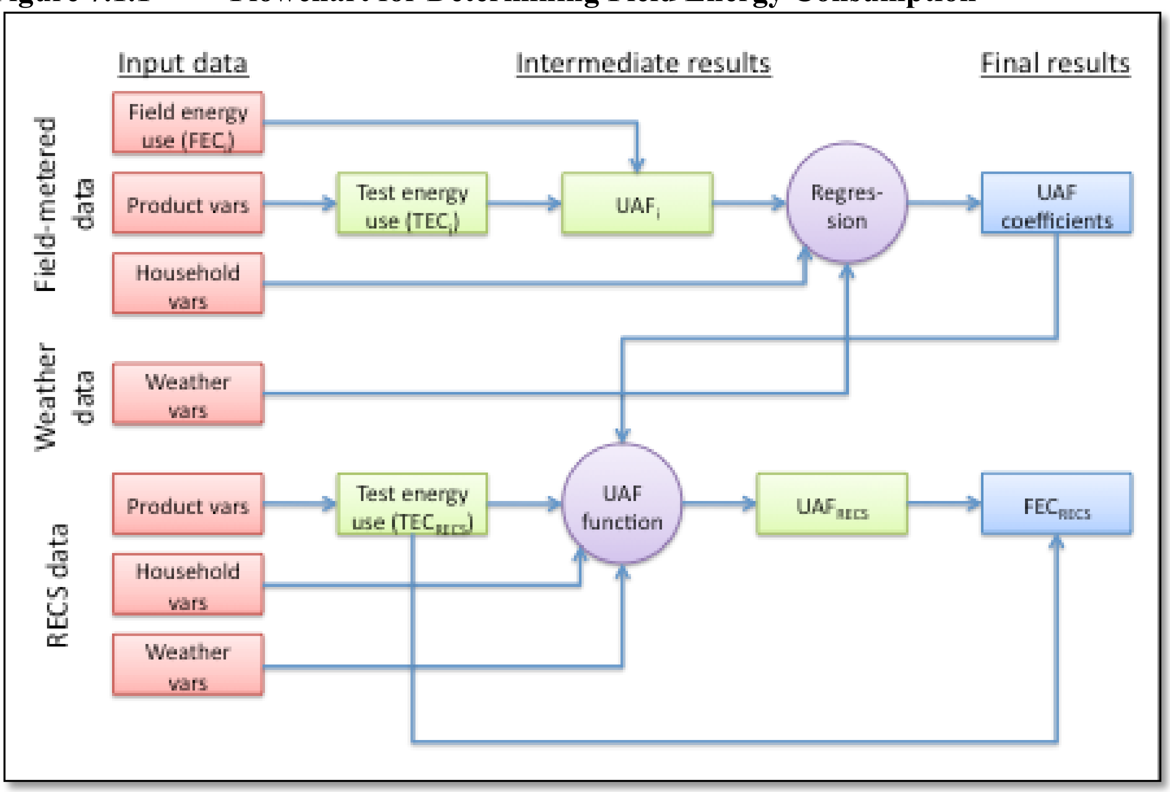
$$FEC_{EL} = FEC_{RECS} \bullet (1 - R) = UAF_{RECS} \bullet TEC_{RECS} \bullet (1 - R) \qquad \textbf{Eq. 7.1}$$

where:

FEC_{EL} = new refrigeration product's field energy consumption at a given efficiency level;
FEC_{RECS} = new refrigeration product's field energy consumption at baseline efficiency level;
R = reduction in energy consumption (expressed as fraction) due to efficiency improvements;
UAF_{RECS} = usage adjustment factor specific to RECS household;
TEC_{RECS} = maximum allowable test energy consumption for the new baseline refrigeration product.

Figure 7.1.1 illustrates the data analysis process flow graphically. The items in rectangles represent data sets, while the items in circles represent major calculation procedures.

Figure 7.1.1 Flowchart for Determining Field Energy Consumption



7.2 HOUSEHOLD SAMPLES FOR REFRIGERATION PRODUCTS

DOE developed household samples for refrigeration products from the 2005 RECS. The survey, which sampled 4,382 housing units, was constructed to represent the household population throughout the United States.

RECS results indicate whether a household uses a standard-size refrigerator or freezer. For households that have a standard-size refrigerator, RECS specifies whether the freezer is top-or bottom-mounted, or is side-mounted. Units in the sample that have top-mounted freezers (product class 3) cannot be distinguished from those having bottom-mounted freezers (product class 5). Therefore, DOE used the same household sample for product classes 3 and 5. However, adjustments were made to the household weightings for these two product classes; see below.

For a household's primary (or "first") refrigerator, RECS specifies whether there is through-the-door (TTD) ice service. For households that have standard-size freezers, RECS specifies whether the unit is upright or a chest-type. With the above data, DOE was able to assign each product class considered for potential new efficiency standards to a set of household records (Table 7.2.1). For each of the representative built-in product classes, DOE used the sample that corresponds most closely to the type of built-in product (e.g., for product class 3A-BI, DOE used the sample for product class 3).

Table 7.2.1 Refrigeration Products in Households by Product Class

Product Class	Number of Household Records*	Percent of Total Household Records*	Relative Standard Error Due to Sampling*
3. Refrigerator-freezer: automatic defrost with top-mounted freezer and no TTD[†] ice service 5. Refrigerator-freezer: automatic defrost with bottom-mounted freezer and no TTD ice service	2,303	52.6%	2.1%
7. Refrigerator-freezer: automatic defrost with side-mounted freezer and TTD ice service	1,026	23.4%	3.1%
9. Upright freezer with automatic defrost	248	5.7%	6.4%
10. Chest freezer and all other freezers except compact models	369	8.4%	5.2%

* From the Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS).
[†] Through-the-door.

The relative standard errors associated with the subsamples that contain specific product classes are not considered so large as to affect the validity of the derived results presented in this chapter. Specifically, the relative standard error of a sample of size N, expressed as a percentage, is approximated closely as 100 divided by the square root of (N-1). For the full 2005 RECS sample, the associated relative standard error due to sampling is 1.5 percent. For the subsamples containing product classes 9 and 10, the associated relative standard errors are 6.4 percent and 5.2 percent, respectively. Although the standard error for the smallest subsample is more than four times the error for the entire 2005 RECS, it still is less than 10 percent, a relative standard error considered small enough to yield meaningful results. Therefore, DOE believes the results generated from the household samples for refrigeration products are representative of U.S. households using those appliances.

For the NOPR and final rule analyses, DOE made adjustments to the statistical weightings of RECS samples for product classes 3 and 5 based on relationships between income and product class ownership provided by AHAM.[a] Therefore, even though the same RECS households are used to represent both product classes 3 and 5, the statistical contribution of these households to the economic analyses differed. Table 7.2.2 provides the resulting shares by income group.

Table 7.2.2 RECS Shares of Top-Mount and Bottom-Mount Refrigerator-Freezers

		Values Used in NOPR and Final Rule Analyses	
Annual Income	**Values Used in Preliminary Analysis for Top- and Bottom-Mount Refrigerator-Freezers**	**Top-Mount Refrigerator-Freezers (Product Class 3)**	**Bottom-Mount Refrigerator-Freezers (Product Class 5)**
<$25,000	36.9%	40.1%	25.1%
$25,000-$49,000	29.4%	31.1%	30.0%
$50,000-$99,999	24.2%	21.5%	28.7%
$100,000-$119,999	3.9%	3.1%	6.6%
$120,000+	5.6%	4.2%*	9.6%*
Sum	100.0%	100.0%	100.0%

* Because AHAM data only provided ownership fractions in two bins ($100,000-$149,999 and $150,000+), ownership for the $120,000+ income level was calculated by weighting data from these above two bins by data from the American Housing Survey (2005) indicating the fraction of households in each bin (62% between $100,000-$149,999, and 38% at $150,000 or above).

For built-in products (product classes 3A-BI, 5-BI, 7-BI and 9-BI), DOE used a single relationship between income and built-in ownership provided by AHAM to weight the RECS ownership of each built-in product class, shown in Table 7.2.3.

Table 7.2.3 Ownership Fraction of Built-In Refrigeration Equipment

Annual Income	**Ownership Fraction of Built-ins**
<$25,000	2%
$25,000-$49,000	2%
$50,000-$99,999	2%
$100,000-$119,999	3%
$120,000+	6%*

[a] Association of Home Appliance Manufacturers (AHAM), "Product Saturation by Income," personal communication, April 1, 2010.

* Because AHAM data only provided ownership fractions in two bins ($100,000-$149,999 and $150,000+), ownership for the $120,000+ income level was calculated by weighting data from these above two bins by data from the American Housing Survey (2005) indicating the fraction of households in each bin (62% between $100,000-$149,999, and 38% at $150,000 or above).

7.3 FIELD-METERED DATASETS AND UAF FUNCTION DETERMINATION

DOE used field-metered energy use data, combined with estimates of the test energy use of each field-metered unit, to calculate the UAF for each data point from the following formula:

$$UAF_i = FEC_i / TEC_i \qquad \textbf{Eq. 7.2}$$

Where:

UAF_i = usage adjustment factor specific to the field-metered data point;
FEC_i = field-metered annualized electricity use;
TEC_i = test energy consumption annual electricity use.

DOE divided the data into four categories: standard-sized primary refrigerator-freezers, standard-sized secondary refrigerator-freezers, standard-sized freezers, and compact refrigerators. For each category, DOE performed weighted least-squares regressions on numerous variables of potential interest in order to construct a function that predicts the UAF based on household and climate variables. DOE selected for final evaluation a small number of variables for which the regression results had sufficient statistical significance and that could be obtained or reasonably inferred from RECS variables.

For more information on the approach, field-metered data analysis and UAF function determination results, please see the paper in preparation by Greenblatt et al.[2]

7.3.1 Field-Metered Data Sources

DOE obtained metered electricity use data on refrigeration products from seven datasets, shown in Table 7.3.1 below, including more than 100 data points which DOE collected itself. A total of 1,967 data points were collected that included units from all representative product classes except compact freezers, and spanned a variety of collection years, unit ages, U.S. locations and household populations, including some units used in commercial settings (e.g., offices and hotels).

Table 7.3.1 Field-Metered Datasets

						Number of data points				
Study	**Popula -tion**	**State**	**Period metered**	**Average duration**	**Average unit age (years)**	**Standard-sized refrigerator-freezers**		**Standard-sized freezers**	**Compact refri-gerators**	**Total**
						Primary units	Second-ary units			
Proctor Engineering Group	New rebated units	CA	1992-1993	8 mos.	0.5	129	0	0	0	129
Comelec	General	MA	1995-1996	2.2 hrs.	9.2	802	93	52	0	947
Dalhoff & Associates	Low-income	IA	1998-1999	10 days	5.3	44	2	10	0	56
Energy Center of Wisconsin	Single-family homes	WI	1999	2.4 hrs.	7.4	204	17	123	0	344
Energy Center of Wisconsin	Renters	WI	2003	2.0 hrs.	7.9	186	0	0	0	186
NSTAR	General	MA + RI	2003-2004	21 days	14.4	141	41	0	0	182
LBNL	Offices/ hotels	CA	2009-2010	8 days	6.5	27	0	0	96	123
Total						1,533	153	185	96	1,967
Total used for analysis						1,358	109	185	0	1,652

In addition to metered electricity use, the data sets included some identifying information about each unit (such as brand, model number, year manufactured, door style, presence/absence of through-the-door ice service, and interior volume), as well as some household characteristics and geographic location. DOE omitted about 16% of the data points due to missing information and/or data quality issues. For compact refrigerators, all 96 data points were analyzed but DOE decided not to use the resulting fits in the final analysis due to a concern that the data were not sufficiently representative.

7.3.2 Determination of Test Energy Use of Field Units

The test (i.e., rated) energy use for each unit in the analysis was determined by a two-tiered process.

First, DOE looked up the recorded model number of each study unit in several published databases of test results. Data sources included the California Energy Commission, the Federal Trade Commission, the Environmental Protection Agency, and a compilation database hosted by Home Energy Magazine. Given the possibilities of typographical errors in the recorded model numbers and the use of wildcard values by manufacturers within model numbers, a fuzzy string matching algorithm was employed to identify the closest matches to each reported model number. These matches were then checked based on product class, volume, and year of manufacture in addition to manual inspection. This process resulted in confirmed matches for 63% of all units: 1,235 of the total 1,967. The overall matching rate was 70% for the analysis sample (since some units were omitted) and 76% for the primary refrigerators.

For units that could not be matched based on the recorded model number, the Federal efficiency standard for the year of manufacture was used as the estimate, calculated based on product class, adjusted volume and year of manufacture. For units manufactured prior to the 1990 standards, the 1990 standards values were multiplied by year-specific efficiency factors from AHAM. Since the efficiency standard is a maximum value for energy use, it may over-estimate the actual rated use of the units. The extent of the over-estimation was assessed by comparing reported values for matched units to the standards. This analysis found that the average unit built in 1990 or later was rated to use 6.1% less than the Federal standard. For units built prior to 1990 that included a vintage multiplier, the actual rated use averaged just 0.7% less than this estimate. However, in neither case were the rated energy use results scaled or altered.

7.3.3 Field-Metered UAF Regressions

7.3.3.1 Temperature Regressions

Because of the primary role that temperature plays in refrigerator/freezer electricity use (from thermodynamics, about 2.5% to 3.0% per °F temperature difference between inside and outside the unit), it was desirable to obtain correlations of energy use with ambient (indoor) temperature. However, such data were only available for a limited number of data points. By contrast, heating and cooling degree-days were readily available for all data from a historic U.S. weather database, and is already included in RECS data. Previous work including the NSTAR study listed in the table, has found a consistent relationship between indoor and outdoor temperatures that varies with whether space conditioning is needed and used. In addition, the Proctor Engineering study found a similar relationship between refrigerator energy use and outdoor temperature. At outdoor temperatures below approximately 60°F, average indoor temperature decreases by about 0.02 to 0.05°F per outdoor °F, whereas above 70°F, average indoor temperature increases by about 0.1 to 0.4°F per outdoor °F depending on the use of air conditioning. In the range of about 60°F to 70°F, indoor temperature tends to more closely follow outdoor temperature variations as space conditioning is often not used and windows may be open.

Given these relationships between weather, indoor temperature, and refrigerator energy use, DOE decided to model refrigerator energy use using three climate variables: heating degree days base 59°F (HDD59), average outdoor temperature (minus 65°F to approximately center the values), and cooling degree days base 70°F (CDD70). However, RECS provided only heating and cooling degree days calculated with base of 65°F (HDD65 and CDD65, respectively), which unfortunately falls right in the middle of the sensitive portion of the indoor-outdoor temperature relationship. Therefore, DOE developed a model to convert HDD65 and CDD65 values into estimates of HDD59 and CDD70. The average outdoor temperature was also easily obtained from the difference between HDD65 and CDD65.

The estimation of CDD70 and HDD59 from CDD65 and HDD65 was based on calculating each of these four values for each of the 1,020 weather stations included in the Typical Meteorological Year (TMY) 3 weather datasets produced by the National Renewable Energy Laboratory. Regression models of HDD59 and CDD70 were developed that included HDD65, CDD65 and the square roots of each of these values. The resulting regression models provided an excellent fit to the data with R-squared values of 0.9957 for CDD70 and 0.9995 for HDD59. These equations were then used with the RECS data on HDD65 and CDD65 to model the weather impacts of the units. Note that heating and cooling degree days (per year) were converted to heating or cooling degrees (denoted by HD or CD, respectively) by dividing the quantity by the average number of days in a year. Table 7.3.2 shows the temperature parameters.

Table 7.3.2 Temperature Parameters

	Symbol	Coefficient	Standard deviation (1σ)	T-value
HD59 (°F) parameters				
Constant	a_H	-2.30145	0.057953	-39.7
HD65 (°F)	b_H	1.1933	0.003702	302.3
CD65 (°F)	c_H	-0.21377	0.008593	-24.9
$\sqrt{HD65(°F)}$	d_H	-1.32905	0.028216	-47.1
$\sqrt{CD65(°F)}$	e_H	1.500784	0.027742	54.1
CD70 (°F) parameters				
Constant	a_C	-1.714641	0.0502549	-34.1
HD65 (°F)	b_C	-0.0977721	0.0032106	-30.5
CD65 (°F)	c_C	1.038835	0.0074511	139.4
$\sqrt{HD65(°F)}$	d_C	0.8797741	0.0244682	36.0
$\sqrt{CD65(°F)}$	e_C	-1.008089	0.0240571	-41.9
Average outside temperature (T_{out}) minus 65°F parameters				
Constant	a_T	0	Not applicable	
HD65 (°F)	b_T	-1	Not applicable	
CD65 (°F)	c_T	1	Not applicable	

Formulas:

$$HD65\ (°F) = HDD65\ (°F\ days) / 365.25\ days \quad \textbf{Eq. 7.3}$$

$$CD65\ (°F) = CDD65\ (°F\ days) / 365.25\ days \quad \textbf{Eq. 7.4}$$

$$HD59\ (°F) = a_H + b_H \bullet HD65\ (°F) + c_H \bullet CD65\ (°F) + d_H \bullet \sqrt{HD65(°F)} + e_H \bullet \sqrt{CD65(°F)} \quad \textbf{Eq. 7.5}$$

$$CD70\ (°F) = a_C + b_C \bullet HD65\ (°F) + c_C \bullet CD65\ (°F) + d_C \bullet \sqrt{HD65(°F)} + e_C \bullet \sqrt{CD65(°F)} \quad \textbf{Eq. 7.6}$$

$$T_{out} - 65\ (°F) = a_T + b_T \bullet HD65\ (°F) + c_T \bullet CD65\ (°F) = CD65\ (°F) - HD65\ (°F) \quad \textbf{Eq. 7.7}$$

7.3.3.2 Primary Refrigerator-Freezers

For standard-sized primary refrigerator-freezers, which contained the largest number of sample points, the following primary predictor variables were used in the final model: unit age, heating and cooling degree days, outdoor temperature, presence/absence of a TTD icemaker, and number of household occupants. All variables except the last one were obtained from the full set of primary refrigerator-freezer data.

In addition to these predictor variables, the model included control variables to capture other factors related to metered refrigerator energy use including a dummy variable to indicate units manufactured prior to 1993, a dummy variable to indicate units metered for less than a day (typically 2-3 hours), and a dummy variable to indicate a low-income household (identified in just two of the studies). The analysis found that each of these factors was associated with a difference in UAF.

Units built prior to 1993 tended to have a lower UAF than those built later by about 15%.

Units that were only metered for a few hours tended to use about 10% more energy relative to their rating than those metered for longer periods. This finding is believed to reflect a bias from short-term metering since all such metering occurs during the daytime and when occupants are home.

Units in low income households (all units in the Dalhoff Iowa study and some units in the ECW single family Wisconsin study) use on average about 17% more relative to their rating than those not identified as low income. It was concluded that the bias must reflect the prevalence in low-income households of units that are bought used, and tend to run less efficiently than similarly-aged models that were bought new. However, there may have also been a bias in the sample of households metered, because the purpose of the metering program was to identify households with high energy-consumption units in order to qualify them for free replacement. DOE decided not to include this effect as a predictive variable for new units, because it was felt that any "low income" effect in the general population is likely to be much lower than that observed in a sample of high energy use units among low income residents.

DOE explored a number of regression modeling approaches. For the approach finally selected, data were weighted based on the duration of metering, with the weight defined as the square root of the number of metered hours. This weighting reflects the greater variability inherent in short-term data, separate from the bias previously discussed.

The impact of unit age on energy use was explored using several approaches. The data generally supported the hypothesis that a decrease in performance (e.g., increase in energy use) manifested quickly approximately over the first year, and over subsequent years a steady but slower decrease occurred. This type of degradation should be expected due to the degradation in effective R-value of the foam insulation. One dataset (Proctor Engineering Group) provided a little less than a year of continuous data on 129 newer refrigerators. A regression analysis of that data found a first year annual degradation rate of 8.9% (±2.4% at 1σ confidence interval). But the result varied under differing model specifications. Some long-term data on a smaller sample of refrigerators provided by BC Hydro (not included in Table 7.3.1) revealed an annual degradation rate of about 1% per year for older existing units. But the largest sample size and most consistent estimate of degradation came from including an age variable into the larger cross-sectional regression model. The model estimated an annual degradation rate of 1.60% (±0.20%). This figure is fairly close to the 1.37% estimated by Pratt and Miller ("The New York Power Authority's Energy-Efficient Refrigerator Program for the New York City Housing Authority—1997 Savings Evaluation", PNNL-11990, 1998). Attempts to fit differing degradation rates at differing ages were not successful, most likely due to a lack of metered data from refrigerators between 1 and 5 years old.

About half of the primary refrigerator data contained information about the number of household occupants. DOE performed a regression on this subset to obtain a relationship between UAF and number of occupants. DOE tested a regression model where each occupant received its own separate coefficient, and found that the correlation with UAF was linear for 1-3 occupants. Above 3 occupants, the correlation was very weak and inconsistent depending on other variable choices, so that variable was dropped. The final model consisted of a single coefficient times the number of occupants up to 3. Results are shown below in Table 7.3.3.

The presence of through-the-door (TTD) icemaking was found to be statistically significant. While a percentage energy use model was considered, DOE found that slightly better model agreement resulted when TTD icemaking was fitted in absolute (energy) terms, so this variable was treated somewhat differently from the other variables

The TTD variable is strongly correlated with the side-by-side door variable (denoting product class 7), but separate correlations with door style (side-by-side or otherwise) are extremely weak, and were therefore not included in the final model. The large magnitude of the TTD coefficient (about twice the placeholder energy consumption value of 84 kWh/yr associated with the proposed new test procedure) is indicative of older units; but represents approximately 12% of non-TTD icemaking energy consumption as measured by UEC_{test}, consistent with previous estimates of the size of this term.[3]

The UAF function was calculated in two stages, using the set of best-fit coefficients shown in Table 7.3.3. The first stage was based entirely on deterministic variables derived from RECS:

$$UAF_{int}\,(\%) = a_P + b_P \bullet AGE + c_P \bullet HD59 + d_P \bullet CD70 + e_P \bullet (T_{out} - 65°\text{F}) + f_P \bullet OCCUP3 + (g_P / TEC_{RECS}) \bullet TTD \qquad \textbf{Eq. 7.8}$$

Where:

UAF_{int} =	intermediate UAF function for primary refrigerators;
AGE =	age of refrigerator in years;
$HD59$ =	as defined above;

$CD70$ = as defined above;
T_{out} = as defined above;
$OCCUP3$ = number of occupants up to and including three;
TTD = presence of through-the-door icemaking (=1);
TEC_{RECS} = test energy consumption of unit (kWh).

The UAF_{int} function did not capture all the observed variability in the metered data. In order to represent this additional variability, a log normal function was fitted to the residual distribution of ratios of predicted-to-observed UAF values. DOE used this function as a probability distribution to sample from, and multiplied the resulting scaling factor by the above UAF function:

$$UAF_P\,(\%) = UAF_{int} \bullet r_P \qquad \textbf{Eq. 7.9}$$

Where:

UAF_P = UAF of primary refrigerators;
r_P = random draw from residual log normal distribution (with standard parameters).

Table 7.3.3 Final UAF Regression Model for Primary Standard-Sized Refrigerator-Freezers

	Symbol	Coefficient	Standard deviation (1σ)	T-value
Parameters				
Constant	a_P	72.9%	4.33%	16.83
Unit age (years)	b_P	1.60%	0.20%	8.16
Heating degrees base 59°F (HD59)	c_P	1.89%	0.54%	3.47
Cooling degrees base 70°F (CD70)	d_P	-0.81%	0.89%	-0.91
Average outside temperature (T_{out}) minus 65°F	e_P	2.00%	0.46%	4.37
Number of occupants ≤ 3	f_P	12.09%	2.48%	4.87
Through-the-door (TTD) icemaking (= 1)	g_P*	170.5 kWh	43.5 kWh	3.92
Residual	r_P	See below		
Dummy parameters (not used in RECS UAF calculations)				
Unit built before 1993 (= 1)	h_P	-12.51%	4.05%	-3.09
Low income (= 1)	i_P	16.64%	6.35%	2.62
Short-term (≤ 1 day) metering (= 1)	j_P	10.25%	2.36%	4.34
Residual log normal parameters				
Scale	σ_P	0.28771	Not available	
Location	μ_P	-0.04393	Not available	

* Note that for new refrigerators, rather than this icemaking energy coefficient, the placeholder energy consumption value of 84 kWh/yr was used.

7.3.3.3 Secondary Refrigerator-Freezers

For secondary refrigerator-freezers, the number of statistically significant variables was much smaller, and there was no correlation with number of household occupants. The location of the unit in the home, which is frequently in a room other than the kitchen and often experiences a different mean annual temperature, was found to be statistically important. After exploring a number of alternate models, DOE chose a model based on the presence of a basement and/or heated space. If a basement exists in the home, the secondary unit was assumed to reside there, with RECS data providing information on whether the basement is heated or not. If no basement exists, a probability of being located in a heated space was used, based on a statistical distribution derived from the metered data.

The UAF function was calculated from the set of best-fit coefficients shown in Table 7.3.4, and multiplied by a residual scaling factor as for primary refrigerator-freezers:

$$UAF_S\ (\%) = [a_S + b_S \bullet (T_{out} - 65°F) + c_S \bullet (T_{out} - 65°F) \bullet \text{BASEMENT} + d_S \bullet \text{HEATED}] \bullet r_S \quad \textbf{Eq. 7.10}$$

Where:

UAF_S = UAF of secondary refrigerator;

T_{out} = as defined above;

BASEMENT = existence of a basement (=1);

HEATED = heated space, defined as follows: if *BASEMENT* = 1, defined as 1 if basement is heated, 0 if unheated. If *BASEMENT* = 0, probability of 1 is 75% (random draw);

r_S = random draw from residual log normal distribution (with standard parameters).

Table 7.3.4 Final UAF Model for Secondary Standard-Sized Refrigerator-Freezers

	Symbol	Coefficient	Standard deviation (1σ)	T-value
Parameters				
Constant	a_S	100.5%	7.5%	13.5
Average outside temperature minus 65°F	b_S	0.76%	0.36%	2.13
Average outside temperature minus 65°F times Basement (= 1)	c_S	-0.32%	0.39%	-0.82
Heated space (= 1)*	d_S	21.5%	9.4%	2.29
Residual	r_S	See below		
Residual log normal parameters				
Scale	σ_S	0.44544	Not available	
Location	μ_S	-0.12201	Not available	

*See equation 7.10.

7.3.3.4 Standard-Sized Freezers

For standard-sized freezers, DOE found very few variables with statistical significance, and only a single heated space variable was used in the final model. The heated space variable was treated similarly to that for secondary refrigerator-freezers, but with a different probability for being in a heated space if not in a basement (again based on the metered data).

The UAF function was calculated from the set of best-fit coefficients shown in Table 7.3.5, and multiplied by a residual scaling factor as for primary refrigerator-freezers:

$$UAF_F\ (\%) = (a_F + b_F \bullet \text{HEATED}) \bullet r_F \quad \textbf{Eq. 7.11}$$

Where:

UAF_F = UAF of freezer;

HEATED = heated space, defined as follows: if basement exists (= 1), defined as 1 if basement is heated, 0 if unheated. If basement is not present, probability of 1 is 46% (random draw);

r_F = random draw from residual log normal distribution (with standard parameters).

Table 7.3.5 Final UAF Model for Standard-Sized Freezers

	Symbol	Coefficient	Standard deviation (1σ)	T-value
Parameters				
Constant	a_F	80.2%	3.8%	21.1
Heated space (= 1)*	b_F	14.3%	7.7%	1.86
Residual	r_F	See below		
Residual log normal parameters				
Scale	σ_F	0.47022	Not available	
Location	μ_F	-0.02309	Not available	

*See equation 7.11.

7.4 ESTIMATING FIELD ENERGY USE FOR NEW STANDARD-SIZE PRODUCTS

To determine the field energy consumption in each RECS household of a new refrigeration product at each considered efficiency level, DOE used the following equation:

$$FEC_{EL} = FEC_{RECS} \bullet (1 - R) = UAF_{RECS} \bullet TEC_{RECS} \bullet (1 - R) \qquad \textbf{Eq. 7.12}$$

where:

FEC_{EL} = new refrigeration product's field energy consumption at a given efficiency level;

FEC_{RECS} = new refrigeration product's field energy consumption at baseline efficiency level;

R = reduction in energy consumption (expressed as fraction) due to efficiency improvements;

UAF_{RECS} = usage adjustment factor specific to RECS household;

TEC_{RECS} = maximum allowable test energy consumption for the new baseline refrigeration product.

Note that, for standard-size refrigerator-freezers, UAF_{RECS}, and hence FEC_{RECS} and FEC_{EL}, are functions of time.

DOE conducted its analysis with an awareness of proposed revisions to the DOE test procedure for refrigerator-freezers, which will stipulate lower temperatures for the fresh food compartment and the freezer than those that are currently prescribed. DOE has not identified how the tested energy consumption under the new procedure will compare to that determined under the current procedure, but expects this adjustment to take the form of a multiplicative factor termed the "efficiency standard adjustment factor," or ESAF. The ESAF is expected to be multiplicative, because the energy use for a refrigeration unit is close to proportional to the difference between its interior and exterior temperatures. For the current analysis, DOE assumed that this factor is constant for each product class, and does not vary with product efficiency or adjusted volume, with the exception of product class 5. For product class 5, the ESAF is a function of adjusted volume. See chapter 5 for a complete discussion of the derivation of these values. To be general, therefore, the ESAF is referred to by $ESAF(AV)$ in subsequent equations.

Table 7.4.1 provides the value of the ESAF for refrigerator-freezers and freezers.

Table 7.4.1 Efficiency Standard Adjustment Factors (ESAF) for Refrigerator-Freezers and Freezers

Product Class	ESAF
3	1.124
5	1.123*
7	1.140
9	1.000
10	1.000

* At average adjusted volume (24.68 cu. ft.) for this product class.

Fundamentally, the value of the ESAF does not affect estimates of field energy use, because changes in the test procedure do not affect consumer behavior or operation of an appliance within a household. Field energy consumption of future appliances built to meet a national standard, however, may be affected by the test procedure used to define the standard. For this reason, DOE assumed that the effects of consumer behavior and operating conditions, characterized by the UAF, are separate from the effects of the test procedure, characterized by the ESAF. However, in order to convert to the new test energy consumption while keeping the derived field energy consumption FEC_{RECS} the same, an adjustment needed to be made to equation 7.12:

$$FEC_{EL} = UAF_{NEW-RECS} \bullet TEC_{NEW-RECS} \bullet (1 - R) \qquad \textbf{Eq. 7.13}$$

Where:

$$UAF_{NEW-RECS} = \frac{UAF_{RECS}}{ESAF(AV)} \qquad \textbf{Eq. 7.14}$$

$$TEC_{NEW-RECS} = ESAF(AV) \bullet TEC_{RECS} \qquad \textbf{Eq. 7.15}$$

DOE assumed that the UAF for a given household would be the same for products that meet some future energy efficiency standard as it is for their current appliance. In conducting the life-cycle cost analysis (chapter 8), DOE substituted the refrigeration product recorded in RECS with a new product of identical product class and size that the household is assumed to purchase in the year when the new standard goes into effect.

If R is the reduction (expressed as a percent) in energy use by the new standard from the current standard (*e.g*., a 10-percent efficiency improvement would mean $R = 0.1$), then assuming the ESAF is a multiplicative factor, as DOE did for this analysis, the field energy consumption scales simply with $(1 - R)$, regardless of the value of $ESAF(AV)$. A multiplicative ESAF therefore is not needed to calculate energy savings related to a higher efficiency standard.

7.4.1 Usage Adjustment Factors of Standard-Size Products in RECS Households

To determine $UAF_{NEW-RECS}$ for each RECS household, DOE used the appropriate set of regression coefficients (primary refrigerator-freezer, secondary refrigerator-freezer, or freezer), along with values for the necessary variables for the specific household, to generate a UAF estimate for each type of refrigeration product, using equations 7.8 to 7.11 (UAF definitions) and 7.14 (ESAF correction).

7.4.1.1 Conversion to Secondary Refrigerators

When a household purchases a new refrigerator, some first units become second units. (See chapter 8 for a discussion of how DOE modeled the conversion of refrigerators from first to second units.) A second refrigerator, generally located in a basement or garage, enters a new operating environment and may be used less than year-round. For those units that become a second refrigerator, therefore, the annual energy consumption changes, presumably remaining at the new level for the rest of its lifetime.

The UAF over a refrigerator's lifetime can be expressed in the following manner:

$$UAF(y) = \frac{\begin{cases} UAF_P(y), y < y_{conv} \\ UAF_S, y \geq y_{conv} \end{cases}}{ESAF(AV)} \qquad \textbf{Eq. 7.16}$$

Where:

$UAF(y)$ = overall usage adjustment factor (year-dependent);
$UAF_P(y)$ = usage adjustment factor for primary refrigerator phase (year-dependent);
UAF_S = usage adjustment factor for secondary refrigerator phase[b] (year-independent);

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[b] This UAF accounts for the changed operating environment during the second phase.

y_{conv} = year of conversion from primary to secondary refrigerator;
$ESAF(AV)$ = ESAF correction factor.

7.4.1.2 UAF Results by Product Class

Table 7.4.2 shows average overall UAFs, as well as UAFs in year 1 and year 20, by product class for the final rule analysis. For comparison, it also shows average UAFs by product class used in the NOPR and preliminary analyses. Note UAFs have been divided by $ESAF(AV)$ to reflect the new test procedure.

Table 7.4.2 Comparison of Usage Adjustment Factors in Preliminary, NOPR and Final Rule Analyses

Product Class	Sample Size	Mean UAF		
		Final Rule Analysis	**NOPR Analysis**	**Preliminary Analysis**
Top-mount refrigerator-freezer (PC 3)	2,303	1.00 (0.88 to 1.11)*	0.93 (0.82 to 1.04)*	1.23
Bottom-mount refrigerator-freezer (PC 5)	2,303	0.99 (0.87 to 1.10)*	0.92 (0.81 to 1.02)*	1.09
Side-by-side refrigerator-freezer with TTD (PC 7)	1,026	1.01 (0.90 to 1.11)*	0.94 (0.84 to 1.03)*	1.44
Upright freezer (PC 9)	248	0.97	0.85	1.37
Chest freezer (PC 10)	369	0.96	0.89	1.48
Top-mount built-in refrigerator-freezer (PC 3A-BI)	2,303	01.01 (0.90 to 1.12)*	0.94 (0.83 to 1.07)*	N/A
Bottom-mount built-in refrigerator- freezer (PC 5-BI)	2,303	1.00 (0.89 to 1.11)*	0.96 (0.85 to 1.07)*	N/A
Side-by-side built-in refrigerator-freezer (PC 7-BI)	1,026	1.02 (0.91 to 1.11)*	0.94 (0.84 to 1.03)*	N/A
Upright built-in freezer (PC 9-BI)	248	0.97	0.85	N/A

* Averages are based on lifetime distribution and include conversion to 2nd refrigerators. Range indicates average UAF in year 1 (minimum) and year 20 (maximum).

Figures 7.4.1 and 7.4.2 show the distribution of UAFs for the RECS households in the subsample for product class 3 (top-mount refrigerator-freezers) in year 1 and year 20, respectively. Each figure shows the distribution of UAFs used for the LCC analysis. For other standard-size product classes, the UAF distributions appear very similar. Figure 7.4.3 shows the average UAF by year for product class 3. Figure 7.4.4 shows the distribution of UAFs for the

RECS households in the subsample for product class 9 (upright freezers), which is the same for all years. The UAF distribution for product class 10 (chest freezers) is almost identical.

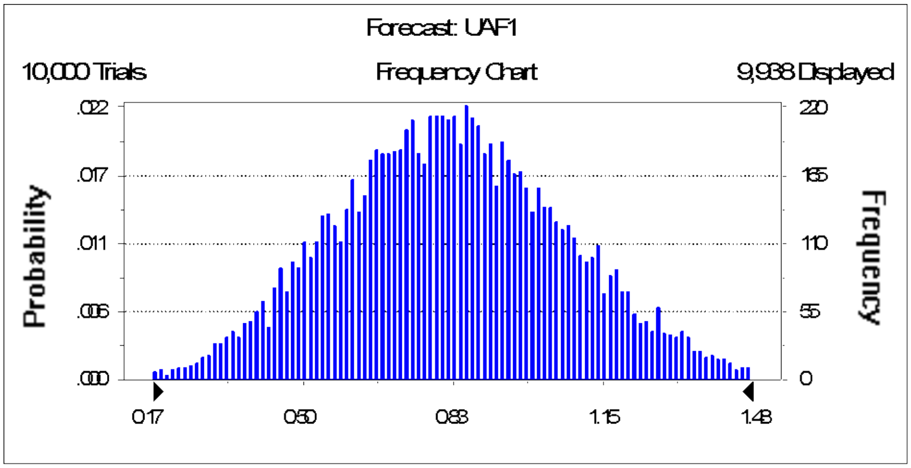

Figure 7.4.1 Product Class 3, Top Mount Refrigerator-Freezers: Distribution of UAF in the first year of the Refrigerator

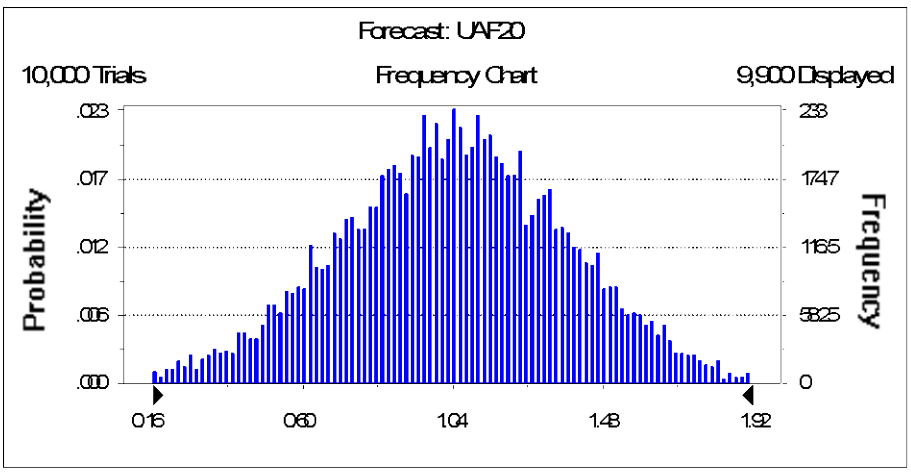

Figure 7.4.2 Product Class 3, Top Mount Refrigerator-Freezers: Distribution of UAF in the 20th year of the Refrigerator

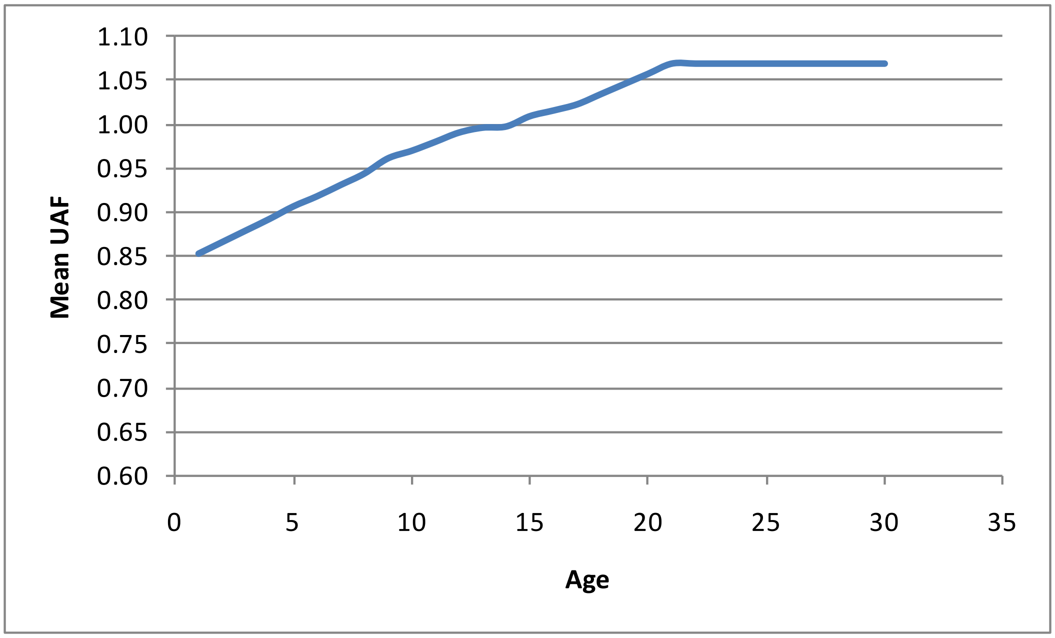

Figure 7.4.3 Product Class 3, UAF as a Function of Age

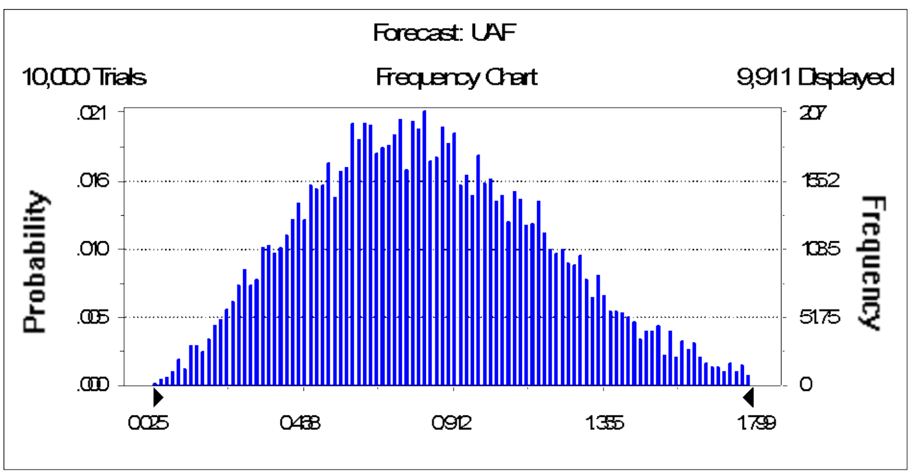

Figure 7.4.4 Product Class 9, Upright Freezers: Distribution of UAF

7.4.2 Test Energy Consumption of Standard-Size Products in RECS Households

It was necessary to develop a unique TEC_{RECS} value for each RECS household because DOE assumed that the new refrigeration product has the same characteristics as the existing-in-2005 product with respect to total interior volume (also referred to as "size"), door style, and presence of TTD ice service. The latter two items determine the product class and hence the formula to calculate test energy consumption. The size is a variable in the formula.

7.4.2.1 Determination of Total Interior Volume or "Size"

The possible answers to the RECS question regarding the size of the first refrigerator or freezer are shown in Table 7.4.3. The distribution of actual sizes is not uniform within the RECS size bins. To estimate the actual size of each unit, DOE estimated the distribution of sizes within each bin. To approximate that distribution, DOE used data on refrigerator models from the 2009 California Energy Commission (CEC) appliance model database. The figures in appendix 7-B show the number of models by size within each RECS size bin for each considered product classes. The size assigned to a sample refrigerator within a RECS size bin was assigned randomly using probabilities derived from the CEC data.

Table 7.4.3 Size Bins for Refrigerators and Freezers

Bin*	Total Interior Volume (Size) of First Refrigerator *cu ft*†
1	Very small (10 or fewer)
2	Small (11 to 14)
3	Medium (15 to 18)
4	Large (19 to 22)
5	Very large (more than 22)

* Bins defined in Residential Energy Consumption Survey, 2005.
† Cubic feet.

DOE noted significant differences in the average total interior volume of product classes 5 and 7 as obtained from the above approach, relative to consumer data provided by CEC and other sources.[c,d] Therefore, DOE scaled the resulting average total interior volumes for these product classes by the ratios shown in Table 7.4.4.

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[c] The NPD Group, Inc., The NPD Group/NPD Houseworld – POS, Refrigerators, January 2007 – December 2008. Port Washington, NY.

[d] Association of Home Appliance Manufacturers (AHAM), "Additional data request from DOE/LBNL," personal communication with DOE, May 14, 2010.

Table 7.4.4 Scaling Ratios of Total Interior Volumes for Standard-Size Refrigerator-Freezers (cu. ft.)

Product class	Data source:	Preliminary analysis (RECS and CEC)	CEC	NPD	AHAM	Correction factor for RECS/CEC (using NPD data)
	Full data range:	2005 (RECS), 1998-2009 (CEC)	1998-2009	2007-2008	2005-2008	
	Range used for average:	1998-2009	2007-2009	2007-2008	2007-2008	
5		17.96	20.75	20.87	21.59	1.16
7		21.07	24.58	24.76	n/a	1.18

7.4.2.2 Calculation of Adjusted Volume

For a refrigerator-freezer, the adjusted volume is defined as the interior volume of the fresh food compartment plus 1.63 times the interior volume of the freezer compartment.[4] Using the CEC database, DOE used the following linear regression to calculate the adjusted volume (Vol_{adj}) from the total interior volume (Vol_{tot}, defined as the sum of fresh food and freezer interior volumes):

$$Vol_{adj} = Vol_{tot} \bullet Slope + Intercept \qquad \textbf{Eq. 7.17}$$

Table 7.4.5 Parameters for Calculating Adjusted Volume from Total Interior Volume of Refrigerator-Freezers

Product Class	Slope	Intercept	$R^{2\,\dagger}$	Count
3. Refrigerator-freezers: automatic defrost with top-mounted freezer and no TTD* ice service	1.2205	-1.1049	0.9691	1,803
5. Refrigerator-freezers: automatic defrost with bottom-mounted freezer and no TTD ice service	1.1851	0.0159	0.9929	778
7. Refrigerator-freezers: automatic defrost with side-mounted freezer and TTD ice service	1.3170	-1.9992	0.9906	1,866

*Through-the-door.

† R^2 is the *coefficient of determination*, a measure of how well the model fits the data.

7.4.2.3 Calculation of Test Energy Consumption

The RECS door style and TTD ice service variables together determine the product class, aside from distinguishing top- from bottom-mount refrigerator-freezers. Table 7.4.6 lists the current energy efficiency standards. The formula that expresses the standard is for maximum allowable kWh per year as a linear function of adjusted volume (AV).[5, 6]

Table 7.4.6 Energy Conservation Standards for Refrigeration Products

Product Class	2001 Standard
3. Top-mount refrigerator-freezers without TTD* ice service	9.80AV+276.0
5. Bottom-mount refrigerator-freezers without TTD ice service	4.6AV+459.0
7. Side-by-side refrigerator-freezers with TTD ice service	10.10AV+406.0
9. Upright freezers with automatic defrost	12.43AV+326.1
10. Chest freezers	9.88AV+143.7

*Through-the-door.

7.5 ENERGY USE OF COMPACT REFRIGERATION PRODUCTS

As mentioned in the introduction to this chapter, compact refrigerators and freezers are used in homes, college dormitories, hotels and motels, and some commercial buildings. While DOE was able to collect about 100 sample points from compact refrigerators used in hotel rooms, concerns over data quality and representativeness prevented DOE from using the data to help determine field energy use. It therefore assumed that the average field energy use of compact refrigerators (and freezers) of a given size is the same as the maximum energy use allowed by the DOE standard, as measured in the DOE test procedure. In effect, DOE assumed that variation in field energy use of compact products is a function solely of volume. To represent the distribution of volumes in the field, DOE used data from the 2008 CEC appliance model database. Figures in appendix 7-B show the distribution of appliance sizes represented within the database.

DOE used the CEC database to develop a linear equation relating listed total volume to adjusted volume for product class 11. The parameters of the equation are listed in Table 7.5.1. For compact freezers, the adjusted volume is equal to 1.73 times the volume.[4] DOE then used the relation between adjusted volume and energy use described by the DOE test procedure to relate the distribution of volumes in the CEC database to a distribution of energy use values. Note that for product class 11, the ESAF of product class 11A (0.977) was used, rather than that of product class 11 (1.125), because according to the CEC database, about 90 percent of available models classified as either product class 11 or 11A are in fact product class 11A (defined as having a freezer compartment less than 0.5 cubic feet).

Table 7.5.1 Parameters for Calculating Adjusted Volume from Total Volume for Compact Refrigerators

Product Category	Slope	Intercept	R^2	Count
Compact Refrigerators	1.0458	-0.0905	0.9822	187

7.6 ANNUAL ENERGY CONSUMPTION BY EFFICIENCY LEVEL

This section reports the annual energy consumption calculated for refrigeration products at various efficiency levels if they were used in RECS 2005 homes.

As discussed in chapter 5, DOE analyzed specific efficiency levels for the considered product classes. Tables 7.6.1 through 7.6.4 show the considered efficiency levels and corresponding average annual energy consumption for each representative product class.

Table 7.6.1 Standard-Size Refrigerator-Freezers: Average Annual Energy Use by Efficiency Level

Product Class 3: Top-Mount Refrigerator-Freezer		**Product Class 5: Bottom-Mount Refrigerator-Freezer**		**Product Class 7: Side-by-Side Refrigerator-Freezer with TTD***	
Efficiency Level (*% less than baseline energy use*)	***kWh*****	**Efficiency Level (*% less than baseline energy use*)**	***kWh*****	**Efficiency Level (*% less than baseline energy use*)**	***kWh*****
Baseline	574	Baseline	716	Baseline	881
1 (10)	517	1 (10)	645	1 (10)	793
2 (15)	488	2 (15)	609	2 (15)	749
3 (20)	460	3 (20)	573	3 (20)	705
4 (25)	431	4 (25)	537	4 (25)	661
5 (30)	402	5 (30)	501	5 (30)	617
6 (36)	370	6 (36)	457	6 (33)	590

*Through-the-door ice service.
**Average energy use calculated over the lifetime of the product, not including icemaker energy (for product class 7).

Table 7.6.2 Standard-Size Freezers: Average Annual Energy Use by Efficiency Level

Product Class 9: Upright Freezer		Product Class 10: Chest Freezer	
Efficiency Level (*% less than baseline energy use*)	***kWh***	**Efficiency Level (*% less than baseline energy use*)**	***kWh***
Baseline	670	Baseline	394
1 (10)	615	1 (10)	360
2 (15)	582	2 (15)	340
3 (20)	548	3 (20)	320
4 (25)	514	4 (25)	300
5 (30)	479	5 (30)	280
6 (35)	445	6 (35)	260
7 (40)	411	7 (41)	235
8 (44)	386		

Table 7.6.3 Compact Refrigeration Products: Average Annual Energy Use by Efficiency Level

Product Class 11: Compact Refrigerator		Product Class 18: Compact Freezer	
Efficiency Level (*% less than baseline energy use*)	***kWh***	**Efficiency Level (*% less than baseline energy use*)**	***kWh***
Baseline	326	Baseline	311
1 (10)	294	1 (10)	281
2 (15)	278	2 (15)	266
3 (20)	262	3 (20)	250
4 (25)	246	4 (25)	235
5 (30)	229	5 (30)	219
6 (35)	213	6 (35)	203
7 (40)	197	7 (42)	182
8 (45)	180		
9 (50)	164		
10 (59)	135		

Table 7.6.4 Built-In Refrigeration Products: Average Annual Energy Use by Efficiency Level

Product Class 3A-BI: Built-in All Refrigerator		**Product Class 5-BI: Built-In Bottom-Mount Refrigerator-Freezer**		**Product Class 7-BI: Built-In Side-by-Side Refrigerator-Freezer with TTD***		**Product Class 9-BI: Built-In Upright Freezer**	
Efficiency Level (*% less than baseline energy use*)	***kWh*****	**Efficiency Level (*% less than baseline energy use*)**	***kWh*****	**Efficiency Level (*% less than baseline energy use*)**	***kWh*****	**Efficiency Level (*% less than baseline energy use*)**	***kWh***
Baseline	594	Baseline	671	Baseline	989	Baseline	646
1 (10)	535	1 (10)	604	1 (10)	901	1 (10)	593
2 (15)	505	2 (15)	570	2 (15)	857	2 (15)	561
3 (20)	475	3 (20)	537	3 (20)	813	3 (20)	528
4 (25)	445	4 (25)	503	4 (22)	800	4 (25)	495
5 (29)	423	5 (27)	488			5 (27)	479

* Through-the-door ice service.
**Average energy use calculated over the lifetime of the product, not including icemaker energy (for product class 7-BI).

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

This chapter describes the Department of Energy (DOE)'s method and metrics for analyzing the economic impacts on individual consumers of potential energy efficiency standards for refrigeration products. The effects of standards on individual consumers include a change (usually a decrease) in operating cost and a change (usually an increase) in product cost. For each of the 11 representative product classes analyzed in this rulemaking, DOE examined the life-cycle cost, payback period, and rebuttable payback period of all of the considered efficiency levels. The terms used in this analysis are defined below.

- *Life-cycle cost* (LCC) is the total cost consumers incur during the life of an appliance, including purchase and operating costs (including energy expenditures). DOE discounts future operating costs to the time of purchase, and sums them over the lifetime of a product.
- *Payback period* (PBP) measures the amount of time it takes consumers to recover the assumed higher purchase cost of more energy efficient products through lower operating costs.
- *Rebuttable payback period*, a special case of the payback period, is based on laboratory conditions (specifically, those that reflect the DOE test procedure) for energy use. Its other inputs (including electricity prices) reflect representative real-world operating conditions.

Inputs to the LCC and the PBP are discussed in sections 8.2 and 8.3, respectively, of this chapter. Results of the LCC and PBP analyses are presented in section 8.4. The rebuttable PBP is discussed in section 8.5. Key variables and calculations are presented for each of the three metrics listed above. DOE performed the calculations discussed here using a series of Microsoft Excel spreadsheets that are accessible on the Internet (www.eere.energy.gov/buildings/appliance_standards/). Details regarding and instructions for using the spreadsheets are discussed in appendix 8-A.

8.1.1 Approach

Recognizing that several inputs to the analysis of consumer LCC and PBP are either variable or uncertain, DOE used Monte Carlo simulation and probability distributions to model both the uncertainty and variability of inputs. Appendix 8-B provides a detailed explanation of Monte Carlo simulation and the use of probability distributions. DOE developed LCC and PBP spreadsheet models that incorporate both Monte Carlo simulation and probability distributions by using Microsoft Excel® spreadsheets combined with Crystal Ball®, a commercially available add-in program.

In addition to using probability distributions to characterize several of the inputs to the calculation, DOE developed samples of individual households that use standard-size refrigeration products. DOE performed the LCC and PBP calculations for each household in the sample to account for the variability in energy consumption and/or energy price associated with a range of households.

As described in chapter 7, DOE used the DOE Energy Information Administration (EIA)'s 2005 Residential Energy Consumption Survey (RECS) to develop household samples for standard-size refrigeration products.[1] EIA constructed the 2005 RECS to represent the range of households throughout the United States.

DOE used the 2005 RECS to establish the variability in the annual energy use of refrigeration products and in energy prices. DOE was able to assign a unique annual energy use and/or energy price to each household in the sample. Because of the large sample of households considered in the LCC and PBP analyses, annual energy use and/or energy prices vary greatly. Thus, although the annual energy use and/or energy prices are known for any particular household, their variability across all households contributes to the range of LCCs and PBPs calculated for any particular possible standard.

DOE did not develop a household sample for compact refrigeration products, because many such products are used in lodging, dormitories, and other commercial establishments. DOE estimated the fractions of shipments of compact refrigeration products used in the residential and commercial sectors, then used appropriate inputs for those fractions.

DOE displays LCC and PBP results as distributions of impacts compared to baseline conditions. Results, presented in section 8.4, were derived from 10,000 samples for each Monte Carlo simulation run. To illustrate the implications of the analysis, DOE generated a frequency chart that depicts the variation in LCC and PBP for each standard level considered for refrigeration products.

8.1.2 Summary of Inputs

The LCC represents the total consumer cost during the life of a product, including purchase and operating costs (including energy expenditures). DOE discounts future operating cost to the time of purchase, then sums them over the lifetime of each product. The PBP is the change in purchase cost due to an increased efficiency standard divided by the change in annual operating cost that results from the standard. The PBP represents the number of years it will take the customer to recover the increased purchase cost through decreased operating cost.

DOE uses two types of inputs to the calculation of LCC and PBP: (1) inputs for establishing the purchase cost, otherwise known as the consumer product cost, and (2) inputs for determining the operating cost.

The following are the primary inputs for establishing the consumer product cost at each efficiency level.

- *Baseline selling price*: The price at which a manufacturer sells a product identified as a baseline model.
- *Increases in manufacturer selling price (MSP)*: The change in manufacturer selling price associated with product that meets a particular efficiency level.
- *Markups and sales tax*: The costs associated with converting increases in the MSP into consumer product cost.

The following are the primary inputs for calculating the operating cost at each efficiency level.

- *Product energy consumption*: The site energy use associated with operating a given product.
- *Energy prices*: The prices consumers paid for energy (electricity) in a recent year.
- *Energy price trends*. Energy prices forecasted into the future.
- *Repair and maintenance costs*: Repair costs are associated with repairing or replacing components that fail. Maintenance costs are associated with maintaining the operation of a product.
- *Lifetime*: The age at which a product is retired from service.
- *Discount rate*: The rate at which DOE discounted future expenditures to establish their present value.

Figure 8.1.1 graphically depicts the relationships among the inputs for installed cost and operating cost used to calculate the LCC and PBP. The yellow boxes in Figure 8.1.1 indicate inputs; the green boxes indicate intermediate outputs; and the blue boxes indicate the final outputs of LCC and PBP.

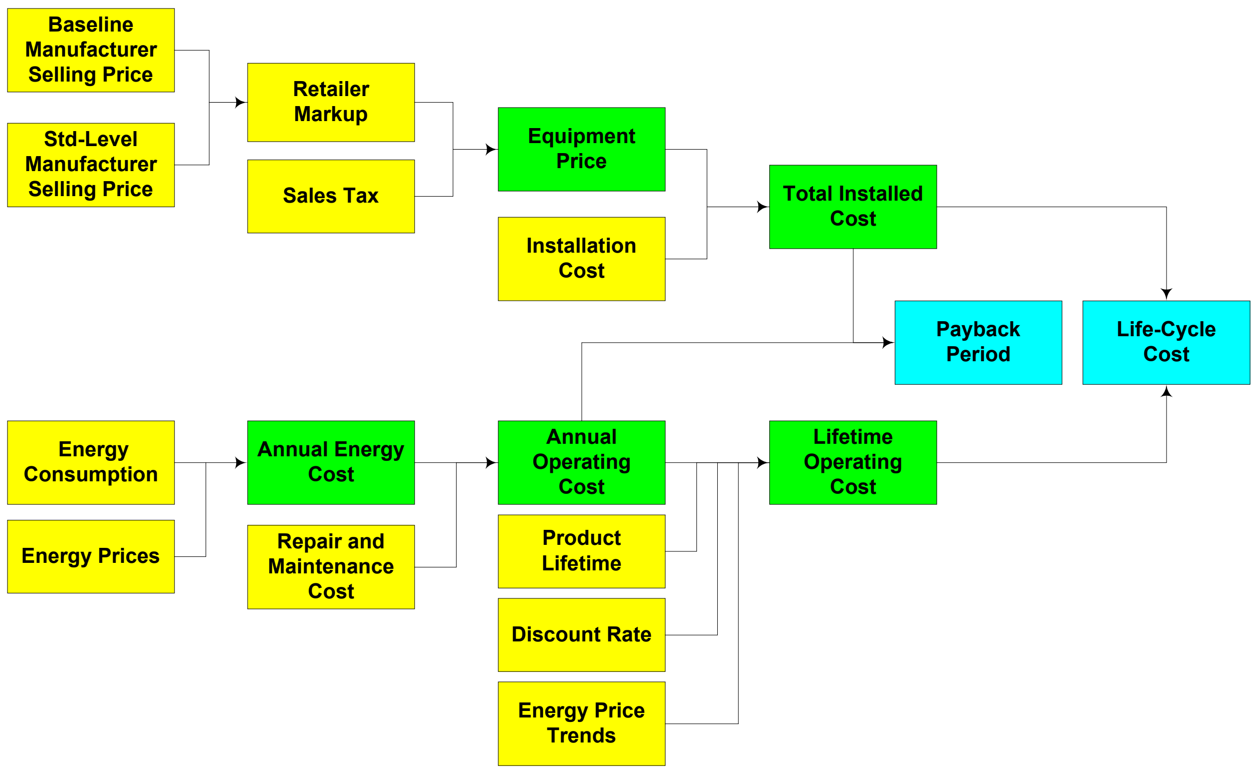

Figure 8.1.1 Flow Diagram of Inputs for Life-Cycle Cost and Payback Period Analyses

Tables 8.1.1 through 8.1.3 summarize the input values that DOE used to calculate the LCC and PBP for refrigeration products. The inputs for calculating total installed and operating costs included the product lifetime, discount rate, and energy price trends. DOE used single-point values to characterize all inputs to total cost, but used probability distributions to capture the uncertainty and/or variability of several inputs to operating cost. For those inputs characterized using probability distributions, the values in the following tables are average or typical values.

Table 8.1.1 Standard-Size Refrigerator-Freezers: Summary of Inputs to Calculations

Input	Product Class	Average or Typical Value	Characterization
Baseline retail price*	Top-mount refrigerator-freezer	492 *2009$*	Custom distribution
	Bottom-mount refrigerator-freezer	861 *2009$*	Custom distribution
	Side-by-side refrigerator-freezer with TTD†	1,044 *2009$*	Custom distribution
Increase in manufacturer selling price**	All	Varies by efficiency level	Single-point value
Retailer markup	All	Baseline = 1.45 Incremental = 1.17	Single-point value
Sales tax	All	7.3%	Varies depending on region
Annual energy use	Top-mount refrigerator-freezer	Baseline use = 574kWh‡	Varies depending on age and usage
	Bottom-mount refrigerator-freezer	Baseline use = 716 kWh	Varies depending on age and usage
	Side-by-side refrigerator-freezer with TTD†	Baseline use = 881 kWh	Varies depending on age and usage
Energy prices	All	11.4 cents per kWh	Varies depending on region
Energy price trend	All	AEO 2010 reference case	Two additional scenarios: AEO high and low growth§
Lifetime	All	16.2 years (median)	Weibull distribution
Discount rate	All	5.1%	Custom distribution

* Retail price after sales tax.
† Through-the-door ice service.
** Includes manufacturer markup.
‡ Kilowatt hours
§ See section 8.2.2.3.

Table 8.1.2 Standard-Size Freezers: Summary of Inputs to Calculations

Input	Product Class	Average or Typical Value	Characterization
Baseline retail price*	Upright	507 *2009$*	Custom distribution
	Chest	369 *2009$*	Custom distribution
Increase in manufacturer selling price†	All	Varies by efficiency level	Single-point value
Retailer markup	All	Baseline = 1.45 Incremental = 1.17	Single-point value
Sales tax	All	7.2%	Varies depending on region
Annual energy use	Upright	Baseline use = 670 kWh**	Varies depending on usage
	Chest	Baseline use = 393 kWh	Varies depending on usage
Energy prices	All	11.4 cents per kWh	Varies depending on region
Energy price trend	All	AEO 2010 reference case	Two additional scenarios: AEO high and low growth‡
Lifetime	All	21.7 years (median)	Weibull distribution
Discount rate	All	5.1%	Custom distribution

* Retail price after sales tax.
† Includes manufacturer markup.
** Kilowatt hours.
‡ See section 8.2.2.3.

Table 8.1.3 Compact Refrigeration Products: Summary of Inputs to Calculations

Input	Product Class	Average or Typical Value	Characterization
Baseline retail price*	Refrigerator	132 *2009$*	Custom distribution
	Freezer	183 *2009$*	Custom distribution
Increase in manufacturer selling price†	All	Varies by efficiency level	Single-point value
Retailer markup	All	Baseline = 1.45 Incremental = 1.17	Single-point value
Sales tax	All	7.3%	Varies depending on region
Annual energy use	Refrigerator	Baseline use = 326 kWh**	Varies depending on usage
	Freezer	Baseline use = 311 kWh	Varies depending on usage
Energy prices	All	10.8 cents per kWh	Varies depending on region
Energy price trend	All	AEO 2010 reference case	Two additional scenarios: AEO high- and low-growth‡
Lifetime	Refrigerator	5.6 years (mean)	Weibull distribution
	Freezer	7.5 years (mean)	Weibull distribution
Discount rate	All	5.1% (residential users) 6.2% (commercial users)	Custom distribution

* Retail price after sales tax.
† Includes manufacturer markup.
** Kilowatt- hours.
‡ See section 8.2.2.3.

8.2 INPUTS TO LIFE-CYCLE COST ANALYSIS

Life-cycle cost (LCC) is the total consumer cost during the life of an appliance, including purchase and operating costs (including energy costs). DOE discounts future operating costs to the time of purchase, then sums them over the lifetime of the product. DOE uses the following equation to define LCC:

$$LCC = PC + \sum_{t=1}^{N} \frac{OC_t}{(1+r)^t}$$

Where:

LCC = life-cycle cost in dollars,
PC = consumer product cost in dollars,
Σ = sum over the lifetime, from year 1 to year N,
N = lifetime of appliance in years,
OC = operating cost in dollars,
r = discount rate, and
t = year for which operating cost is being determined.

DOE expresses dollar values in 2009$ because it gathered most of its data for the LCC and PBP analysis in 2009.

8.2.1 Inputs to Product Cost

DOE calculated the cost consumers pay for baseline products based on the following equation:

$$PC_{BASE} = (RSP_{BASE}) \times (TAX)$$

Where:

PC_{BASE} = consumer cost for baseline product,
RSP_{BASE} = retail selling price for baseline product, and
TAX= sales tax.

DOE calculated the consumer cost for products having higher efficiency levels based on the following equation:

$$PC_{STD} = PC_{BASE} + (\Delta MSP_{STD} \times MU_{RETINCR} \times TAX)$$

Where:

PC_{STD} = consumer product cost for higher-efficiency products,
PC_{BASE} = consumer cost for baseline product
ΔMSP_{STD} = change in MSP for more efficient model,
MU_{RET_INCR} = incremental retailer markup,
TAX= sales tax.

8.2.1.1 Projection of Future Product Prices

Examination of historical price data for certain appliances and equipment that have been subject to energy conservation standards indicates that the assumption of constant real prices and costs may, in many cases, overestimate long-term trends in appliance and equipment prices. Economic literature and historical data suggest that the real costs of these products may in fact trend downward over time according to "learning" or "experience" curves. A draft paper, "Using the Experience Curve Approach for Appliance Price Forecasting," posted on the DOE web site at http://www.eere.energy.gov/buildings/appliance_standards, summarizes the data and literature currently available to DOE that is relevant to price forecasts for selected appliances and equipment.

In light of these data and DOE's aim to improve the accuracy and robustness of its analyses, DOE decided to assess future costs by incorporating learning over time, consistent with the analysis in the available literature. DOE used this approach to forecast future prices of refrigeration products at the considered efficiency levels.

An extensive literature discusses the "learning" or "experience" curve phenomenon, typically based on observations in the manufacturing sector.[a] In the experience curve method, the real cost of production is related to the cumulative production or "experience" with a product. To explain the empirical relationship, the theory of technology learning is used to substantiate a decline in the cost of producing a given product as firms accumulate experience with the technology. A common functional relationship used to model the evolution of production costs is:

$$Y = aX^{-b}$$

Where:

a	=	an initial price (or cost),
b	=	a positive constant known as the learning rate parameter,
X	=	cumulative production, and
Y	=	the price as a function of cumulative production.

As experience (production) accumulates, the cost of producing the next unit decreases. The percentage reduction in cost that occurs with each doubling of cumulative production is referred to as the experience rate. In typical experience curve formulations, the experience rate parameter is derived using two historical data series: price (or cost) and cumulative production, which is a function of shipments during a long time span. The experience rate (*ER*)

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[a] In addition to the draft paper mentioned above, see Weiss, M. Junginger, H.M., Patel, M.K., and Blok, K. 2010. A Review of Experience Curve Analyses for Energy Demand Technologies. *Technological Forecasting & Social Change*. 77:411-428.

corresponding to the parameter *b* is defined as the fractional reduction in price expected from each doubling of cumulative production. *ER* is expressed as:

$$ER = 1 - 2^{-b}$$

For the refrigerator/freezer data that DOE analyzed, the default *ER* = 40.7%. The data sources and method that DOE used to derive experience rates for refrigeration products are described in appendix 8-E. This appendix also discusses alternative approaches for projecting future appliance prices.

DOE derived an index, with 2010 equal to 1, to forecast prices in 2014, the compliance date for amended energy conservation standards in the LCC and PBP analysis. The index value in 2014, 0.916, is a function of the experience rate and the cumulative production forecast through that year. DOE applied the same value to forecast prices for each refrigerator and freezer product class at each considered efficiency level.

8.2.1.2 Baseline Retail Prices

DOE's engineering analysis (chapter 5) did not attempt to estimate the manufacturing sales price (MSP) for baseline models. Instead, it developed incremental increases in MSP associated with increases in efficiency level. This approach required DOE to estimate retail prices for the baseline model in each product class.

DOE drew upon proprietary retail price data collected by The NPD Group.[2] These data reflect prices and sales at many retail outlets in the United States, representing more than 50 percent of retail sales nationwide. The data include model number, refrigerated volume, configuration of doors and ice-making, and whether the unit is an ENERGY STAR product. Based on these data DOE developed a sales-weighted price distribution for non-ENERGY STAR appliances in each product class.[b] For the LCC and PBP analyses of standard-sized products, DOE assigned a baseline price from that distribution to each household sampled from the EIA's 2005 Residential Energy Consumption Survey (RECS).[1] For compact product classes, DOE assigned a baseline price from the distribution to each sampled product. Appendix 8-C presents the distribution histograms DOE developed for each product class. The average baseline retail prices before sales tax for each refrigeration product class, in 2014, are shown in Table 8.2.1.

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[b] DOE assumed that prices for non-ENERGY STAR models are a reasonable approximation of prices for the baseline models.

Table 8.2.1 Residential Refrigeration Products: Average Baseline Retail Price in 2014

Product Class	Baseline Retail Price* *2009$*
Product class 3: Top-mount refrigerator-freezer	492
Product class 5: Bottom-mount refrigerator-freezer	861
Product class 7: Side-by-side refrigerator-freezer with TTD†	1044
Product class 9: Upright freezer	507
Product class 10: Chest freezer	369
Product class 11: Compact refrigerator	132
Product class 18: Compact freezer	183
Product class 3A-BI: Built-in all refrigerator	4333
Product class 5-BI: Built-in bottom-mount refrigerator-freezer	4988
Product class 7-BI: Built-in side-by-side refrigerator-freezer with TTD†	7162
Product class 9-BI: Built-in upright freezer	3943

* Retail price after sales tax.
† Through-the-door ice service.

8.2.1.3 Increases in Manufacturer Selling Price

DOE used a combination of cost data submitted by the Association of Home Appliance Manufacturers (AHAM)[3] and a reverse engineering analysis to estimate increases to manufacturing cost associated with increases in efficiency levels for refrigeration products. Refer to chapter 5, Engineering Analysis, for details. Adding the manufacturer markup described in chapter 6 yielded the MSP increases for each considered efficiency level and product class. Tables 8.2.2 through 8.2.5 show the values for 2014.

Table 8.2.2 Standard-Size Refrigerator-Freezers: Increase in Manufacturer Selling Prices Relative to Baseline in 2014

Product Class 3: Top-Mount Refrigerator-Freezer		Product Class 5: Bottom-Mount Refrigerator-Freezer		Product Class 7: Side-Mount Refrigerator-Freezer with TTD* ice	
Efficiency Level ***(% less than baseline energy use)***	**Increase in Manufacturer Selling Price (2009$)**	**Efficiency Level** ***(% less than baseline energy use)***	**Increase in Manufacturer Selling Price (2009$)**	**Efficiency Level** ***(% less than baseline energy use)***	**Increase in Manufacturer Selling Price (2009$)**
1 (10)	$10.71	1 (10)	$11.78	1 (10)	$8.97
2 (15)	$17.89	2 (15)	$19.62	2 (15)	$17.25
3 (20)	$66.29	3 (20)	$34.03	3 (20)	$38.48
4 (25)	$96.76	4 (25)	$81.15	4 (25)	$85.40
5 (30)	$163.59	5 (30)	$158.68	5 (30)	$187.51
6 (36)	$259.43	6 (36)	$266.03	6 (33)	$267.61

* Through-the-door.

Table 8.2.3 Standard-Size Freezers: Increases in Manufacturer Selling Prices Relative to Baseline in 2014

Product Class 9: Upright Freezer		**Product Class 10: Chest Freezer**	
Efficiency Level (*% less than baseline energy use)*	**Increase in Manufacturer Selling Price (2009$)**	**Efficiency Level (*% less than baseline energy use)***	**Increase in Manufacturer Selling Price (2009$)**
1 (10)	$10.14	1 (10)	$5.84
2 (15)	$25.80	2 (15)	$13.31
3 (20)	$39.68	3 (20)	$21.93
4 (25)	$60.74	4 (25)	$56.50
5 (30)	$79.97	5 (30)	$71.77
6 (35)	$123.01	6 (35)	$115.19
7 (40)	$183.04	7 (41)	$202.65
8 (44)	$316.01		

Table 8.2.4 Compact Refrigeration Products: Increases in Manufacturer Selling Prices Relative to Baseline in 2014

Product Class 11: Compact Refrigerator or Refrigerator-Freezer		**Product Class 18: Compact Chest Freezer**	
Efficiency Level **(*% less than baseline energy use)***	**Increase in Manufacturer Selling Price (2009$)**	**Efficiency Level** **(*% less than baseline energy use)***	**Increase in Manufacturer Selling Price (2009$)**
1 (10)	$4.21	1 (10)	$5.43
2 (15)	$7.41	2 (15)	$15.14
3 (20)	$11.96	3 (20)	$47.80
4 (25)	$21.05	4 (25)	$55.79
5 (30)	$28.28	5 (30)	$79.63
6 (35)	$48.60	6 (35)	$85.64
7 (40)	$54.52	7 (42)	$142.41
8 (45)	$79.29		
9 (50)	$92.78		
10 (59)	$141.38		

Table 8.2.5 Built-In Refrigeration Products: Increases in Manufacturer Selling Prices Relative to Baseline in 2014

Product Class 3A-BI: Built-in All Refrigerators		**Product Class 5-BI: Built-in Bottom-Mount Refrigerator-Freezers**	
Efficiency Level (*% less than baseline energy use)*	**Increase in Manufacturer Selling Price (2009$)**	**Efficiency Level (*% less than baseline energy use)***	**Increase in Manufacturer Selling Price (2009$)**
1 (10)	$6.47	1 (10)	$19.46
2 (15)	$17.13	2 (15)	$77.80
3 (20)	$115.22	3 (20)	$150.38
4 (25)	$246.65	4 (25)	$267.68
5 (29)	$346.01	5 (27)	$335.60
Product Class 7-BI: Built-in Side-by-Side Refrigerator-Freezers		**Product Class 9-BI: Built-in Upright Freezers**	
Efficiency Level (*% less than baseline energy use)*	**Increase in Manufacturer Selling Price (2009$)**	**Efficiency Level (*% less than baseline energy use)***	**Increase in Manufacturer Selling Price (2009$)**
1 (10)	$46.64	1 (10)	$14.21
2 (15)	$111.92	2 (15)	$24.87
3 (20)	$255.21	3 (20)	$89.96
4 (22)	$336.56	4 (25)	$191.94
		5 (27)	$269.74

8.2.1.4 Markup and Sales Tax

To derive the incremental increase in consumer product cost for each efficiency level, DOE applied an incremental retail markup and sales tax to the MSP increases shown above. Refer to Chapter 6, Markups for Equipment Price Determination, for details. DOE also applied sales tax to the baseline retail prices.

8.2.1.5 Installation Cost

Because the cost to install refrigeration products does not change as efficiency increases, DOE did not incorporate installation costs in its analysis.

8.2.1.6 Consumer Product Cost

Tables 8.2.6 through 8.2.9 present the shipment-weighted consumer product cost in 2014 at each considered efficiency standard level for the refrigeration product classes under consideration for new standards. These costs reflect the market efficiency distributions discussed in section 8.2.6.

Table 8.2.6 Standard-Size Refrigerator-Freezers: Average Consumer Cost in 2014

Product Class 3: Top-Mount Refrigerator-Freezer		Product Class 5: Bottom-Mount Refrigerator-Freezer		Product Class 7: Side-by-Side Refrigerator-Freezer	
Efficiency Level ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**	**Efficiency Level** ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**	**Efficiency Level** ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**
Baseline	$492	Baseline	$861	Baseline	$1,044
1 (10)	$503	1 (10)	$863	1 (10)	$1,047
2 (15)	$510	2 (15)	$864	2 (15)	$1,052
3 (20)	$566	3 (20)	$870	3 (20)	$1,069
4 (25)	$604	4 (25)	$929	4 (25)	$1,128
5 (30)	$688	5 (30)	$1,027	5 (30)	$1,256
6 (36)	$809	6 (36)	$1,162	6 (33)	$1,356

Table 8.2.7 Standard-Size Freezers: Average Consumer Cost in 2014

Product Class 9: Upright Freezer		Product Class 10: Chest Freezer	
Efficiency Level ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**	**Efficiency Level** ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**
Baseline	$507	Baseline	$369
1 (10)	$518	1 (10)	$375
2 (15)	$537	2 (15)	$384
3 (20)	$554	3 (20)	$395
4 (25)	$581	4 (25)	$438
5 (30)	$605	5 (30)	$457
6 (35)	$659	6 (35)	$512
7 (40)	$734	7 (41)	$622
8 (44)	$901		

Table 8.2.8 Compact Refrigeration Products: Average Consumer Cost in 2014

Product Class 11: Compact Refrigerator		Product Class 18: Compact Freezer	
Efficiency Level ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**	**Efficiency Level** ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**
Baseline	$132	Baseline	$183
1 (10)	$137	1 (10)	$190
2 (15)	$141	2 (15)	$202
3 (20)	$147	3 (20)	$243
4 (25)	$158	4 (25)	$253
5 (30)	$167	5 (30)	$283
6 (35)	$193	6 (35)	$290
7 (40)	$200	7 (42)	$362
8 (45)	$231		
9 (50)	$248		
10 (59)	$309		

Table 8.2.9 Built-In Refrigeration Products: Average Consumer Cost in 2014

Product Class 3A-BI: Built-in All Refrigerators		Product Class 5-BI: Built-in Bottom-Mount Refrigerator-Freezers	
Efficiency Level ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**	**Efficiency Level** ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**
Baseline	$4,333	Baseline	$4,988
1 (10)	$4,339	1 (10)	$4,991
2 (15)	$4,351	2 (15)	$5,001
3 (20)	$4,469	3 (20)	$5,032
4 (25)	$4,643	4 (25)	$5,188
5 (29)	$4,775	5 (27)	$5,278
Product Class 7-BI: Built-in Side-by-Side Refrigerator-Freezers		**Product Class 9-BI: Built-in Upright Freezers**	
Efficiency Level ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**	**Efficiency Level** ***(% less than baseline energy use)***	**Average Consumer Cost (2009$)**
Baseline	$7,162	Baseline	$3,943
1 (10)	$7,175	1 (10)	$3,958
2 (15)	$7,216	2 (15)	$3,972
3 (20)	$7,335	3 (20)	$4,058
4 (22)	$7,443	4 (25)	$4,192
		5 (27)	$4,295

8.2.2 Inputs to Operating Cost

DOE defines operating cost (*OC*) by the following equation:

$$OC = EC + RC + MC$$

Where:

EC = energy cost associated with operating the product,
RC = repair cost associated with component failure, and
MC = cost for maintaining appliance operation.

DOE used the following equation to calculate the annual operating cost for baseline products:

$$OC_{BASE} = (AEC_{BASE} \times PRICE_{ENERGY}) + RC_{BASE} + MC_{BASE}$$

Where:

OC_{BASE} = operating cost for baseline product,
AEC_{BASE} = annual energy consumption for baseline product,
$PRICE_{ENERGY}$ = energy price,
RC_{BASE} = repair costs associated with component failure for baseline product, and
MC_{BASE} = maintenance costs for baseline product.

DOE used the following equation to calculate the annual operating cost for higher efficiency products:

$$OC_{STD} = (AEC_{STD} \times PRICE_{ENERGY}) + RC_{STD} + MC_{STD}$$

Where:

OC_{STD} = operating cost of higher-efficiency product,
AEC_{STD} = annual energy consumption of higher-efficiency product,
$PRICE_{ENERGY}$ = energy price in each year,
RC_{STD} = repair costs associated with component failure for higher-efficiency product, and
MC_{STD} = maintenance costs for higher-efficiency product.

8.2.2.1 Annual Energy Consumption

As described in Chapter 7, Energy Use Determination, DOE developed samples of individual households that use each of the standard-sized refrigeration products considered herein. By developing the samples, DOE was able to calculate the LCC and PBP for each household to account for the variability in both energy use and energy price associated with that household.

Tables 8.2.10 through 8.2.13 are derived from the analysis described in chapter 7. The values shown for annual energy consumption are averages in the field. For compact products, DOE did not use the RECS sample, and the energy consumption is as measured using the DOE test procedure. DOE captured the variability in energy consumption by using a range of values in its LCC and PBP analyses.

Table 8.2.10 Standard-Size Refrigerator-Freezers: Average Annual Energy Use by Efficiency Level

Product Class 3: Top-Mount Refrigerator-Freezer		**Product Class 5: Bottom-Mount Refrigerator-Freezer**		**Product Class 7: Side-by-Side Refrigerator-Freezer with TTD***	
Efficiency Level ***(% less than baseline energy use)***	**Energy Use** ***kWh****	**Efficiency Level** ***(% less than baseline energy use)***	**Energy Use** ***kWh****	**Efficiency Level** ***(% less than baseline energy use)***	**Energy Use** ***kWh**,†***
Baseline	574	Baseline	716	Baseline	881
1 (10)	517	1 (10)	645	1 (10)	793
2 (15)	488	2 (15)	609	2 (15)	749
3 (20)	460	3 (20)	573	3 (20)	705
4 (25)	431	4 (25)	537	4 (25)	661
5 (30)	402	5 (30)	501	5 (30)	617
6 (36)	370	6 (36)	457	6 (33)	590

*Through-the-door ice service.
** Energy use before applying time-dependent UAF.
†Not including ice maker energy.

Table 8.2.11 Standard-Size Freezers: Average Annual Energy Use by Efficiency Level

Product Class 9: Upright Freezer		Product Class 10: Chest Freezer	
Efficiency Level ***(% less than baseline energy use)***	**Energy Use** ***kWh***	**Efficiency Level** ***(% less than baseline energy use)***	**Energy Use** ***kWh***
Baseline	670	Baseline	394
1 (10)	615	1 (10)	360
2 (15)	582	2 (15)	340
3 (20)	548	3 (20)	320
4 (25)	514	4 (25)	300
5 (30)	479	5 (30)	280
6 (35)	445	6 (35)	260
7 (40)	411	7 (41)	235
8 (44)	386		

Table 8.2.12 Compact Refrigeration Products: Average Annual Energy Use by Efficiency Level

Product Class 11: Compact Refrigerator		Product Class 18: Compact Freezer	
Efficiency Level ***(% less than baseline energy use)***	**Energy Use** ***kWh***	**Efficiency Level** ***(% less than baseline energy use)***	**Energy Use** ***kWh***
Baseline	326	Baseline	311
1 (10)	294	1 (10)	281
2 (15)	278	2 (15)	266
3 (20)	262	3 (20)	250
4 (25)	246	4 (25)	235
5 (30)	229	5 (30)	219
6 (35)	213	6 (35)	203
7 (40)	197	7 (42)	182
8 (45)	180		
9 (50)	164		
10 (59)	135		

Table 8.2.13 Built-In Refrigeration Products: Average Annual Energy Use by Efficiency Level

Built-in All Refrigerators (3A-BI)		Built-in Bottom-Mount Refrigerator-Freezers (5-BI)	
Efficiency Level ***(% less than baseline energy use)***	***Energy Use (kWh)*****	**Efficiency Level** ***(% less than baseline energy use)***	***Energy Use (kWh)*****
Baseline	594	Baseline	671
1 (10)	535	1 (10)	604
2 (15)	505	2 (15)	570
3 (20)	475	3 (20)	537
4 (25)	445	4 (25)	503
5 (29)	423	5 (27)	488
Built-in Side-by-Side Refrigerator-Freezers (7-BI)		**Built-in Upright Freezers (9-BI)**	
Efficiency Level ***(% less than baseline energy use)***	***Energy Use (kWh)*,*****	**Efficiency Level** ***(% less than baseline energy use)***	***Energy Use (kWh)***
Baseline	989	Baseline	646
1 (10)	901	1 (10)	593
2 (15)	857	2 (15)	561
3 (20)	813	3 (20)	528
4 (22)	800	4 (25)	495
		5 (27)	479

* Not including ice maker energy.
** Energy use before applying time-dependent UAF.

8.2.2.2 Energy Prices

Using data from EIA Form 861[4], DOE derived average energy prices for 13 geographic areas in the United States: the nine U.S. Census divisions, plus four large states (New York, Florida, Texas, and California) considered individually. For Census divisions containing one of those large states, DOE left out data for the large state when calculating average regional values. For example, the Pacific region average excludes California, and the West South Central region excludes Texas. Using the modified regional data, DOE assigned an appropriate energy price to each household in the sample.

DOE used data from EIA to estimate electricity prices for residential consumers in each of the 13 geographic areas These data, which are published annually, include annual electricity sales in kilowatt hours (kWh), revenues from electricity sales, and number of consumers by sector for every utility that serves final consumers. The calculation of an area-average residential or commercial electricity price proceeds in two steps.

1. For each utility, an average sector (residential or commercial) price is estimated by dividing sector revenues by sector sales.
2. An average regional price is calculated, whereby each utility having customers in a region is weighted by the number of residential consumers served in that region.

The calculation used the most recent EIA data available at the time the analysis was conducted. Table 8.2.14 shows the average residential and commercial electricity price in 2007 for each Census division and large state.

Table 8.2.14 Average Electricity Prices in 2007

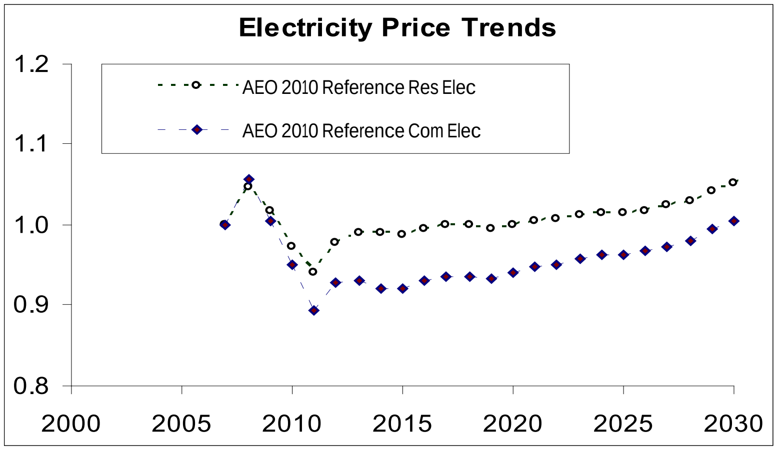
Geographic Area	Average Residential Price *2009$/kWh*	Average Commercial Price *2009$/kWh*
New England	0.162	$0.153
Middle Atlantic	0.127	$0.111
East North Central	0.102	$0.091
West North Central	0.088	$0.075
South Atlantic	0.098	$0.085
East South Central	0.087	$0.086
West South Central	0.093	$0.085
Mountain	0.097	$0.083
Pacific	0.099	$0.094
New York State	0.178	$0.168
California	0.150	$0.136
Texas	0.128	$0.118
Florida	0.116	$0.101

Source: U.S. Department of Energy–Energy Information Administration EIA Form 861.

8.2.2.3 Energy Price Trends

To estimate energy prices in future years, DOE multiplied the average prices listed in Table 8.2.14 by the forecast of annual average price changes in EIA's *Annual Energy Outlook 2010 (AEO 2010*[5]*)*. To estimate the trend after 2035, DOE followed guidelines that the EIA had provided to the Federal Energy Management Program, which called for using the average rate of change for electricity during 2025–2035.

Figure 8.2.7 shows the projected trends in residential and commercial electricity prices based on the *AEO 2010* reference case. For the LCC results presented in this chapter, DOE used only the energy price forecasts from the AEO reference case.



Source: Energy Information Administration, Annual Energy Outlook. 2010.

Figure 8.2.1 Residential and Commercial Electricity Price Trends Indexed on 2007 Price

8.2.2.4 Repair and Maintenance Costs

DOE estimated the increase in repair costs due to the use of specific technology in some higher efficiency design options. DOE found no evidence that maintenance costs change as the efficiency of refrigeration products increases, however, and thus excluded those costs from its analysis.

The estimated average repair cost can be expressed as the product of two elements: the average rate of repair of a component times the incremental cost of repair or replacement compared to the baseline. While detailed incremental component costs were readily available from the detailed engineering cost models that DOE developed for two sizes per product class, DOE needed to estimate component repair rates.

DOE obtained relative component repair rates from a prior rulemaking for commercial refrigeration equipment.[c] In this rulemaking, the total repair rates of the compressor, evaporator, condenser, evaporator fan, and condenser fan were reported over the 10-year equipment lifetime. These were converted to constant annual rates, and a rate for electronics component repair was estimated to be the same as that of the compressor. Table 8.2.15 shows the assumed annual repair rates.

[c] Commercial Refrigeration Equipment Final Rule Technical Support Document. Available at: http://www1.eere.energy.gov/buildings/appliance_standards/commercial/refrig_equip_final_rule_tsd.html

Table 8.2.15 Repair Rates Estimated From Commercial Refrigeration Rulemaking

Component	**10-year repair rate**	**Assumed annual repair rate**
Compressor	25%	2.5%
Evaporator + condenser*	5%	0.5%
Evaporator fan	50%	5.0%
Condenser fan	25%	2.5%
Electronics**		2.5%
Total		13%

*DOE assumed these repair rates are equally shared between evaporator and condenser, e.g., each at a 0.25% annual rate.
**Assumed same repair rate as compressor.

To evaluate whether the above commercial total repair rate (sum of individual rates) is applicable for residential refrigerator-freezers, DOE sought data for total repair rates from Consumers Union, which conducts an annual survey of approximately 100,000 members in the U.S. The survey gathered in April-June 2009 provided total repair rates for standard-size refrigerator-freezer product classes, both with and without automatic icemaking, for units sold in 2005 or later. For products with automatic icemaking, repairs due to icemaking were separated in the data, and could be subtracted from total repairs to obtain a non-icemaking total repair rate for the first 4.4 years of a product's life. Icemaking repair rates, while important to consumers, were not needed for this analysis since this rulemaking does not specifically address icemaking energy reductions and the design options do not change any icemaking-specific components.

Consumers Union provided cumulative rates of repair in 2005-2009 by asking consumers whether the appliance "has ever been repaired," and from this data DOE was able to extract annual rates of repair by year. Because there was no consistent trend in repair rates over time, DOE assumed that annual repair rates were constant. Without additional data, this assumption was also extended to ages 5 years and beyond for subsequent analysis.

DOE used the total annual non-icemaking repair rates to scale the commercial refrigerator component-specific repair rates (Table 8.2.15) to obtain residential component-specific repair rates for standard-size refrigerator-freezer product classes (3, 5 and 7). The scaling factor is the ratio of the average annual non-icemaking repair rate to the total commercial refrigerator repair rate (13%). To derive the scaling factor for standard-size freezers and compact refrig products, DOE used the shipment-weighted average repair rate for product classes 3, 5 and 7. Total repair rates excluding icemaking ranged from 2.1%/yr for PC3 to 5.7%/yr for PC5, equivalent to about 16-44% of the commercial refrigeration equipment total repair cost. See Table 8.2.16.

Table 8.2.16 Rates of Repair by Product Class and Year, With Icemaking Separately Calculated

	Non-icemaking annualized repair rate					
Product class	**2008-2009 (17 months)**	**2007**	**2006**	**2005**	**Average**	**Scaling factor for commercial rates***
3	3.8%	1.9%	0.6%	1.5%	2.12%	0.163
5	4.0%	8.0%	7.2%	4.2%	5.68%	0.437
7	3.9%	3.5%	3.5%	4.5%	3.86%	0.297
Weighted Average	3.9%	4.4%	3.4%	3.2%	3.75%	0.288
	Icemaking annualized repair rate					
3	0.8%	0.6%	0.5%	0.6%	0.64%	
5	1.1%	2.0%	1.8%	1.3%	1.51%	
7	3.9%	3.5%	3.5%	4.5%	3.86%	

Table 8.2.17 shows the annual repair rates estimated for residential refrigerator-freezers.

Table 8.2.17 Annual Repair Rates Estimated for Residential Refrigerator-Freezers

Component	Product Class 3: Top-Mount Refrigerator-Freezer	Product Class 5: Bottom-Mount Refrigerator-Freezer	Product Class 7: Side-Mount Refrigerator-Freezer with TTD* icemaker	Other Product Classes
Compressor	0.41%	1.09%	0.74%	0.72%
Evaporator	0.04%	0.11%	0.07%	0.07%
Evaporator fan	0.82%	2.18%	1.48%	1.44%
Condenser	0.04%	0.11%	0.07%	0.07%
Condenser fan	0.41%	1.09%	0.74%	0.72%
Electronics	0.41%	1.09%	0.74%	0.72%
Total	2.12%	5.68%	3.86%	3.75%

* Through-the-door

Component repair costs were estimated from the incremental cost models developed in Chapter 5, and multiplied by the above repair rates to come up with annual costs by component for each size and product class. Incremental manufacturer's costs were scaled by the manufacturer markup, incremental retail markup, average sales tax markup and repair markup representative of the residential repair and maintenance industry and provided by RSMeans. See Table 8.2.18.

Table 8.2.18 Markups Used in Determining Incremental Repair Costs

Type of Markup	Value		Reference
	Conventional	Built-in	
Manufacturer markup	1.26	1.40	TSD Chapter 6
Incremental retail markup	1.17		TSD Chapter 6
Sales tax markup	1.069		TSD Chapter 6
Repair markup	1.10		RSMeans 2010
Total markup	1.734	1.926	

Finally, baseline repair costs were obtained from data provided by Best Buy Co., Inc. [2010, "Geek Squad Black Tie Protection," data provided by Chartis Insurance]; they reflect average national repair cost. No markups were applied to these end-consumer based costs. See Table 8.2.19.

Table 8.2.19 Average National Baseline Repair Costs for Standard-Sized Residential Refrigerator-Freezers

Component	Repair cost
Compressor	$535
Evaporator fan	$215
Condenser	$310
Condenser fan	$215
Thermostat	$205
Icemaker	$295

Source: Best Buy, 2010, "Geek Squad Black Tie Protection". Data provided by Chartis Insurance (www.chartisinsurance.com). Pricing reflects average national repair cost.

Average annual repair costs were obtained by multiplying the baseline repair costs by the repair rate for product classes 3, 5, and 7. As the Best Buy data was only applicable to product classes 3, 5 and 7, DOE extrapolated to other product classes by examining the ratio of annual cost to initial purchase price for product classes 3, 5, and 7. DOE found that for all three product classes, this ratio was close to 1%. Therefore, DOE assumed a similar ratio holds for product classes 9, 10, 11 and 18, and used these to assign annual baseline repair costs to these product classes. For built-in product classes 3A, 5, 7 and 9, DOE used the same annual repair costs as for the corresponding conventional product classes 3, 5, 7 and 9, respectively. See Table 8.2.20.

Tables 8.2.21 through 8.2.24 show the estimated annual repair costs by efficiency level for each product group.

Table 8.2.20 Baseline Annual Repair Cost Estimates

Product class	Annual repair cost excluding icemaking	Icemaking repair cost	Total annual repair cost
3	$5.77	$1.89	$7.66
5	$15.47	$4.45	$19.92
7	$10.51	$11.39	$21.90
9	$4.37		$4.37
10	$2.83		$2.83
11	$1.43		$1.43
18	$1.80		$1.80

Table 8.2.21 Annual Repair Cost For Standard-Size Refrigerator-Freezers

Product Class 3: Top-Mount Refrigerator-Freezer		Product Class 5: Bottom-Mount Refrigerator-Freezer		Product Class 7: Side-Mount Refrigerator-Freezer with TTD* icemaking	
Efficiency Level ***(% less than baseline energy use)***	**Total annual repair cost**	**Efficiency Level** ***(% less than baseline energy use)***	**Total annual repair cost**	**Efficiency Level** ***(% less than baseline energy use)***	**Total annual repair cost**
1 (10)	$7.70	1 (10)	$20.14	1 (10)	$21.99
2 (15)	$7.74	2 (15)	$20.25	2 (15)	$22.11
3 (20)	$8.03	3 (20)	$20.35	3 (20)	$22.26
4 (25)	$8.06	4 (25)	$20.68	4 (25)	$22.62
5 (30)	$8.09	5 (30)	$21.24	5 (30)	$22.99
6 (36)	$8.34	6 (36)	$21.68	6 (33)	$22.99

* Through-the-door

Table 8.2.22 **Annual Repair Cost For Standard-Size Freezers**

Product Class 9: Upright Freezer		**Product Class 10: Chest Freezer**	
Efficiency Level ***(% less than baseline energy use)***	**Total annual repair cost**	**Efficiency Level** ***(% less than baseline energy use)***	**Total annual repair cost**
1 (10)	$4.53	1 (10)	$2.89
2 (15)	$4.66	2 (15)	$2.93
3 (20)	$4.74	3 (20)	$2.95
4 (25)	$4.74	4 (25)	$2.95
5 (30)	$4.74	5 (30)	$2.95
6 (35)	$5.17	6 (35)	$3.54
7 (40)	$5.65	7 (41)	$3.54
8 (44)	$5.65		

Table 8.2.23 **Annual Repair Cost For Compact Refrigeration Products**

Product Class 11: Compact Refrigerator or Refrigerator-Freezer		**Product Class 18: Compact Chest Freezer**	
Efficiency Level ***(% less than baseline energy use)***	**Total annual repair cost**	**Efficiency Level** ***(% less than baseline energy use)***	**Total annual repair cost**
1 (10)	$1.47	1 (10)	$1.86
2 (15)	$1.50	2 (15)	$1.88
3 (20)	$1.50	3 (20)	$1.88
4 (25)	$1.50	4 (25)	$1.88
5 (30)	$1.50	5 (30)	$2.50
6 (35)	$1.82	6 (35)	$2.50
7 (40)	$1.82	7 (42)	$2.50
8 (44)	$2.15		
9 (50)	$2.15		
10 (59)	$2.15		

Table 8.2.24 Annual Repair Cost For Built-In Refrigeration Products

Product Class 3A-BI: Built-in All Refrigerators		**Product Class 5-BI: Built-in Bottom-Mount Refrigerator-Freezers**	
Efficiency Level ***(% less than baseline energy use)***	**Total annual repair cost**	**Efficiency Level** ***(% less than baseline energy use)***	**Total annual repair cost**
1 (10)	$7.73	1 (10)	$20.16
2 (15)	$7.83	2 (15)	$21.26
3 (20)	$7.83	3 (20)	$21.26
4 (25)	$8.30	4 (25)	$22.51
5 (29)	$8.76	5 (27)	$22.51
Product Class 7-BI: Built-in Side-by-Side Refrigerator-Freezers		**Product Class 9-BI: Built-in Upright Freezers**	
Efficiency Level ***(% less than baseline energy use)***	**Total annual repair cost**	**Efficiency Level** ***(% less than baseline energy use)***	**Total annual repair cost**
1 (10)	$22.38	1 (10)	$4.54
2 (15)	$23.32	2 (15)	$4.72
3 (20)	$23.32	3 (20)	$5.38
4 (22)	$23.32	4 (25)	$5.38
		5 (27)	$5.38

8.2.3 Product Lifetimes

DOE estimated product lifetimes by fitting a survival probability function to data of historical shipments and age distributions of products. DOE performed separate modeling for standard size refrigerator-freezers, standard size freezers, and compact refrigeration products. The conversion from primary to secondary refrigerator-freezers was also modeled as part of the lifetime determination for standard size refrigerator-freezers.

8.2.3.1 Estimated Survival Function

The Energy Information Agency (EIA)'s Residential Energy Consumption Survey (RECS)[1] of occupied primary housing units records the presence of various appliances in each household, and places the age of each appliance into bins comprising several years. Data from the U.S. Census's *American Housing Survey* (AHS),[6] which surveys all housing including vacant and second homes, enabled DOE to adjust the RECS data to reflect some appliance use outside of primary residences. By combining the results of both surveys with the known history of appliance shipments (collected from *Appliance* magazine or directly from manufacturer trade associations), DOE estimated the percentage of appliances of a given age still in operation. This survival function, which DOE assumed has the form of a cumulative Weibull distribution, provides an average and a median appliance lifetime.

The Weibull distribution is a probability distribution commonly used to measure failure rates.[d] Its form is similar to an exponential distribution, which models a fixed failure rate, except that a Weibull distribution allows for a failure rate that changes over time in a particular fashion. The cumulative Weibull distribution takes the form:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta \text{ and}$$

$$P(x) = 1 \text{ for } x \leq \theta$$

Where:

$P(x)$ = probability that the appliance is still in use at age x,
x = appliance age,
α = scale parameter, which would be the decay length in an exponential distribution,
β = shape parameter, which determines the way in which the failure rate changes through time, and
θ = delay parameter, which allows for a delay before any failures occur.

When $\beta = 1$, the failure rate is constant over time, giving the distribution the form of a cumulative exponential distribution. In the case of appliances, β commonly is greater than 1, reflecting an increasing failure rate as appliances age.

The RECS survey is DOE's primary resource for appliance ages. For several appliances, including refrigerators and freezers, the survey asks respondents to identify the appliance's age as:

- less than 2 years old,

[d] For reference on the Weibull distribution, see sections 1.3.6.6.8 and 8.4.1.3 of the *NIST/SEMATECH e-Handbook of Statistical Methods*, <www.itl.nist.gov/div898/handbook/>.

- 2 to 4 years old,
- 5 to 9 years old,
- 10 to19 years old, or
- more than 20 years old.

The RECS survey has been conducted every three or four years for the past several decades. For this analysis, DOE used the surveys conducted in 1990, 1993, 1997, 2001, and 2005. DOE used the AHS count of housing units that contain refrigerators to scale the RECS data to better match the total installed stock. The U.S. Census AHS does not include data on freezers. DOE used the RECS micro-data to exclude from this analysis refrigerators that are both "half-height" and less than 10 cubic feet in capacity, because such refrigerators are not standard-sized. To determine overall refrigerator lifetime, DOE included all appropriately sized refrigerators, whether the household's first (primary) or second refrigerator. Households that did not know the age of their appliance were allocated among the remaining age bins according to the distribution of respondents who did report the appliance age.

Refrigerator ownership exhibits complex consumer behavior, which is not adequately reflected in AHS. In particular, AHS records only whether a housing unit contains a refrigerator, not the number of refrigerators. In addition, AHS may record a unit as containing a refrigerator when it contains a compact, rather than standard-size, appliance. Therefore, DOE used AHS only to scale the number of first refrigerators recorded by RECS. The baseline number of refrigerators reported in each RECS age bin is the sum of the AHS-scaled first refrigerators and the un-scaled, standard-size second refrigerators.

DOE adjusted the RECS survey data to account for the fact that the RECS survey begins its reference year with July, whereas shipments data are provided for each calendar year. DOE adjusted the data by using the survival function to model the additional retirement and replacement of appliances that takes place in the latter half of a survey year (after a given respondent is surveyed).

DOE used the RECS data on appliance ages, combined with the history of appliance shipments, to develop survival functions for refrigeration products. For example, DOE summed the total shipments from 5 to 9 years before each RECS survey, then compared this number with the number of units still in use at the time of the survey to approximate the percentage of surviving appliances within that age bin. By combining the age bins from the five RECS surveys with shipments data, DOE had enough data to use a least-squares method to build a fit to a Weibull distribution and find the parameters (α, β, θ) that best approximate the number of surviving units. Because the first two (youngest) RECS bins tend to have a large scatter relative to the shipments in those years, DOE combined the RECS and shipments data in the first two bins. Refrigerators and freezers generally do not fail during their first four years, so combining bins did not lower appreciably the accuracy of the distribution. DOE weighted each bin's contribution to the sum of squares by the inverse of the variance in RECS survey results, which controls for the changes in sample size between bins and through time.[e] RECS has a complex error model. DOE used only the error due to finite sample size to determine the variance for weighting the age bins. The equation for the sum of squares that DOE minimized is:

$$\sum_i \frac{(RECS_i - Surv_i)^2}{\sigma_{i,RECS}^2},$$

Where:

i = the identifier for a bin from a single RECS,
$RECS_i$ = the number of appliances reported by RECS in bin *I*,
$Surv_i$ = the number of surviving appliances in bin *i* predicted by the Weibull distribution applied to the number of appliances shipped (a function of α, β, and θ), and
$\sigma_{i,RECS}$ = the standard error (square root of the variance) of the RECS data point for bin *i*.

Table 8.2.25 shows the RECS data for refrigerators, the associated total shipments, and the best-fit Weibull calculation of stock by age bin. Figure 8.2.8 plots the data from the third and fourth columns of Table 8.2.25 against each other to show the quality of the fit. DOE allowed the delay parameter, θ, to vary only between 1 and 5 years, which corresponds to common warranty periods (see discussion below). For refrigerators and freezers, the best fit within this range is 5 years.

The Weibull distribution, shown in Figure 8.2.3, is characterized by the parameters α = 13.91, β = 1.68, and θ = 5.0. This distribution has a mean refrigerator lifetime of 17.43 years and a median lifetime of 16.18 years.

[e] See sections 4.1.4.3, 4.4.3.2, and 4.4.5.2 of *NIST/SEMATECH e-Handbook of Statistical Methods*, <www.itl.nist.gov/div898/handbook/>.

Table 8.2.25 Standard-Size Refrigerator-Freezers: Comparison of Survey and Shipments Data with Modeled Stock

		RECS 2005			
		All Refrigerators		**Second Refrigerators**	
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	51,119,128	56,880,896	51,119,128	5,311,005	3,041,016
5 to 9	42,988,500	40,150,841	41,031,292	4,983,112	3,524,129
10 to 19	68,088,000	36,771,769	40,997,548	8,672,157	6,942,353
20 or more	165,800,000	10,337,608	12,039,872	4,139,841	4,628,220
		RECS 2001			
		All Refrigerators		**Second Refrigerators**	
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	44,319,100	46,312,479	44,319,100	2,460,510	2,637,703
5 to 9	36,982,000	39,491,335	35,298,172	3,868,224	3,031,985
10 to 19	60,556,000	35,970,898	36,813,807	6,572,685	6,198,453
20 or more	144,325,000	11,301,203	11,920,574	3,955,496	4,580,842
		RECS 1997			
		All Refrigerators		**Second Refrigerators**	
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	38,185,000	44,356,564	38,185,000	2,047,982	2,274,485
5 to 9	32,698,000	36,760,359	31,123,487	2,782,204	2,695,071
10 to 19	56,244,000	31,056,224	33,972,064	5,078,190	5,724,270
20 or more	122,660,000	10,989,427	11,832,244	3,879,197	4,475,841
		RECS 1993			
		All Refrigerators		**Second Refrigerators**	
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	33,088,000	37,322,759	33,088,000	1,605,544	1,972,965
5 to 9	31,584,000	35,001,768	30,138,108	2,289,052	2,591,010
10 to 19	52,400,000	32,735,032	30,891,143	4,695,960	5,348,774
20 or more	101,577,000	13,119,858	11,723,329	5,708,862	4,296,210
		RECS 1990			
		All Refrigerators		**Second Refrigerators**	
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	32,670,000	38,098,670	32,670,000	1,784,095	1,950,717
5 to 9	26,419,000	30,724,176	25,249,353	2,227,766	2,158,527
10 to 19	56,584,000	34,088,557	33,242,186	5,316,297	5,767,417
20 or more	82,797,000	12,571,836	10,159,632	4,869,236	3,737,018

Source: U.S. Department of Energy–Energy Information Agency. Residential Energy Consumption Survey. 1990, 1993, 1997, 2001, and 2005.

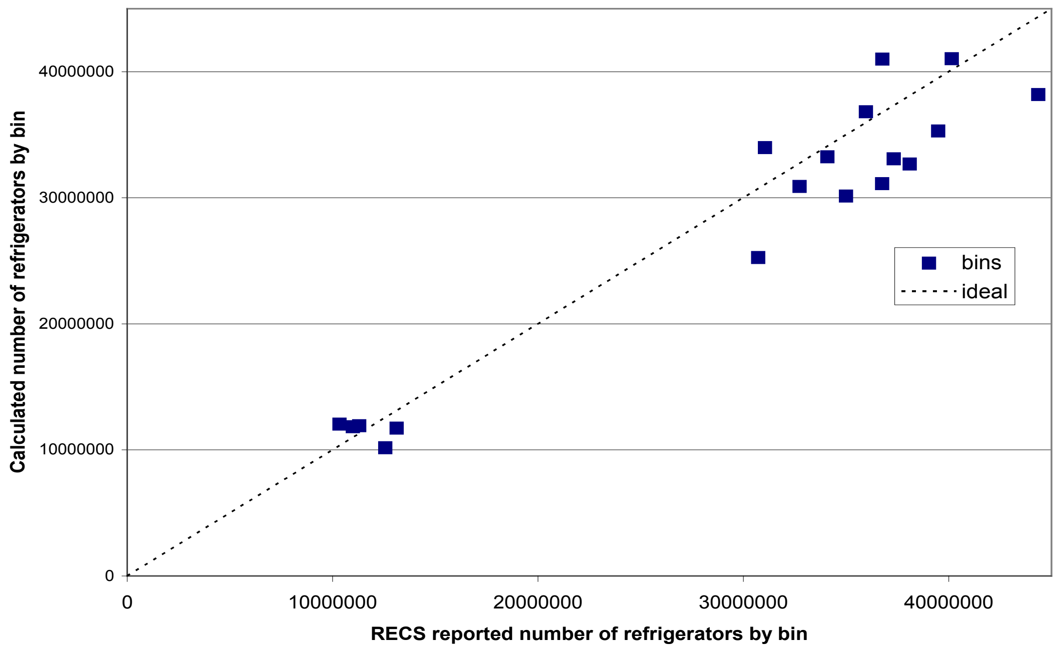


Figure 8.2.2 Comparison of Modeled Refrigerator Age Distribution with Data from Residential Energy Consumption Surveys

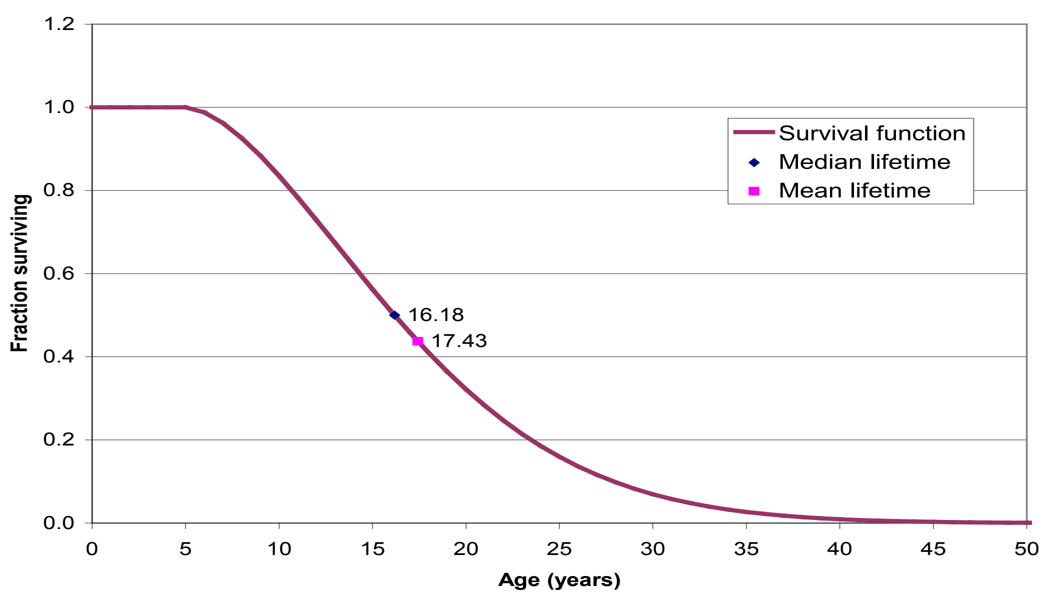


Figure 8.2.3 Survival Function for Standard-Size Refrigerator-Freezers

The method DOE used to calculate product lifetimes incorporates several assumptions:

- Appliance lifetime can be modeled by a survival function. In particular, a Weibull distribution is an appropriate survival function.
- The appliance survival function does not change through time.
- The survival function is independent of other household factors (such as household size or geographic region) as well as product class (within standard-size refrigerators or freezers).
- RECS respondents neither systematically overestimated nor underestimated the current age of their appliance.
- The historical shipment data are accurate.
- The shipped appliances are installed exclusively (or almost exclusively) in residences.
- The Weibull delay parameter, θ, is limited to between 1 and 5 years.

Three of these assumptions reflect analytical choices made by DOE. The first is the assumption that a Weibull distribution is the appropriate distribution to use for rates of appliance retirement. This distribution is the standard one used in lifetime analyses, but it is not guaranteed to reflect actual real-world experience. The second assumption is that consumer behavior and mechanical appliance lifetime have not changed over time. This assumption required DOE to treat equally all data from the several RECS surveys. Using only recent surveys (which may better reflect recent consumer behavior and appliance lifetime) would provide only a few data points for attempting least-squares fits, producing large statistical uncertainty.

The third assumption concerns the Weibull delay parameter. DOE limited the delay parameter to between 1 and 5 years to reflect the range of common appliance warranties. A delay of less than 1 year would imply that some appliances fail or are replaced within their first year of use. A delay of more than 5 years would imply that no appliances are replaced for some time after the end of the longest standard warranty. Fits using $\theta > 5$ also commonly show nonsensical behavior, with sharp changes in consumer behavior or appliance survival immediately following the delay period.

8.2.3.2 Conversion of First to Second Refrigerators

When a household purchases a new refrigerator, sometimes it uses its original unit as a secondary appliance in the basement or garage. DOE modeled the process by which first refrigerators are converted to second refrigerators as a Weibull process having a cumulative distribution of the form:

$$P(x) = \delta + (1-\delta)\times\left(1-e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}}\right) \text{ for } x > \theta \text{ and}$$

$$P(x) = \delta \text{ for } x \le \theta$$

Where:

P(x) =	probability that the appliance has been converted at age *x*,
x =	appliance age,
α =	the scale parameter, which would be the decay length in an exponential distribution,
β =	the shape parameter, which determines the way in which the conversion rate changes through time,
δ =	the percentage of shipments that are used immediately as second refrigerators, and
θ =	the delay parameter, which allows for a delay before any conversions occur.

Rather than comparing second refrigerators to shipments, DOE compared them with the existing total installed base of refrigerators of a certain age, as measured by RECS. As with calculating appliance lifetime, the RECS data were adjusted with AHS data. In essence, DOE constructed a Weibull distribution to model a conversion function rather than a survival function. In addition, the model allows for the direct purchase of a new second refrigerator. A refrigerator bought to be a second refrigerator is modeled as being converted from first to second immediately at purchase; the offset parameter δ represents those units. Refrigerators commonly are bought to be second units, as indicated by the relatively large number of young second refrigerators reported by in RECS surveys.

DOE fit the conversion function using results from the 1990, 1993, 1997, 2001, and 2005 RECS. The RECS micro-data again enabled removing refrigerators that are not standard size, which has a significant effect given that many compact refrigerators are used as second units. In Table 8.2.25 the fifth column shows the RECS-derived stock of second refrigerators by age bin, and the sixth column shows the best fit from a Weibull distribution. Figure 8.2.4 shows the Weibull distribution. The best-fit Weibull parameters for the conversion function are α = 38.12, β = 2.03, and θ = 0.0, with an offset of 5.6 percent (meaning that 5.6 percent of shipments are sold as new second refrigerators). Roughly 1.5 percent of surviving refrigerators are converted from first to second refrigerator status each year, and roughly 20 percent of surviving refrigerators are converted to second refrigerators before they reach 15 years of age.

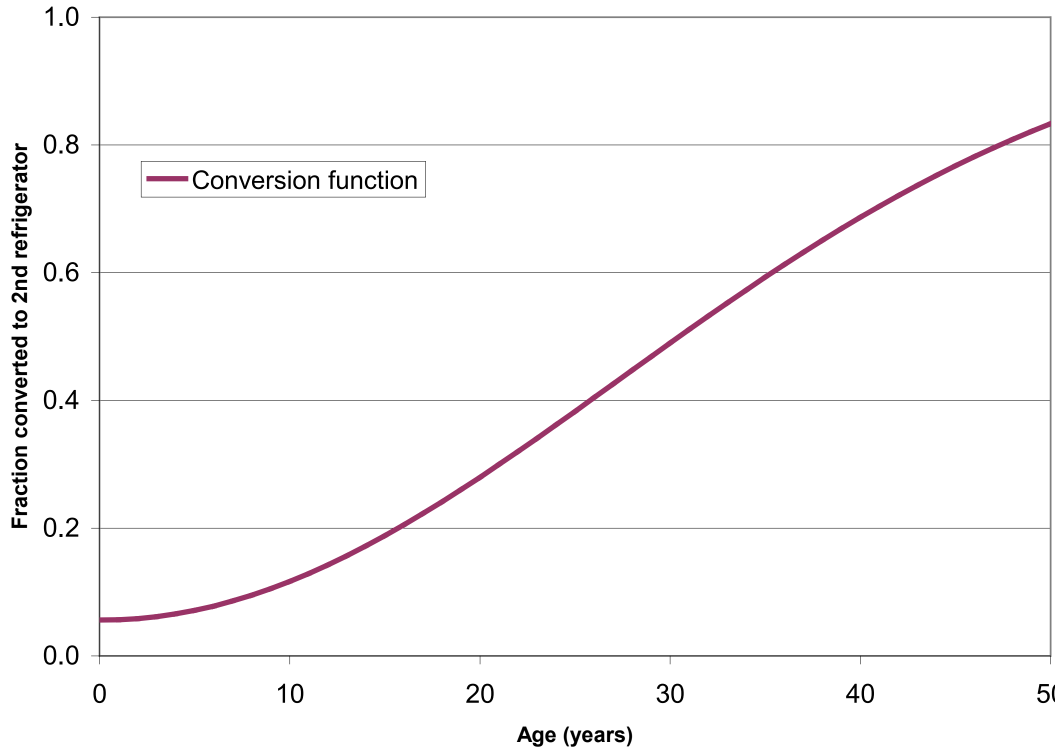


Figure 8.2.4 Function for Conversion of First to Second Refrigerator-Freezers

8.2.3.3 Standard-Size Freezers

DOE assumed relatively simple consumer behavior related to freezers. DOE did not model the conversion from first to second freezer for households having more than one freezer, but simply used all freezer data from RECS. Standard-sized freezers were assumed to have a capacity greater than 10 cubic feet. As with refrigerators, RECS bins were adjusted for units replaced in the second half of a year to synchronize the RECS and shipments data. RECS did not collect freezer lifetime data in 1990, so DOE used results from only the 1993, 1997, 2001, and 2005 surveys. The U.S. Census AHS survey does not report data on freezers, so the RECS bins were not scaled by the AHS total as for refrigerators. Before 2005, RECS reported the age distribution only for a household's first freezer, so DOE assumed that second and third freezers have the same age distribution as first freezers.

The best-fit Weibull parameters for freezer lifetime are α = 19.49, β = 2.40, and θ = 5.0. The resulting calculated mean freezer lifetime is 22.28 years; the median is 21.73 years. Table 8.2.26 lists the (adjusted) number of freezers reported in each RECS age bin, along with the modeled stock based on the best-fit Weibull survival function and the manufacturer-provided shipments history. Figure 8.2.5 shows the survival function used for standard-size freezers in the LCC and national impact analyses.

Table 8.2.26 Standard-Size Freezers: Comparison of Survey and Shipments Stock to Modeled Stock

RECS 2005			
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**
0–4	12,003,000	9,378,328	12,003,000
5–9	8,617,000	8,118,709	8,557,502
10–19	13,571,000	9,886,011	11,269,325
20 or more	47,672,000	7,607,227	6,973,305
RECS 2001			
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**
0–4	9,284,000	8,462,128	9,284,000
5–9	7,615,000	6,939,187	7,557,289
10–19	12,648,000	12,144,649	10,366,534
20 or more	42,528,000	7,494,606	7,817,703
RECS 1997			
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**
0–4	7,580,000	7,192,449	7,580,000
5–9	6,578,000	7,527,447	6,529,381
10–19	13,920,000	12,591,552	11,241,688
20 or more	36,203,000	6,561,157	8,045,004
RECS 1993			
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**
0–4	6,700,000	6,018,630	6,700,000
5–9	6,250,000	6,924,204	6,202,243
10–19	17,801,000	13,279,168	14,110,780
20 or more	27,388,000	8,277,900	6,374,921

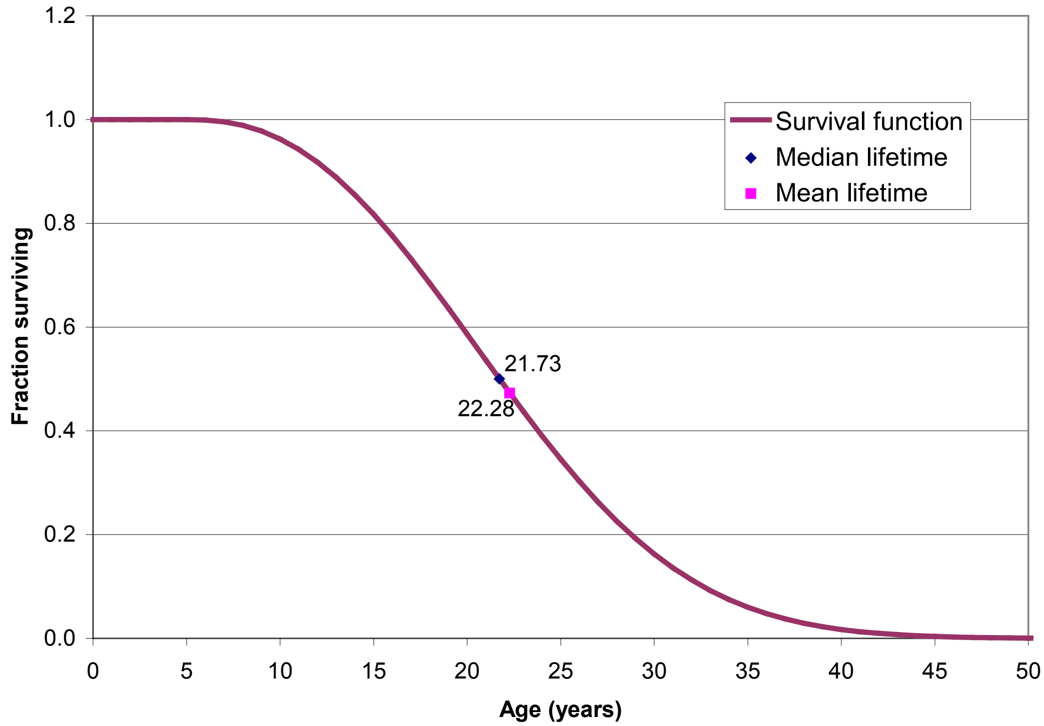


Figure 8.2.5 Survival Function for Standard-Size Freezers

8.2.3.4 Compact Refrigeration Products

As mentioned previously, compact refrigeration products are used in the residential and commercial sectors. RECS micro-data identify households that have refrigerators that are "half-height" and less than 10 cubic feet in capacity. DOE considered those households as potentially using compact refrigerators. EIA's *Commercial Building Energy Consumption Survey* (CBECS) survey of 2003[7] notes the presence of a residential-style refrigerator in an establishment. However, CBECS provides no further detail regarding the size of the refrigerator. Thus, RECS and CBECS data together do not provide enough detail on compact refrigerators to develop a survival function similar to the ones developed for standard-sized refrigerator-freezers and freezers.

DOE assumed that a Weibull distribution remains the appropriate functional form to represent retirement rates of compact refrigeration products. DOE initially used the average value of lifetime and historical shipments data from *Appliance* magazine to estimate Weibull parameters for compact refrigerators. When DOE applied the average lifetime of 10 years, given in *Appliance* magazine, to historical shipments, the model yielded a stock of compact refrigerators that was more than double the stock indicated by RECS and CBECS. DOE therefore calibrated the average lifetime to match the stock of compact refrigerators as reported by the surveys (see chapter 9 for further details).

The estimated Weibull parameters for compact refrigerator lifetime are α = 5.75 and β = 1.75. The resulting calculated mean lifetime is 5.62 years. For determining the lifetime of compact freezers, DOE used a scaling factor proportional to the ratio of the lifetimes of standard-sized refrigerators and standard-sized freezers. The calculated mean lifetime of a compact freezer is 7.46 years.

8.2.4 Discount Rates

To discount future operating cost expenditures to establish their present value, DOE uses consumer (or customer) discount rates. DOE derived discount rates for the LCC and PBP analyses from estimates of the cost to finance purchase of the considered products. In addition to estimating discount rates for appliances bought directly by residential consumers, DOE also estimated discount rates for purchasers of compact refrigerators and freezers in the commercial sector.

8.2.4.1 Discount Rates for Residential Consumers

Households use various methods to finance the purchase of major appliances. In principle, one could estimate the interest rates on the actual financing vehicles used to purchase appliances. The frequency with which each financing vehicle is used to purchase an appliance is unknown, however.

DOE's approach involves identifying all possible debt or asset classes that might be used to purchase the considered appliances or that might be affected indirectly. An indirect effect would arise if a household sold assets in order to pay off a loan or credit card debt that might have been used to finance the appliance purchase.

To develop a weighting for the debt or asset classes, DOE estimated the average percentage shares of the various types of debt and equity in the average U.S. household using data from the Federal Reserve Board's *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.[8] (The survey is conducted every three years.) DOE excluded debt from primary mortgages and assets considered non-liquid (such as retirement accounts), because the magnitude of these classes is great, and they are unlikely to be used for or affected by purchase of appliances. Table 8.2.27 shows the average percentages of each considered type of debt or equity in each survey, as well as the mean percentage of each source of financing throughout the 7 years surveyed. The mean shares are the basis for the weight given to each class.

Table 8.2.27 Percent of Total Value for Considered Household Debt and Equity Classes

Type of Debt or Equity	1989 %	1992 %	1995 %	1998 %	2001 %	2004 %	2007 %	Mean %
Home equity loan	4.3	4.5	2.7	2.8	2.8	4.4	4.6	3.7
Credit card	1.6	2.1	2.6	2.2	1.7	2.0	2.4	2.1
Other installment loan	2.8	1.7	1.4	1.7	1.1	1.3	1.1	1.6
Other residential loan	4.4	6.9	5.2	4.3	3.1	5.8	7.1	5.3
Other line of credit	1.1	0.6	0.4	0.2	0.3	0.5	0.3	0.5
Checking account	5.8	4.7	4.9	3.9	3.6	4.2	3.4	4.4
Savings or money market account	19.2	18.8	14.0	12.8	14.2	15.1	13.0	15.3
Certificate of deposit	14.5	11.7	9.4	7.0	5.4	5.9	6.5	8.6
Savings bond	2.2	1.7	2.2	1.1	1.2	0.9	0.7	1.4
Bonds	13.8	12.3	10.5	7.0	7.9	8.4	6.7	9.5
Stocks	22.4	24.0	25.9	36.9	37.5	28.0	28.6	29.0
Mutual funds	8.0	11.1	20.9	20.1	21.3	23.4	25.5	18.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.

The source for interest rates for loans, credit cards, and lines of credit was the Federal Reserve Board's *SCF* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007. Table 8.2.28 shows the average nominal rates in each year and the inflation factors used to calculate real rates. DOE calculated effective interest rates for home equity loans by taking into account that interest on such loans is tax deductible. Table 8.2.29 shows the average effective real rates in each year and the mean rate across years. Because the interest rates for each type of household debt reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2014.

Table 8.2.28 Average Nominal Interest Rates for Household Debt

Type of Debt	1989 %	1992 %	1995 %	1998 %	2001 %	2004 %	2007 %	Mean %
Home equity loans	11.5	9.6	9.6	9.8	8.7	5.7	7.9%	9.0%
Credit cards*	-	-	14.2	14.5	14.2	11.7	12.6%	13.4%
Other installment loans	9.0	7.8	9.3	7.8	8.7	7.4	10.4%	8.6%
Other residential loans	8.8	7.6	7.7	7.7	7.5	6.0	6.3%	7.4%
Other line of credit	14.8	12.7	12.4	11.9	14.7	8.8	12.7%	12.6%
Inflation rate	4.82	3.01	2.83	1.56	2.85	2.66	2.85	

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.
* No data on interest rates available for credit cards in 1989 or 1992.

Table 8.2.29 Average Real Effective Interest Rates for Household Debt

Type of Debt	1989 %	1992 %	1995 %	1998 %	2001 %	2004 %	2007 %	Mean %
Home equity loans	3.8	4.3	4.4	5.8	3.8	1.9	3.3	3.9
Credit cards*	-	-	11.0	12.7	11.1	9.1	9.7	10.7
Other installment loans	4.9	5.8	7.0	6.6	6.1	5.4	5.8	6.0
Other residential loans	4.0	4.7	4.8	6.0	4.6	3.3	3.4	4.4
Other line of credit	9.6	9.4	9.3	10.2	7.3	6.0	9.7	8.8

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.
* No data on interest rates available for credit cards in 1989 or 1992.

Rate data are not available from the *SCF* for classes of assets, so DOE derived a distribution of rates for each class from other sources. The interest rates associated with certificates of deposit,[9] savings bonds,[10] and bonds (AAA corporate bonds)[11] were collected from Federal Reserve Board time-series data for 1977–2008. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts came from Cost of Savings Index data covering 1984–2008.[12] The rates for stocks are the annual returns on the Standard and Poor's 500 for 1977–2008.[13] Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year for 1977–2008. DOE adjusted the nominal rates to real rates using the annual inflation rate for each year.

Average nominal and real interest rates for the classes of household assets are listed in Table 8.2.30. Because the interest and return rates for each type of asset reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2014.

Table 8.2.30 Average Nominal and Real Interest Rates for Household Equity

Type of Equity	Average Nominal Rate %	Average Real Rate %
Checking accounts	-	0.0
Savings and money market	5.4	2.2
CDs	6.6	2.3
Savings bonds	7.7	3.3
Bonds	8.5	4.1
Stocks	11.6	7.1
Mutual funds	10.3	5.8

Table 8.2.31 summarizes the mean real effective rates of each type of equity or debt, and also shows the weights for each class derived from the *SCF* data. The average rate across all types of household debt and equity, weighted by the share of each type, is 5.1 percent.

Table 8.2.31 Average Interest on Household Debt and Equity

Type of Debt or Equity	Average % of Household Debt plus Equity*	Mean Effective Real Rate %**
Home equity loan	3.7	3.0%
Credit card	2.1	3.9%
Other installment loan	1.6	10.7%
Other residential loan	5.3	6.0%
Other line of credit	0.5	4.4%
Checking account	4.4	0.0%
Savings and money market account	15.3	2.3%
Certificate of deposit	8.6	2.2%
Savings bond	1.4	3.4%
Bonds	9.5	4.1%
Stocks	29.0	7.7%
Mutual funds	18.6	6.2%
Total/weighted-average discount rate	100.0	**5.1%**

* Not including primary mortgage or retirement accounts.

** Adjusted for inflation and, for home equity loans, tax deduction of interest.

8.2.4.2 Assignment of Discount Rates to Sample Households

To account for variations among households, DOE assigned each sampled RECS household a rate from the distribution of rates developed for each type of debt and equity. Appendix 8-D presents the distributions that DOE used in the LCC and PBP analyses.

8.2.4.3 Discount Rates for Commercial Purchasers

DOE derived the discount rate for commercial-sector compact refrigeration products from the cost of capital of publicly-traded firms in the sectors that purchase those products (lodging and other commercial sectors).[f] The firms typically finance equipment purchases through debt and/or equity capital. DOE estimated the cost of the firms' capital as the weighted average of the cost of equity financing and the cost of debt financing for each year between 2001 and 2008. The costs of debt and equity financing are publicly available for firms in the sectors that purchase compact refrigeration products.

DOE estimated the cost of equity using the capital asset pricing model (CAPM).[14] The CAPM assumes that the cost of equity (k_e) for a given company is proportional to the systematic risk faced by that company, whereby high risk is associated with a high cost of equity and low risk is associated with a low cost of equity. The systematic risk facing a firm is determined by

[f] The "other commercial" sector includes financial institutions and all services other than lodging (SIC 6-8).

several variables: the risk coefficient of the firm (β), the expected return on risk-free assets (R_f), and the equity risk premium (*ERP*). The risk coefficient of a firm describes the risk associated with that firm represented by standard deviations in the firm's stock price. The expected return on risk-free assets is defined by the yield on long-term government bonds. The *ERP* represents the difference between the expected stock market return and the risk-free rate. To estimate the expected return on risk-free assets and the equity risk premium, DOE used stock and bond data from Damodaran Online, a widely used source of information about debt and equity financing for most types of firms. [15,16] The Damodaran Online data were adjusted for annual inflation using deflator data for the gross domestic product from the Bureau of Economic Analysis' *National Income and Product Accounts Tables*.[17]

The cost of equity financing is estimated using the following equation:

$$k_e = R_f + (\beta \times ERP)$$

Where:

k_e =	cost of equity,
R_f =	inflation-adjusted expected return on risk-free assets,[g]
β =	risk coefficient of the firm, and
ERP =	equity risk premium.

The cost of debt financing (k_d) is the interest rate paid on money a company borrows. The cost of debt is estimated by adding a risk adjustment factor (R_a) to the risk-free rate. This risk adjustment factor depends on the variability of stock returns represented by standard deviations in the firm's stock price. Thus for firm *i*, the cost of debt financing is:

$$k_{di} = R_f + R_{ai}$$

Where:

k_d =	cost of debt financing for firm *i*,
R_f =	expected return on risk-free assets, and
R_{ai} =	risk adjustment factor to risk-free rate for firm *i*.

DOE estimates the weighted-average cost of capital using the following equation:

$$WACC = k_e \times w_e + k_d \times w_d$$

---

[g] Ibbotson Associates argues that the arithmetic mean equates the expected future value with the present value and should be used in calculating the risk-free rate and equity risk premium when using CAPM to estimate discount rates (*Stocks, Bonds, Bills, and Inflation 2009 Yearbook*, Ibbotson Associates, p. 60).

Where:

WACC =	weighted average cost of capital,
w_e =	proportion of equity financing, and
w_d =	proportion of debt financing.

The values of the parameters used in the calculations are shown in Table 8.2.32.

Table 8.2.32 Data for Calculating Weighted-Average Cost of Capital for Commercial Sectors

Sector	Year	β	R_f %	ERP %	R_a %	w_e %	w_d %
Lodging	2001	1.18	3.25	5.17	1.50	88	12
	2002	1.27	3.55	3.66	1.50	89	11
	2003	1.71	3.40	4.70	1.25	93	7
	2004	0.98	3.43	4.34	1.00	89	11
	2005	1.45	3.36	4.08	1.25	93	7
	2006	1.24	3.36	4.13	1.25	93	7
	2007	1.25	3.54	4.33	1.00	96	4
	2008	1.23	4.10	2.33	2.00	86	14
Other Commercial	2001	0.87	3.25	5.17	3.50	77	23
	2002	0.92	3.55	3.66	3.50	77	23
	2003	0.87	3.40	4.70	1.50	81	19
	2004	0.90	3.43	4.34	1.25	84	16
	2005	0.88	3.36	4.08	1.50	82	18
	2006	0.91	3.36	4.13	2.00	84	16
	2007	0.87	3.54	4.33	1.25	79	21
	2008	0.93	4.10	2.33	3.00	68	32

Note: Parameters are defined on the preceding two pages.

Using the procedure described above and the data in Table 8.2.32, DOE developed the real weighted-average cost of capital for the two commercial sectors that purchase compact refrigeration products. Those costs are listed in Table 8.2.33.

Table 8.2.33 Weighted-Average Cost of Capital for Commercial Sectors

Year	Lodging %	Other Commercial %
2001	5.69	6.75
2002	5.11	6.21
2003	5.49	6.64
2004	5.82	6.62
2005	5.95	6.24
2006	6.04	6.46
2007	6.42	6.40
2008	5.74	5.60
Sector average	5.78	6.37

DOE developed a distribution of discount rates within each sector. The standard deviation of the distribution for each sector is provided in Table 8.2.34. Weighting each sector's discount rate by its share of compact refrigerator purchases,[h] DOE estimated that the average discount rate for companies that purchase compact refrigeration products is 6.2 percent.

Table 8.2.34 Discount Rates for Commercial Sectors

Sector	Discount Rate				% of Purchases
	Average %	Max. %	Min. %	Standard Deviation %	
Lodging	5.78	11.98	2.35	1.26	29
Other commercial	6.37	15.65	2.48	1.72	71
Weighted average	6.20	-	-	-	100

To account for variations in discount rates within each sector, DOE applied a normal probability distribution to the average values and standard deviations in Table 8.2.34. DOE truncated the normal distribution using the maximum and minimum values presented in Table 8.2.34.

8.2.5 Compliance Date of Standard

The compliance date of a potential new standard is the date when it would become operative. Based on DOE's implementation report for energy conservation standards activities submitted pursuant to section 141 of the Energy Policy Act of 2005, a final rule pertaining to the appliances being considered for this rulemaking is scheduled for December 2010.[18] The compliance date of any new energy efficiency standards for the products is 3 years after the final

[h] The approach for estimating the share of total purchases by each of the two commercial sectors is described in chapter 9.

rule is published, or January 2014. The Department calculated the LCC and PBP for all consumers as if each would purchase a new appliance in 2014.

8.2.6 Base-Case Energy Efficiencies

To estimate the percentage of consumers who would be affected by a standard at any of the potential efficiency levels, in its LCC analysis DOE considers the projected distribution of efficiencies for products that consumers purchase under the base case (the case without new energy efficiency standards). DOE refers to this distribution of product energy efficiencies as the base-case efficiency distribution. Using the projected distribution of efficiencies for each product class, DOE assigned a specific efficiency to each sample household. If a household is assigned an efficiency that is greater than or equal to the efficiency of the standard level under consideration, the LCC calculation would show that this household would not be affected by that standard level.

DOE began with the distribution (market shares) of energy efficiency levels for refrigeration products in 2007 and, where available, 2008, based on data provided by AHAM (see Table 8.2.35).[19] In 2007, efficiency level 2 for refrigerator-freezers (15 percent less energy use than the DOE standard) corresponded to the efficiency required for ENERGY STAR certification. In 2008, the criteria changed so that efficiency level 3 (20 percent less energy use than the DOE standard) corresponded to the efficiency required for ENERGY STAR certification.

Efforts to promote ENERGY STAR refrigerator-freezers through various means, including consumer rebates, are expected to increase their market share by 2014. Although it is difficult to predict appliance sales in 2014, it is not unreasonable to assume that the increase in market shares of ENERGY STAR products will generally follow a similar pattern as it did in the period before 2008. However, because the ENERGY STAR efficiency level is higher than it was before, the growth in market share may be slower. Thus, DOE assumed that the projected market share of ENERGY STAR models in 2014 (under current requirements) is equal to the average of ENERGY STAR market shares in 2007 (under the old requirements) and 2008 (under current requirements). In this way, the ENERGY STAR market shares for product classes 3 and 5 grow more slowly between 2008 and 2014 than they had grown under the old requirements before 2008. For product class 7, the method yields a slight decline in share because a large share of sales already qualified for ENERGY STAR in the first year of the current requirements (2008).

Table 8.2.35 Standard-Size Refrigerator-Freezers: Historic and Base-Case Efficiency Distributions

Product Class 3: Top-Mount Refrigerator-Freezer				Product Class 5: Bottom-Mount Refrigerator-Freezer			
Efficiency Level *(% less than baseline energy use)*	**Market Share %**			**Efficiency Level** *(% less than baseline energy use)*	**Market Share %**		
	2007	**2008**	**2014**		**2007**	**2008**	**2014**
Baseline	80.6	75.7	78.2	Baseline	11.8	14.2	13.0
1 (10)	5.9	2.4	4.2	1 (10)	0.1	0.0	0.1
2 (15)	13.2	18.7	9.4	2 (15)	69.8	38.6	19.3
3 (20)†	0.2	3.2	8.3	3 (20)†	18.3	47.2	67.7
4 (25)	0.0	0.0	0.0	4 (25)	0.0	0.0	0.0
5 (36)	0.0	0.0	0.0	5 (36)	0.0	0.0	0.0

Product Class 7: Side-by-Side Refrigerator-Freezer with TTD*			
Efficiency Level *(% less than baseline energy use)*	**Market Share %**		
	2007	**2008**	**2014**
Baseline	25.0	18.4	21.7
1 (10)	43.0	9.7	26.4
2 (15)	30.3	30.1	15.0
3 (20)†	1.7	41.9	37.0
4 (25)	0.0	0.0	0.0
5 (33)	0.0	0.0	0.0

* Through-the-door ice service.
† Meets current (2008) ENERGY STAR criteria.

ENERGY STAR requirements for standard-size freezers and compact products were initiated in 2003, and have not changed since then. Those ENERGY STAR requirements correspond to efficiency level 1 for standard-size freezers and level 3 for compact products. Because the ENERGY STAR requirements for these products have not changed and because these products are less impacted by rebate programs than standard-size refrigerator-freezers, DOE assumed that the market shares of ENERGY STAR products would remain the same between 2007 (or, for product class 11, the average of 2007 and 2008)[i] and 2014 (Tables 8.2.36 and 8.2.37).

[i] 2008 AHAM data was only available for one product class (11).

Table 8.2.36 Standard-Size Freezers: Historic and Base-Case Efficiency Distributions

Product Class 9: Upright Freezer			Product Class 10: Chest Freezer		
Efficiency Level *(% less than baseline energy use)*	**Market Share %**		**Efficiency Level** *(% less than baseline energy use)*	**Market Share %**	
	2007	**2014**		**2007**	**2014**
Baseline	81.5	81.5	Baseline	84.6	84.6
1 (10)*	17.0	17.0	1 (10)*	14.3	14.3
2 (15)	1.0	1.0	2 (15)	0.8	0.8
3 (20)	0.1	0.1	3 (20)	0.0	0.0
4 (25)	0.2	0.2	4 (25)	0.0	0.0
5 (30)	0.2	0.2	5 (30)	0.0	0.0
6 (35)	0.0	0.0	6 (35)	0.4	0.4
7 (40)	0.0	0.0	7 (41)	0.0	0.0
8 (44)	0.0	0.0			

* Meets current ENERGY STAR criteria.

Table 8.2.37 Compact Refrigeration Products: Historic and Base-Case Efficiency Distributions

Product Class 11: Compact Refrigerator				Product Class 18: Compact Freezer		
Efficiency Level *(% less than baseline energy use)*	**Market Share %**			**Efficiency Level** *(% less than baseline energy use)*	**Market Share %**	
	2007	**2008**	**2014**		**2007**	**2014**
Baseline	97.1	99.8	98.5	Baseline	95.4	95.4
1 (10)	0.3	0.2	0.3	1 (10)	4.6	4.6
2 (15)	0.0	0.0	0.0	2 (15)	0.0	0.0
3 (20)*	0.9	0.0	0.5	3 (20)*	0.0	0.0
4 (25)	0.2	0.0	0.1	4 (25)	0.0	0.0
5 (30)	1.5	0.0	0.8	5 (30)	0.0	0.0
6 (35)	0.0	0.0	0.0	6 (35)	0.0	0.0
7 (40)	0.0	0.0	0.0	7 (42)	0.0	0.0
8 (45)	0.0	0.0	0.0			
9 (50)	0.0	0.0	0.0			
10 (59)	0.0	0.0	0.0			

Although RECS 2005 provides information on ownership of ENERGY STAR refrigerators purchased between 2001 and 2005, the data seem to greatly overestimate the stock of ENERGY STAR refrigerators compared to data regarding shipments made during those years. In assigning product efficiencies to the households in the sample for each product class, DOE therefore developed a method that predicts ENERGY STAR ownership in the RECS sample based on annual average market shares of ENERGY STAR refrigerators and on household income. DOE based its approach on a study from Natural Resources Canada[20] that reported ENERGY STAR buyers based on three income categories. DOE assumed that the relative behavior of each income category is the same in the United States as for Canadian consumers. After matching the three income categories to RECS income bins, DOE assigned a probability of owning an ENERGY STAR unit to each household record as a function of its income. This probability was then scaled to reflect income levels in the RECS sample and national ENERGY STAR sales. The following equation was used.

$$Estar_{year} = scale_{year} \times (F_{low} \times P\_Estar_{low} + F_{mid} \times P\_Estar_{mid} + F_{high} \times P\_Estar_{high})$$

Where:

$Estar_{year}$ = percent of annual national refrigerator sales that were ENERGY STAR qualified,

$F_{low|mid|high}$ = percent of weighted number of RECS 2005 households in low, medium, and high income bins,

$P\_Estar_{low|mid|high}$ = probability of households in an income bin buying an ENERGY STAR appliance, and

$scale_{year}$ = scaling factor to obtain the appropriate percent of ENERGY STAR refrigerators for each vintage.

Table 8.2.38 shows the market shares of ENERGY STAR refrigerators ($Estar_{year}$), which were obtained from the ENERGY STAR program.[21] The market shares of ENERGY STAR freezers are estimates.

Table 8.2.38 Market Share of ENERGY STAR Products

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005
Refrigerators	25.3%	19.0%	25.0%	27.0%	17.3%	20.1%	25.7%	33.2%	32.9%
Freezers	-	-	-	-	-	-	10%	10%	10%

The scaling factor for each year was calculated as:

$$scale_{year} = \frac{Estar_{year}}{(F_{low} \times P\_Estar_{low} + F_{mid} \times P\_Estar_{mid} + F_{high} \times P\_Estar_{high})}$$

A household in the low-income bin that purchased a refrigerator in a given year was a assigned a probability $Scale_{year}$ times P_Estar_{low} for having an ENERGY STAR refrigerator. A similar approach was taken for households in the mid- and-high income bins.

8.3 INPUTS TO PAYBACK PERIOD ANALYSIS

The payback period (PBP) refers to the time it takes a consumer to recover, through lower operating costs, the assumed higher purchase cost of more energy efficient products. Numerically, the PBP is the ratio of the increase in purchase cost (from a less to a more efficient design) to the decrease in annual average operating cost. This calculation does not use a discount rate to discount future operating costs.

The equation for determining PBP is:

$$PBP = \frac{\Delta IC}{\Delta OC}$$

Where:

ΔIC = the difference in total installed cost between the more efficient design based on a potential standard level and the base case product, and
ΔOC = the difference in annual average operating cost between the two products.

Payback periods are expressed in years. Payback periods greater than the life of a product mean that the increase in total installed cost is not recovered through reduced operating cost.

The data inputs to calculating PBP are the total installed cost to the consumer for each product at each efficiency level and the average annual operating cost for each efficiency level. The inputs to calculating total installed cost are the product and installation costs. The inputs to calculating operating cost are the annual energy, repair, and maintenance costs. The annual average operating cost includes an annualized value for repair and maintenance costs.

8.4 RESULTS OF ANALYSES

This section presents the results of the life-cycle cost (LCC) and payback period (PBP) analyses for the considered efficiency levels for the representative refrigeration product classes. As discussed in section 8.1.1, DOE's approach to the LCC analysis involved developing a sample of consumers who use each product. DOE also used probability distributions to characterize the uncertainty in many of the analytical inputs. DOE used a Monte Carlo simulation technique to perform the LCC calculations on data pertaining to the consumers in each sample. For each set of sample consumers who use the appliance in each product class, DOE calculated the average LCC, the LCC savings, and the median PBP for each standard level.

LCC and PBP calculations were performed 10,000 times on the sample of consumers developed for each product. Each calculation was performed on a single consumer who was selected from the sample based on its weight in the RECS. Each LCC and PBP calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

Based on the Monte Carlo simulations that DOE performed, for each efficiency level, DOE calculated the percentage of consumers who would experience a net LCC benefit, a net LCC cost, or no impact. DOE considered a consumer to receive no impact at a given efficiency level if the base-case product DOE assigned to that consumer had the same or higher efficiency than that of the new standard being evaluated. Note that the average LCC savings and the median PBP at each efficiency level are relative to the base-case efficiency distribution, not the baseline efficiency level. For that reason, average LCC impacts are not equal to the difference between the LCC of a specific efficiency level and the LCC of the baseline product. DOE calculated the average LCC savings and median PBPs at each efficiency level by excluding those households that would not be affected by the standard.

The following subsections summarize results of the LCC and PBP analyses for each representative product class. Tables present average results. Figures show the distribution of LCC impacts and the distribution of PBPs (probabilities of occurrence) for specific efficiency levels. Other figures showing show the range of LCC savings and PBPs for all the efficiency levels considered for each product class.

8.4.1 Standard-Size Refrigerator-Freezers

8.4.1.1 Summary of Results

Tables 8.4.1 through 8.4.3 show the LCC and PBP results for each standard-size refrigerator-freezer representative product class.

Table 8.4.1 Product Class 3, Top-Mount Refrigerator-Freezers: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience			Median
						Net Cost	No Impact	Net Benefit	
	Baseline	$491	$787	$1,278					
	1 (10)	$501	$730	$1,231	$46	0.28%	21.9%	77.8%	2.3
	2 (15)	$508	$701	$1,209	$69	0.60%	17.6%	81.8%	2.6
1, 2	3 (20)	$564	$671	$1,235	$44	34.0%	8.31%	57.7%	8.0
3	4 (25)	$602	$634	$1,236	$42	45.7%	0.0%	54.3%	9.5
4	5 (30)	$686	$598	$1,284	-$6	65.1%	0.0%	34.9%	13.3
5	6 (36)	$806	$560	$1,365	-$87	79.7%	0.0%	20.3%	17.8

Table 8.4.2 Product Class 5, Bottom-Mount Refrigerator-Freezers: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience			Median
						Net Cost	No Impact	Net Benefit	
	Baseline	$858	$970	$1,828					
	1 (10)	$860	$961	$1,820	$9	0.02%	86.9%	13.1%	2.1
	2 (15)	$861	$956	$1,817	$14	0.05%	86.9%	13.1%	2.3
1, 2,3	3 (20)	$867	$943	$1,809	$22	2.53%	67.8%	29.7%	4.2
	4 (25)	$926	$901	$1,827	$5	67.9%	0.03%	32.0%	14.9
4	5 (30)	$1,023	$862	$1,885	-$53	82.8%	0.03%	17.2%	21.0
5	6 (36)	$1,157	$810	$1,968	-$136	89.0%	0.00%	11.1%	24.7

Table 8.4.3 Product Class 7, Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience			Median
						Net Cost	No Impact	Net Benefit	
	Baseline	$1,040	$1,252	$2,292					
	1 (10)	$1,043	$1,228	$2,271	$22	0.00%	78.1%	21.9%	1.3
	2 (15)	$1,048	$1,202	$2,249	$44	0.06%	51.7%	48.3%	2.1
1	3 (20)	$1,064	$1,167	$2,232	$62	4.27%	36.9%	58.8%	4.0
2, 3	4 (25)	$1,123	$1,114	$2,237	$57	41.5%	0.00%	58.6%	9.2
4	5 (30)	$1,251	$1,061	$2,312	-$18	69.7%	0.00%	30.3%	15.6
5	6 (33)	$1,351	$1,026	$2,377	-$83	79.5%	0.00%	20.5%	19.1

8.4.1.2 Distributions of Impacts

Figure 8.4.1 presents a frequency chart that shows the distribution of LCC impacts for the case of efficiency level 4 for top-mount refrigerator-freezers. DOE could generate a similar frequency chart for every efficiency level.

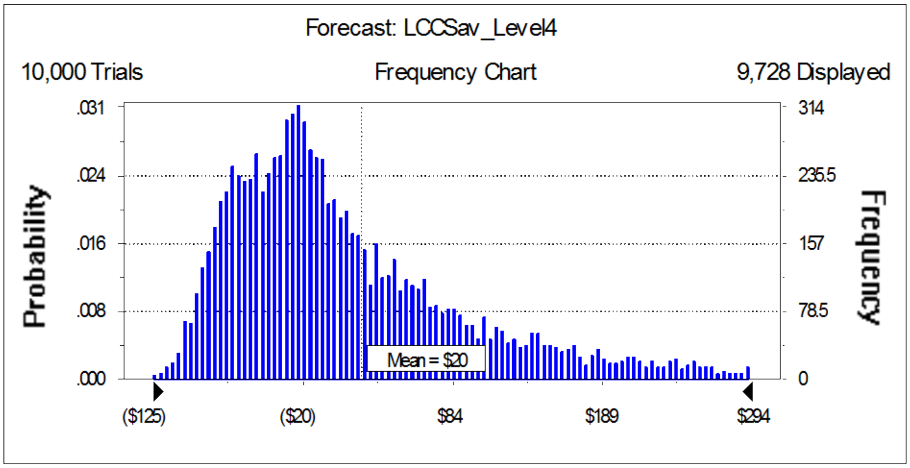


Figure 8.4.1 Product Class 3, Top-Mount Refrigerator-Freezers: Distribution of Life-Cycle Cost Impacts for Efficiency Level 4

Figure 8.4.2 is an example of a frequency chart showing the distribution of payback periods for efficiency level 4 for top-mount refrigerator-freezers. DOE could generate a similar frequency chart for every efficiency level.

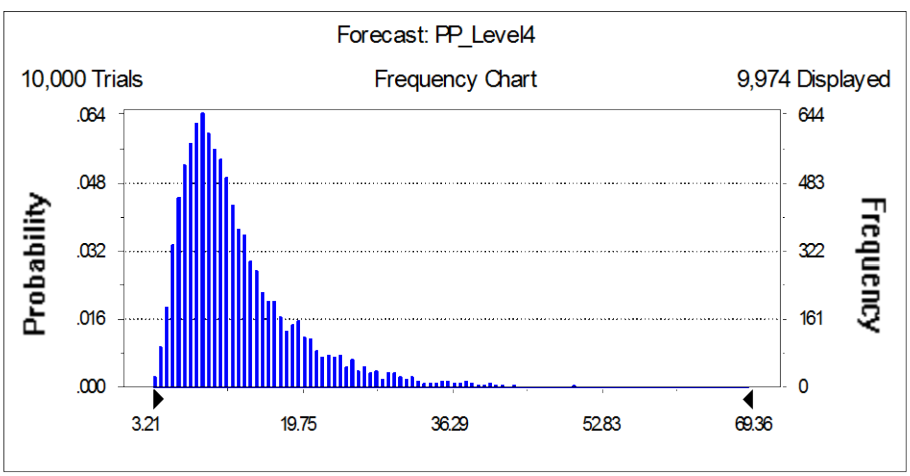


Figure 8.4.2 Product Class 3, Top-Mount Refrigerator-Freezers: Distribution of Payback Periods for Efficiency Level 4

Figures 8.4.3 through 8.4.5 show the range of LCC savings for all the efficiency levels considered for each refrigerator-freezer product class. For each efficiency level, the top and bottom of the box in the figure indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of households have LCC savings that exceed this value. The horizontal lines above and below each box indicate the 95th and 5th percentiles, respectively. The small box indicates the average LCC savings for each efficiency level.

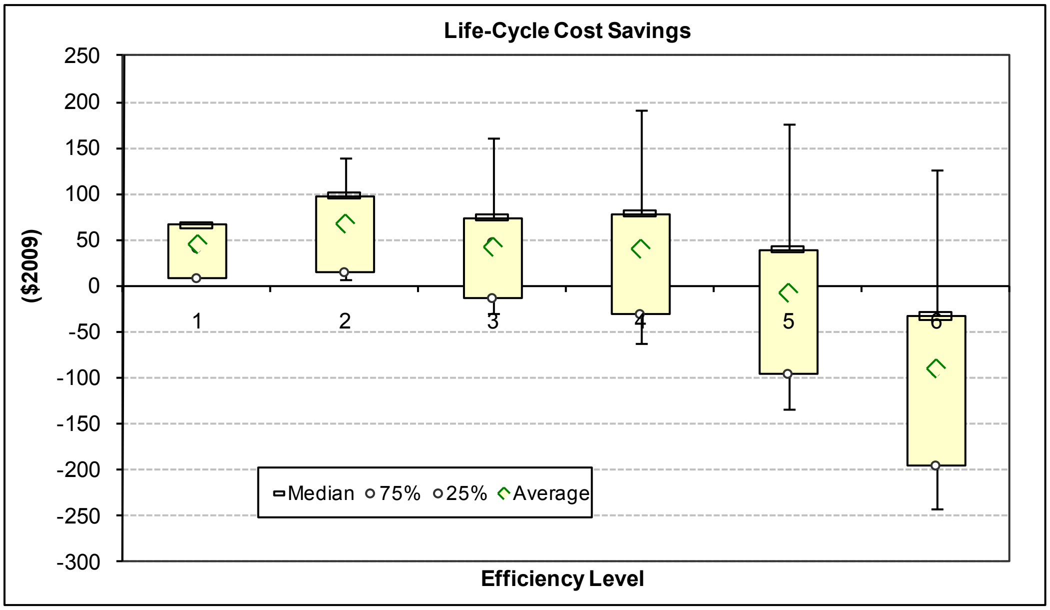


Figure 8.4.3 Product Class 3, Top-Mount Refrigerator-Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

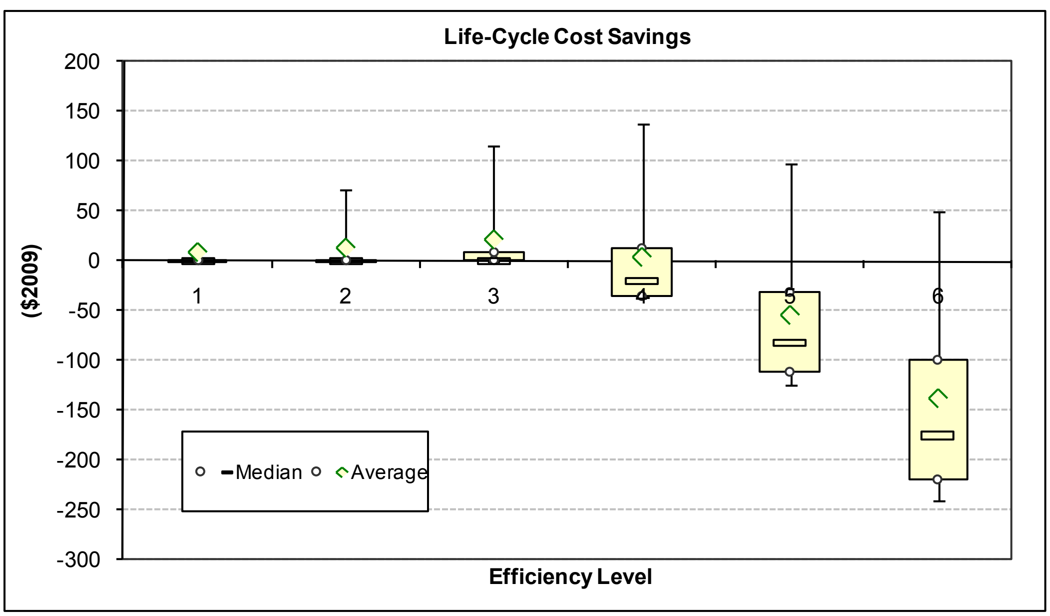


Figure 8.4.4 Product Class 5, Bottom-Mount Refrigerator-Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

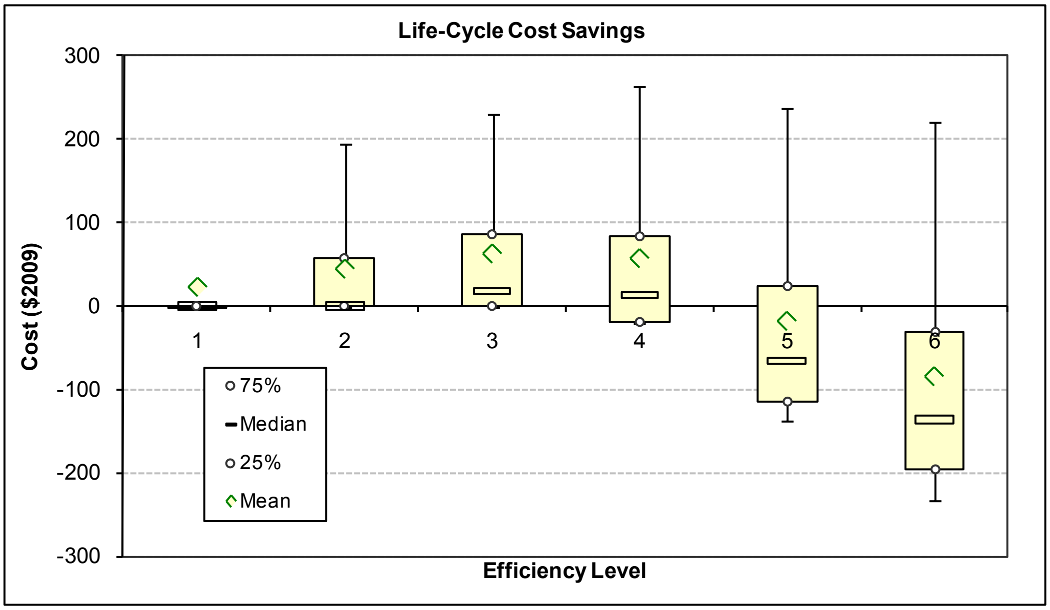


Figure 8.4.5 Product Class 7, Side-by-Side Refrigerator-Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

Figures 8.4.6 through 8.4.8 show the range of PBPs for all efficiency levels considered for each analyzed refrigerator-freezer product class. For each efficiency level, the top and bottom of the box in the figure indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have a PBP above this value. The horizontal lines above and below each box indicate the 95th and 5th percentiles, respectively. The small box indicates the average PBP for each efficiency level.

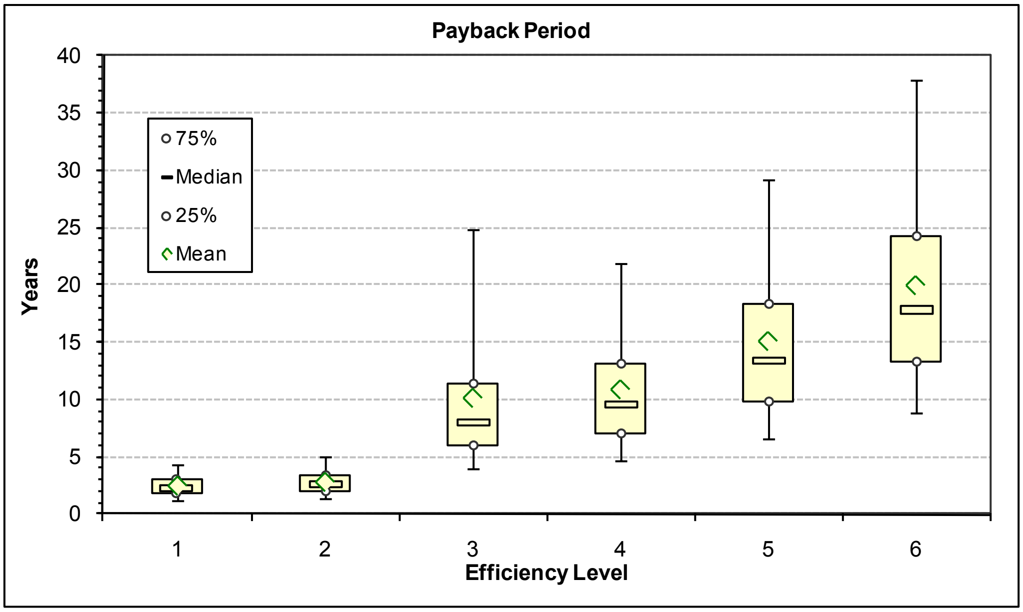


Figure 8.4.6 Product Class 3, Top-Mount Refrigerator-Freezers: Range of Payback Periods by Efficiency Level

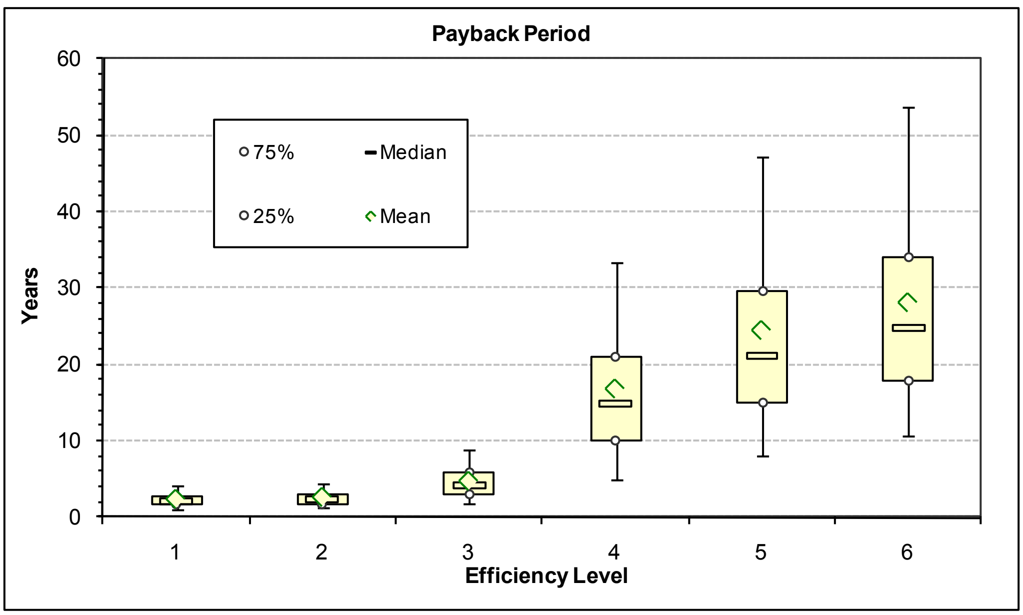


Figure 8.4.7 Product Class 5, Bottom-Mount Refrigerator-Freezers: Range of Payback Periods by Efficiency Level

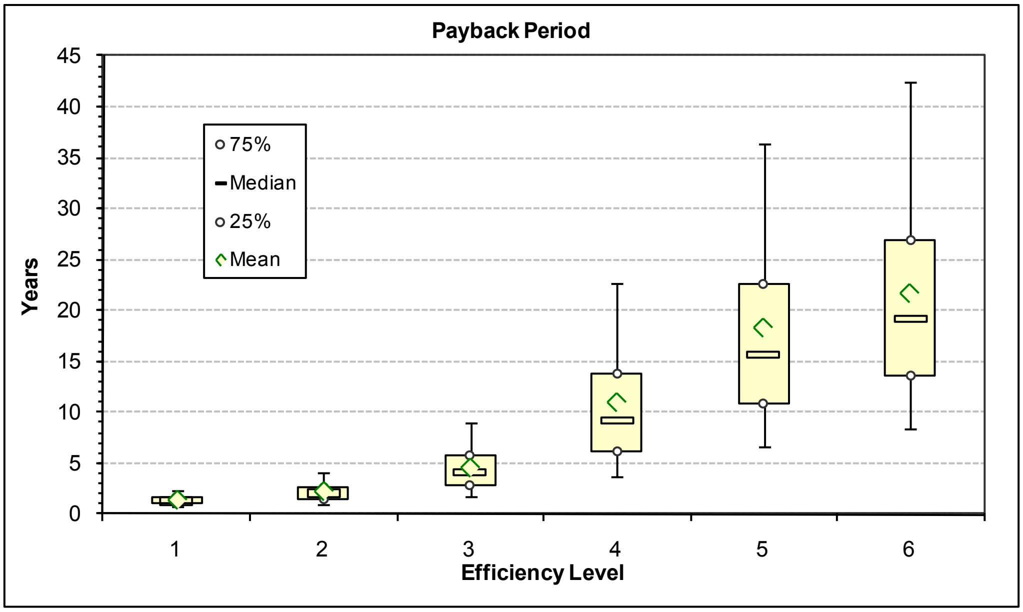


Figure 8.4.8 Product Class 7, Side-by-Side Refrigerator-Freezers: Range of Payback Periods by Efficiency Level

8.4.2 Standard-Size Freezers

8.4.2.1 Summary of Results

Tables 8.4.4 and 8.4.5 show the LCC and PBP results for each representative standard-size freezer product class.

Table 8.4.4 Product Class 9, Upright Freezers: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
	Baseline	$505	$1,098	$1,603					
	1 (10)	$516	$1,015	$1,530	$73	0.25%	19.9%	79.9%	1.9
	2 (15)	$535	$964	$1,499	$105	5.02%	1.67%	93.3%	3.6
1	3 (20)	$552	$912	$1,464	$140	6.03%	0.59%	93.4%	4.0
	4 (25)	$578	$859	$1,437	$166	9.58%	0.41%	90.0%	4.9
2	5 (30)	$602	$806	$1,408	$195	11.5%	0.22%	88.2%	5.3
3	6 (35)	$656	$758	$1,414	$189	21.9%	0.00%	78.1%	7.1
4	7 (40)	$731	$711	$1,442	$161	34.6%	0.00%	65.4%	9.3
5	8 (44)	$898	$673	$1,570	$33	59.7%	0.00%	40.3%	14.7

Table 8.4.5 Product Class 10, Chest Freezer: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
	Baseline	$367	$623	$990					
	1 (10)	$373	$573	$947	$43	0.20%	16.2%	83.6%	2.0
	2 (15)	$383	$544	$927	$63	3.01%	1.18%	95.8%	3.2
1	3 (20)	$393	$515	$908	$82	5.14%	0.22%	94.6%	3.9
2	4 (25)	$436	$485	$921	$69	27.3%	0.22%	72.5%	8.1
3	5 (30)	$456	$455	$911	$79	29.1%	0.22%	70.6%	8.5
4	6 (35)	$510	$433	$943	$47	48.7%	0.00%	51.4%	12.1
5	7 (41)	$620	$395	$1,015	-$25	69.1%	0.00%	31.0%	17.8

8.4.2.2 Distributions of Impacts

Figure 8.4.9 presents a frequency chart showing the distribution of LCCs for the case of standard level 7 for upright freezers. DOE could generate a similar frequency chart for every efficiency level.

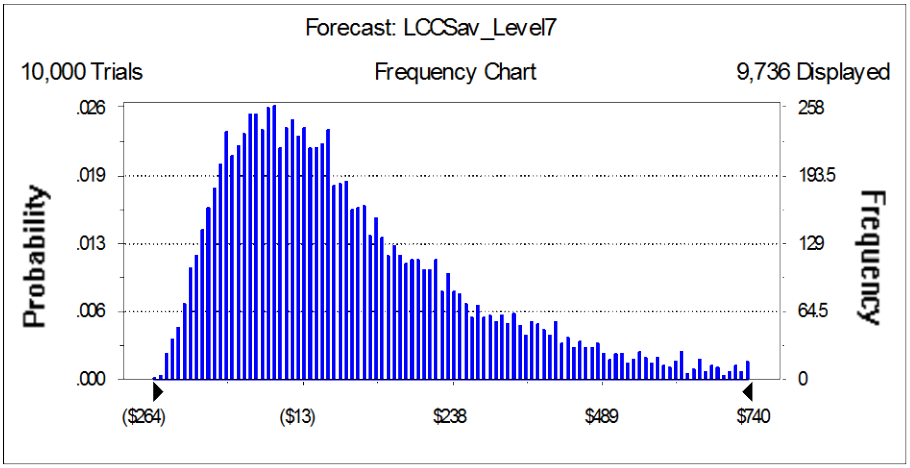


Figure 8.4.9 Product Class 9, Upright Freezers: Distribution of Life-Cycle Cost Impacts for Efficiency Level 7

Figure 8.4.10 presents a frequency chart showing the distribution of payback periods for standard level 7 for upright freezers. DOE could generate a similar frequency chart for every efficiency level within each product class.

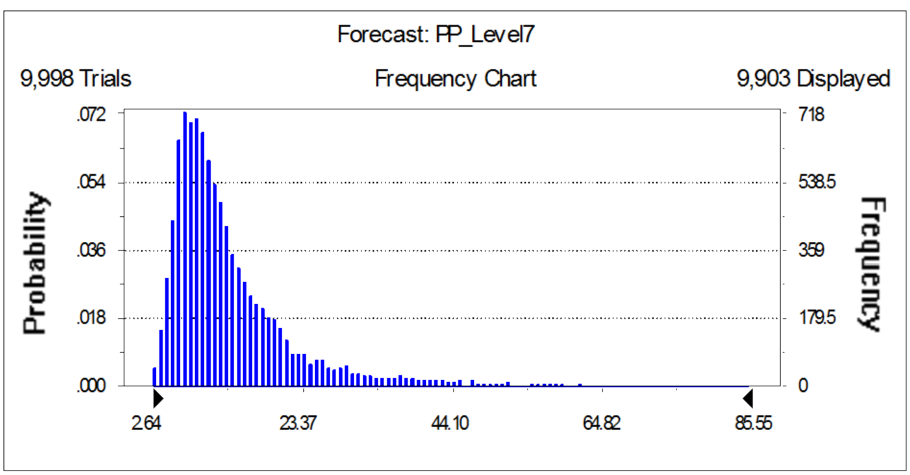


Figure 8.4.10 Product Class 9, Upright Freezers: Distribution of Payback Periods for Efficiency Level 7

Figures 8.4.11 and 8.4.12 show the range of LCC savings for the efficiency levels considered for each freezer product class. For each standard level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have LCC savings that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average LCC savings for each efficiency level.

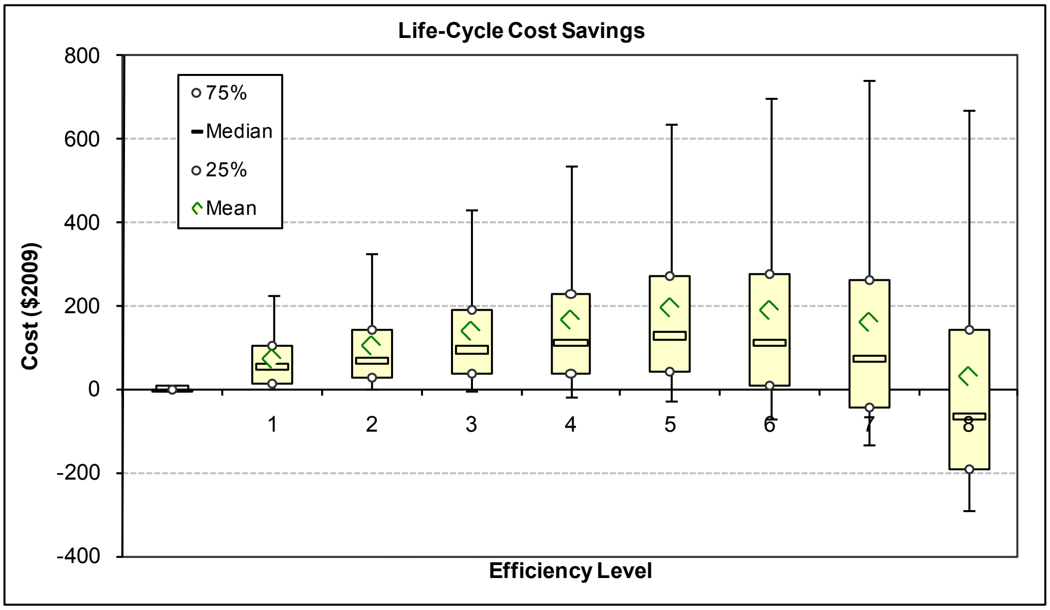


Figure 8.4.11 Product Class 9, Upright Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

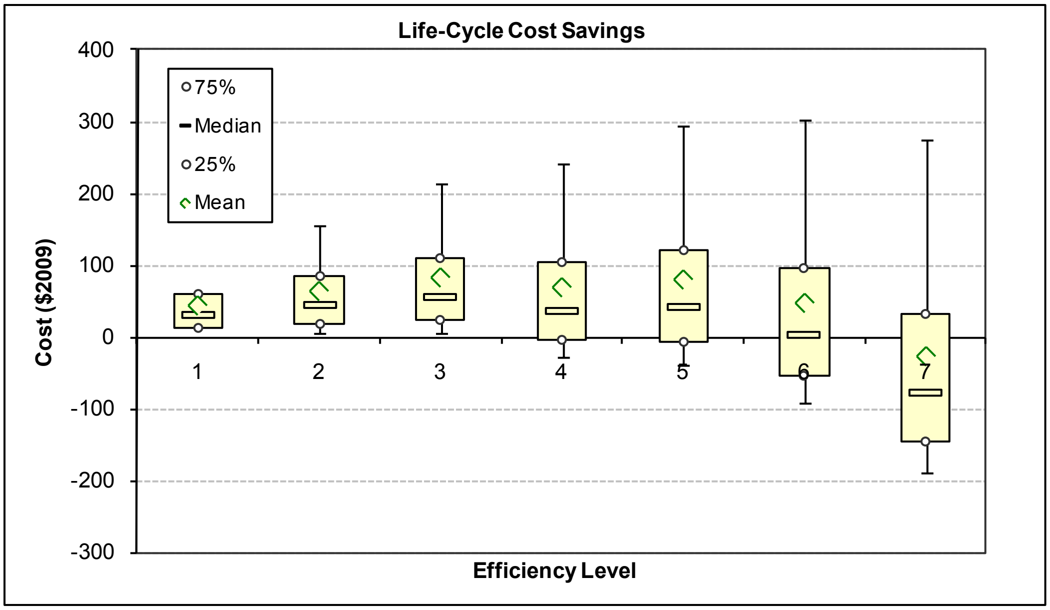


Figure 8.4.12 Product Class 10, Chest Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

Figures 8.4.13 and 8.4.14 show the range of PBPs for the efficiency levels considered for each freezer product class. For each standard level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have PBPs that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average PBP for each efficiency level.

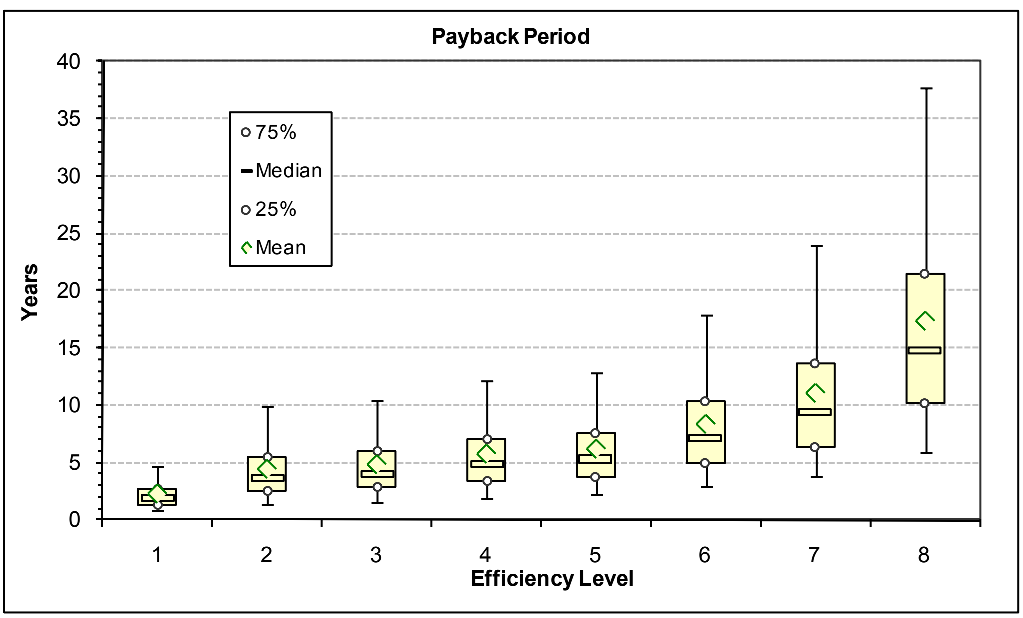


Figure 8.4.13 Product Class 9, Upright Freezers: Range of Payback Periods by Efficiency Level

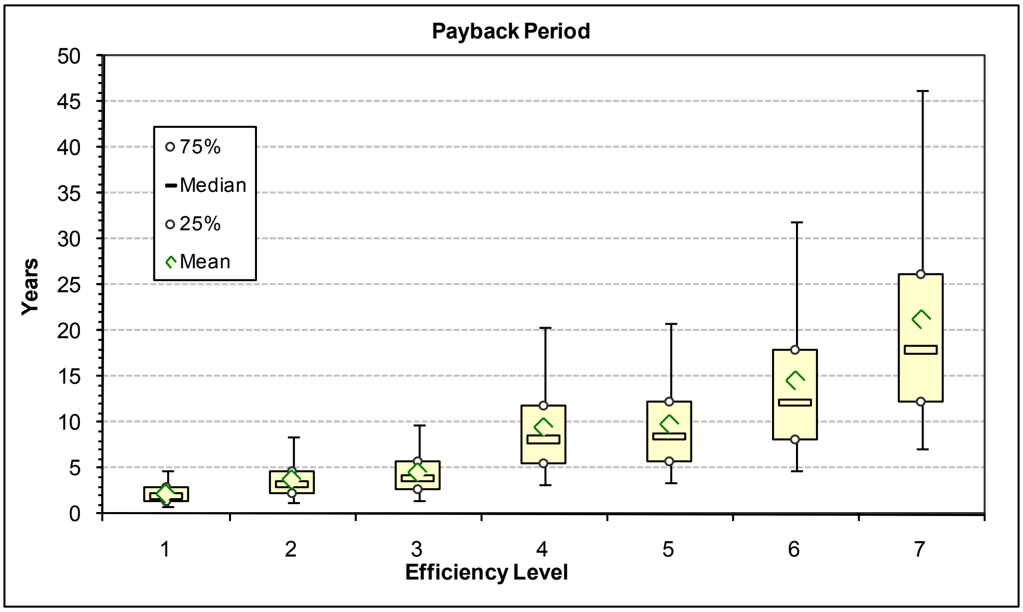


Figure 8.4.14 Product Class 10, Chest Freezers: Range of Payback Periods by Efficiency Level

8.4.3 Compact Refrigeration Products

8.4.3.1 Summary of Results

Tables 8.4.6 and 8.4.7 show the results of LCC and PBP analyses for compact refrigerators and freezers.

Table 8.4.6 Product Class 11, Compact Refrigerators: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
	Baseline	$131	$167	$298					
	1 (10)	$137	$151	$287	$11	9.01%	1.60%	89.4%	1.8
	2 (15)	$141	$143	$284	$14	13.6%	1.39%	85.0%	2.1
1	3 (20)	$146	$135	$281	$17	19.7%	1.39%	79.0%	2.5

2	4 (25)	$157	$127	$284	$14	36.8%	1.00%	62.3%	3.5
3	5 (30)	$166	$119	$285	$13	43.4%	0.92%	55.6%	3.9
	6 (35)	$192	$112	$304	-$6	71.3%	0.00%	28.7%	6.0
4	7 (40)	$199	$104	$303	-$5	69.8%	0.00%	30.2%	5.8
	8 (45)	$230	$97	$327	-$29	83.5%	0.00%	16.5%	7.7
	9 (50)	$247	$89	$336	-$38	85.4%	0.00%	14.6%	8.0
5	10 (59)	$308	$75	$383	-$85	92.2%	0.00%	7.85%	10.4

Table 8.4.7 Product Class 18, Compact Freezers: LCC and PBP Results

Trial Standard Level	**Efficiency Level** ***(% less than baseline energy use)***	**Life-Cycle Cost *2009$***			**Life-Cycle Cost Savings**				**Payback Period (years)**
					Average Savings *2009$*	**% of Households that Experience**			
		Installed Cost	**Discounted Operating Cost**	**LCC**		**Net Cost**	**No Impact**	**Net Benefit**	**Median**
	Baseline	$182	$200	$382					
1,2	1 (10)	$189	$182	$370	$12	7.98%	4.66%	87.4%	2.2
3	2 (15)	$201	$172	$373	$9	33.9%	0.00%	66.1%	4.2
	3 (20)	$242	$163	$404	-$22	87.4%	0.00%	12.6%	9.8
4	4 (25)	$252	$153	$405	-$23	84.5%	0.00%	15.5%	9.1
	5 (30)	$282	$146	$428	-$46	92.4%	0.00%	7.6%	11.4
	6 (35)	$289	$137	$426	-$44	89.6%	0.00%	10.4%	10.4
5	7 (42)	$360	$124	$484	-$102	96.7%	0.00%	3.3%	14.4

8.4.3.2 Distributions of Impacts

Figure 8.4.15 presents a frequency chart showing the distribution of LCCs for the case of efficiency level 5 for compact refrigerators. DOE could generate a similar frequency chart for each efficiency level.

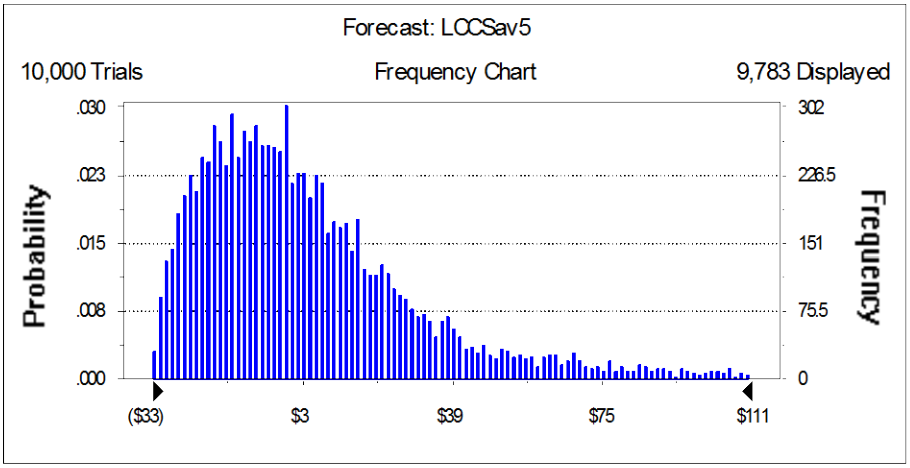


Figure 8.4.15 Product Class 11, Compact Refrigerators: Distribution of Life-Cycle Cost Impacts for Efficiency Level 5

Figure 8.4.16 presents a frequency chart showing the distribution of payback periods for efficiency level 5 for compact refrigerators. DOE could generate a similar frequency chart for each considered efficiency level for each product class.

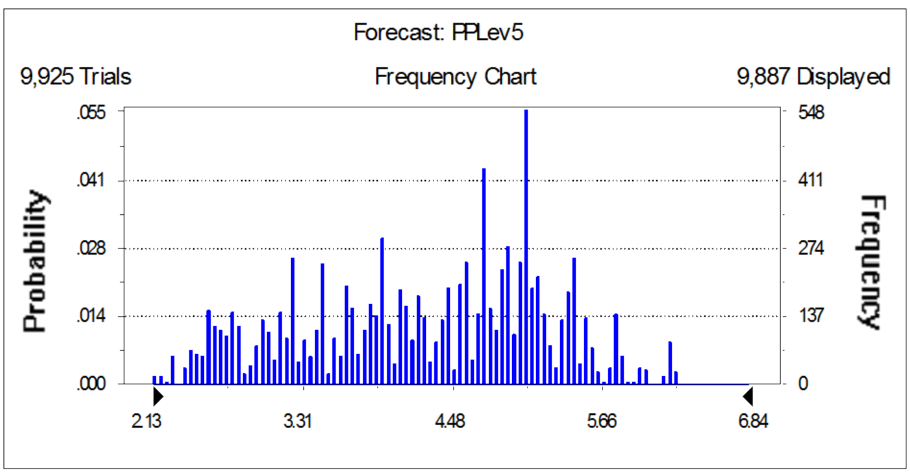


Figure 8.4.16 Product Class 11, Compact Refrigerators: Distribution of Payback Period for Efficiency Level 5

Figures 8.4.17 and 8.4.18 show the range of LCC savings for the standard levels considered for compact refrigerators and freezers. For each standard level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have LCC savings that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average LCC savings for each efficiency level. Figures 8.4.19 and 8.4.20 show the range of PBPs for each efficiency level considered.

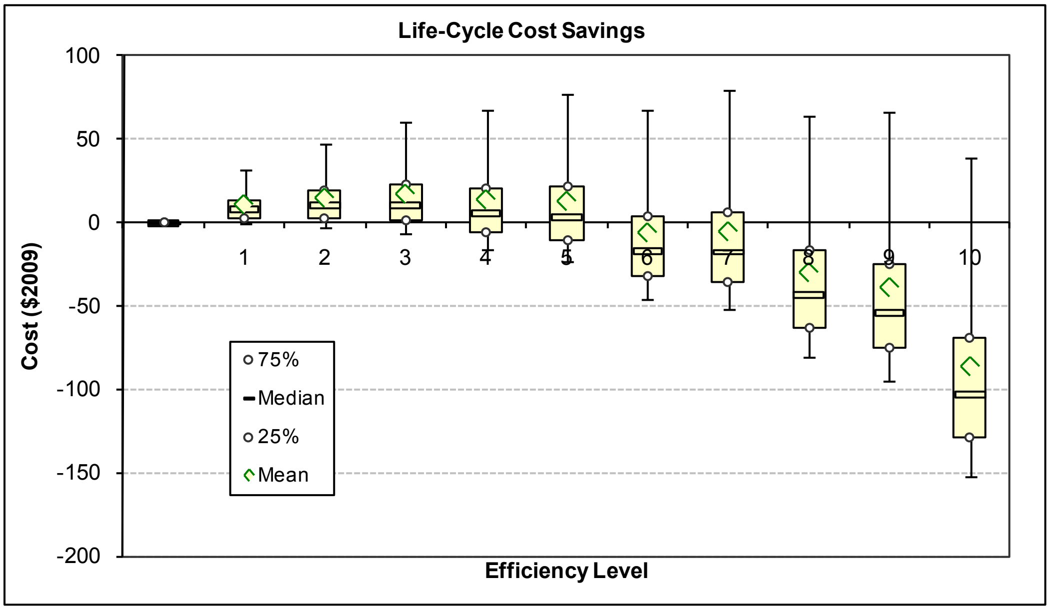


Figure 8.4.17 Product Class 11, Compact Refrigerators: Range of Life-Cycle Cost Savings by Efficiency Level

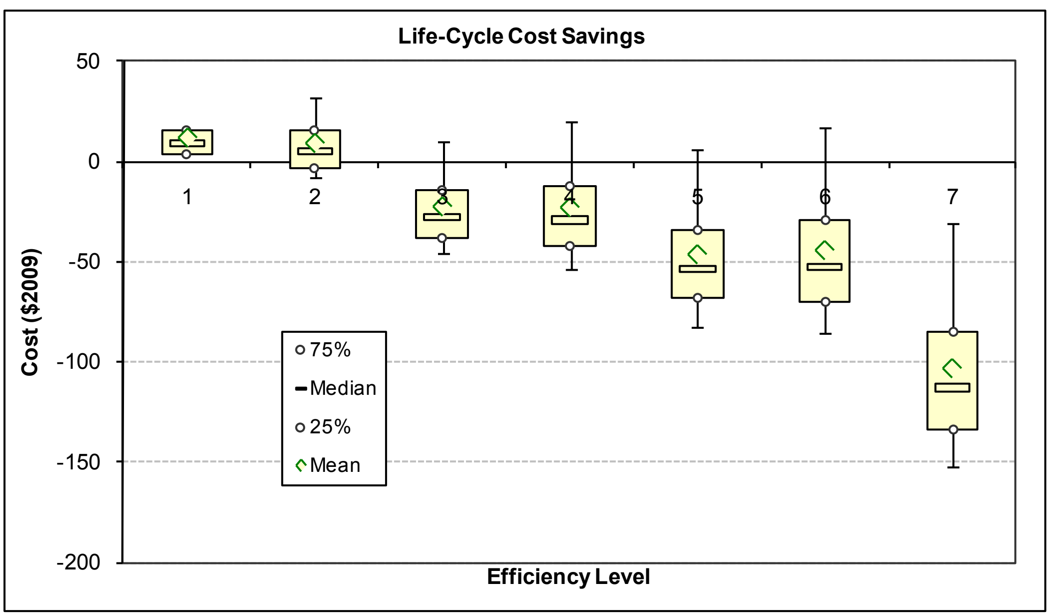


Figure 8.4.18 Product Class 18, Compact Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

Figures 8.4.19 and 8.4.20 show the range of PBPs for the standard levels considered for compact refrigerators and freezers. For each standard level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have PBPs that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average PBP for each efficiency level.

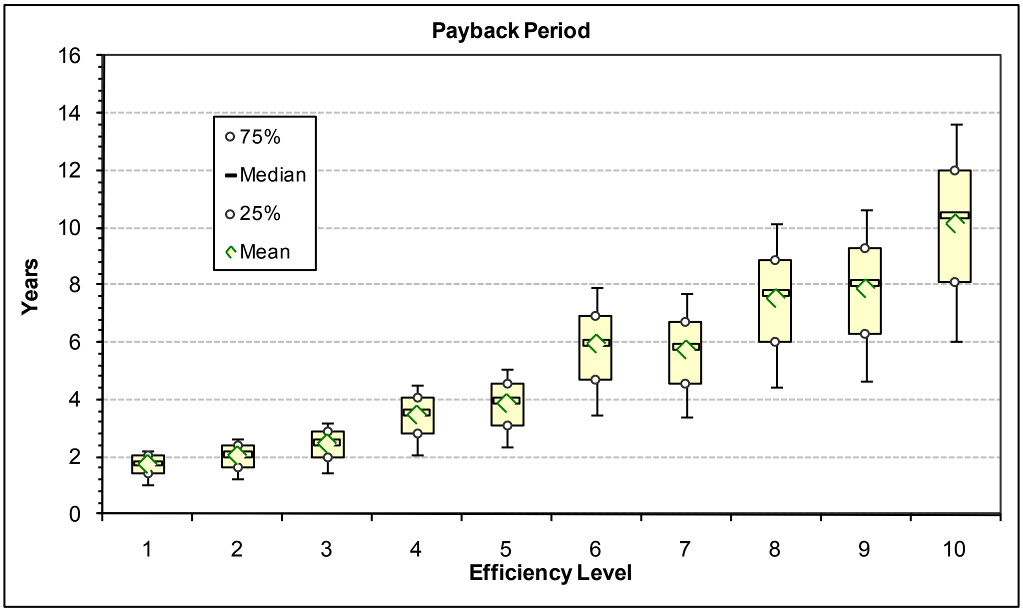


Figure 8.4.19 Product Class 11, Compact Refrigerators: Range of Payback Periods by Efficiency Level

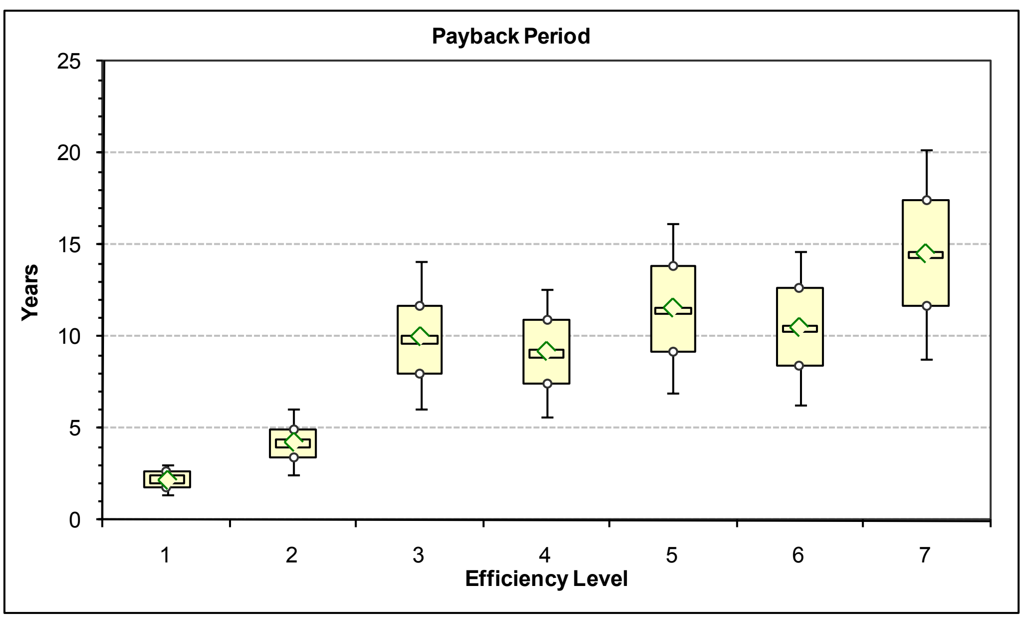


Figure 8.4.20 Product Class 18, Compact Freezers: Range of Payback Periods by Efficiency Level

8.4.4 Built-In Refrigeration Products

8.4.4.1 Summary of Results

Tables 8.4.8 through 8.4.11 show the results of LCC and PBP analyses for the representative built-in refrigeration product classes.

Table 8.4.8 Product Class 3A-BI, Built-In All Refrigerators: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
	Baseline	$4,316	$828	$5,144					
1	1 (10)	$4,323	$769	$5,091	$52	0.02%	22.6%	77.4%	1.4
2	2 (15)	$4,334	$739	$5,073	$71	0.94%	18.4%	80.7%	2.6
3	3 (20)	$4,452	$703	$5,155	-$11	61.5%	9.10%	29.4%	13.7
4	4 (25)	$4,625	$670	$5,295	-$151	91.0%	0.00%	9.02%	25.5
5	5 (29)	$4,756	$646	$5,402	-$258	95.0%	0.00%	5.01%	31.4

Table 8.4.9 Product Class 5-BI, Built-In Bottom-Mount Refrigerator-Freezers: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
						% of Households that Experience			
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
	Baseline	$4,968	$960	$5,928					
1	1 (10)	$4,972	$951	$5,923	$8	0.60%	87.1%	12.3%	3.8
2,3	2 (15)	$4,982	$957	$5,939	$2	7.03%	87.0%	5.94%	11.1
	3 (20)	$5,013	$943	$5,955	-$14	27.4%	67.5%	5.09%	22.3
4	4 (25)	$5,168	$911	$6,079	-$138	98.0%	0.00%	2.03%	52.8
5	5 (27)	$5,257	$891	$6,148	-$207	98.5%	0.00%	1.50%	52.2

Table 8.4.10 Product Class 7-BI, Built-In Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: LCC and PBP Results

Trial Standard Level	Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
						% of Households that Experience			
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
	Baseline	$7,134	$1,494	$8,628					
1,2	1 (10)	$7,147	$1,476	$8,623	$10	5.77%	78.5%	15.7%	7.5
	2 (15)	$7,188	$1,459	$8,647	-$9	36.4%	52.4%	11.2%	17.6
3,4	3 (20)	$7,307	$1,423	$8,729	-$91	58.5%	37.2%	4.28%	31.0
5	4 (22)	$7,414	$1,405	$8,820	-$182	97.6%	0.00%	2.40%	50.4

Table 8.4.11 Product Class 9-BI, Built-In Upright Freezers: LCC and PBP Results

Trial Standard Level	Efficiency Level	Life-Cycle Cost *2009$*	Life-Cycle Cost Savings	Payback Period (years)

	(% less than baseline energy use)	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience			Median
						Net Cost	No Impact	Net Benefit	
	Baseline	$3,928	$1,071	$4,999					
1	1 (10)	$3,943	$990	$4,933	$66	1.53%	19.9%	78.6%	2.9
	2 (15)	$3,956	$942	$4,898	$101	3.99%	1.70%	94.3%	3.6
2	3 (20)	$4,042	$898	$4,940	$59	42.9%	0.57%	56.5%	10.7
3,4	4 (25)	$4,176	$847	$5,023	-$23	68.8%	0.49%	30.7%	17.8
5	5 (27)	$4,278	$822	$5,100	-$101	79.8%	0.27%	20.0%	22.6

8.4.4.2 Distributions of Impacts

Figure 8.4.21 presents a frequency chart showing the distribution of LCCs for the case of efficiency level 1 for built-in side-by-side refrigerator-freezers. DOE could generate a similar frequency chart for every efficiency level.

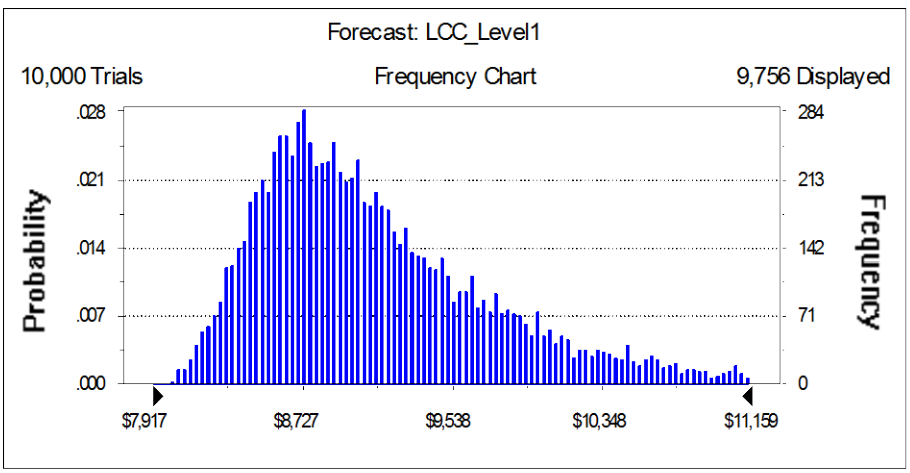


Figure 8.4.21 Product Class 7-BI, Built-In Side-by-Side Refrigerator-Freezers: Distribution of Life-Cycle Cost Impacts for Efficiency Level 1

Figure 8.4.22 presents a frequency chart showing the distribution of payback periods for efficiency level 1 for built-in side-by-side refrigerator-freezers. DOE could generate a similar frequency chart for every efficiency level within each product class.

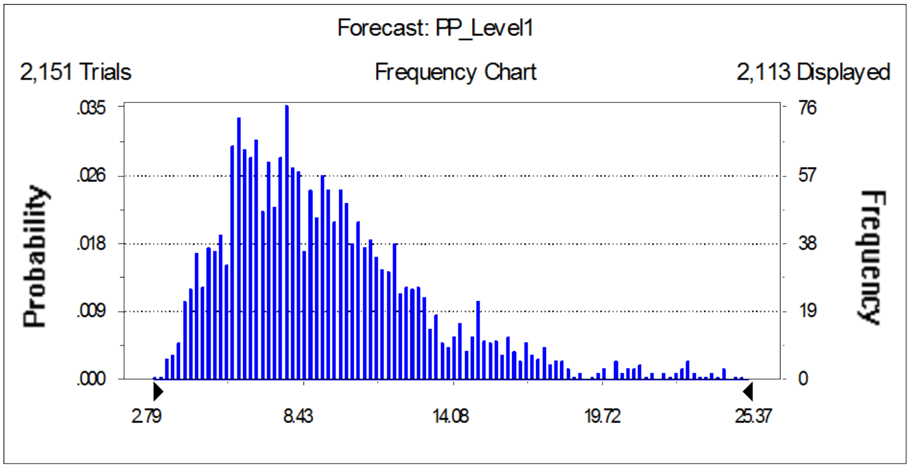


Figure 8.4.22 Product Class 7-BI, Built-In Side-by-Side Refrigerator-Freezers: Distribution of Payback Period for Efficiency Level 1

Figures 8.4.23 through 8.4.30 show the range of LCC savings for the efficiency levels considered for built-in refrigeration products. For each efficiency level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have LCC savings that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average LCC savings for each efficiency level. Figures 8.4.19 through 8.4.20 show the range of PBPs for each efficiency level considered.

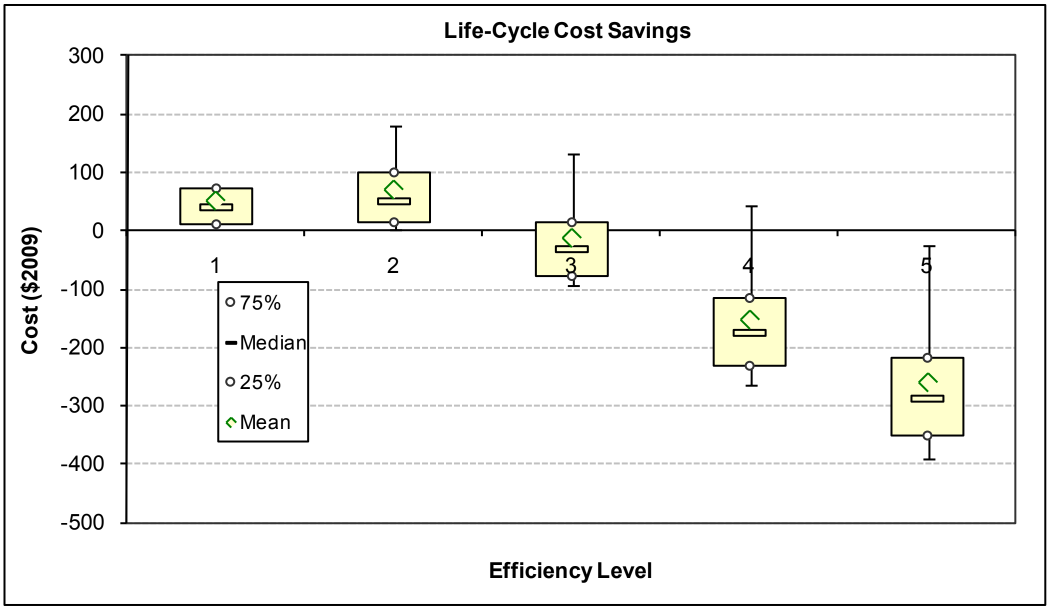


Figure 8.4.23 Product Class 3A-BI, Built-In All Refrigerators: Range of Life-Cycle Cost Savings by Efficiency Level

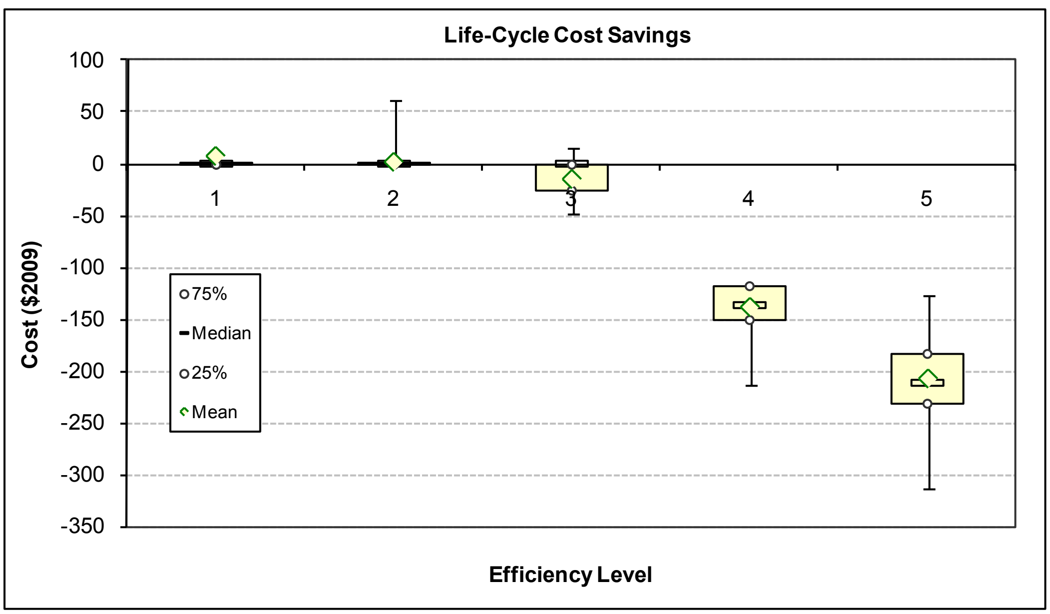


Figure 8.4.24 Product Class 5-BI, Built-In Bottom-Mount Refrigerator-Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

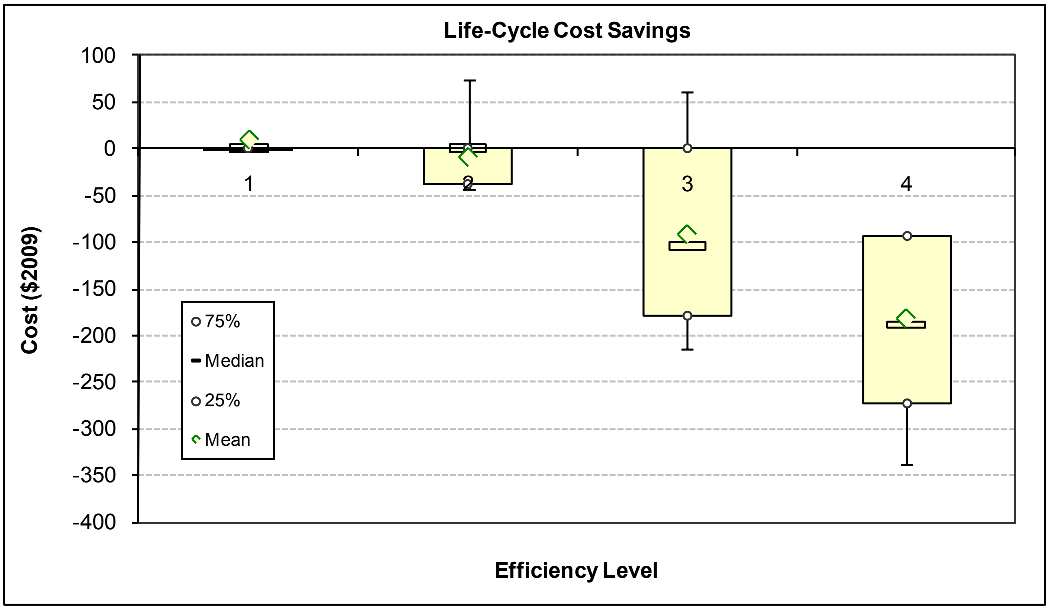


Figure 8.4.25 Product Class 7-BI, Built-In Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: Range of Life-Cycle Cost Savings by Efficiency Level

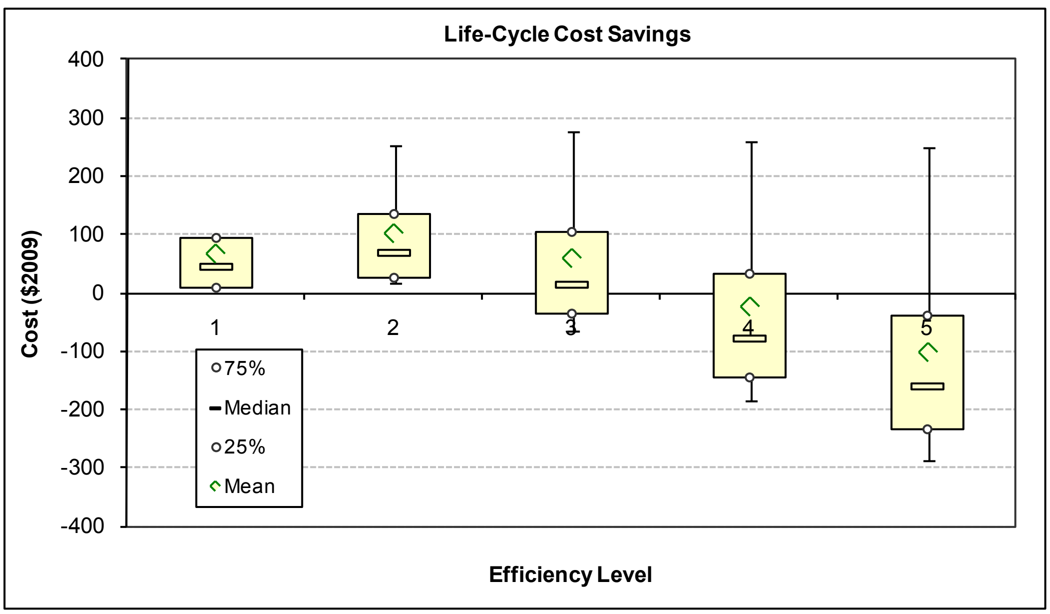


Figure 8.4.26 Product Class 9-BI, Built-In Upright Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

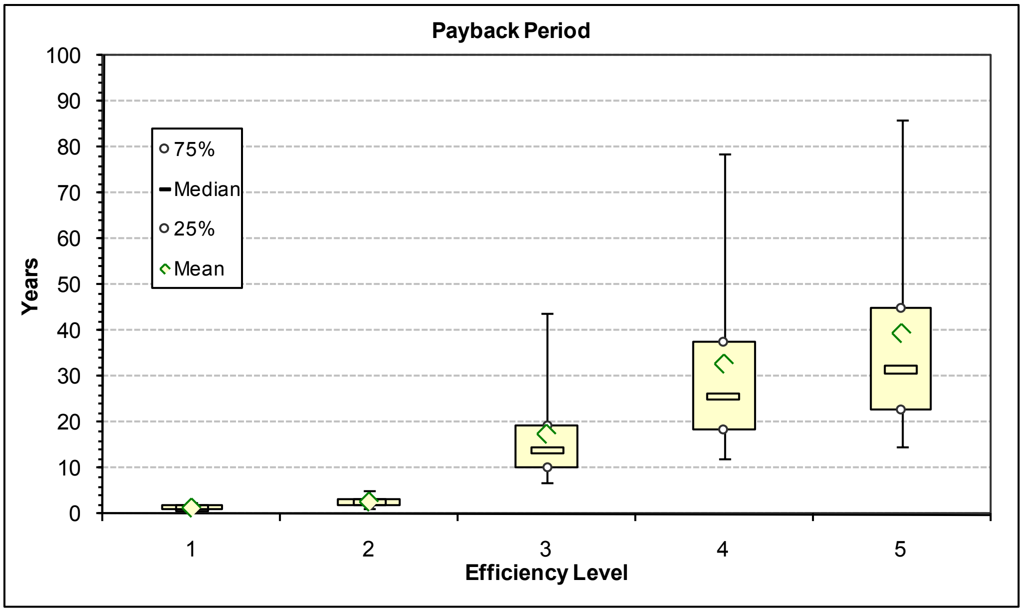


Figure 8.4.27 Product Class 3A-BI, Built-In All Refrigerators: Range of Payback Periods by Efficiency Level

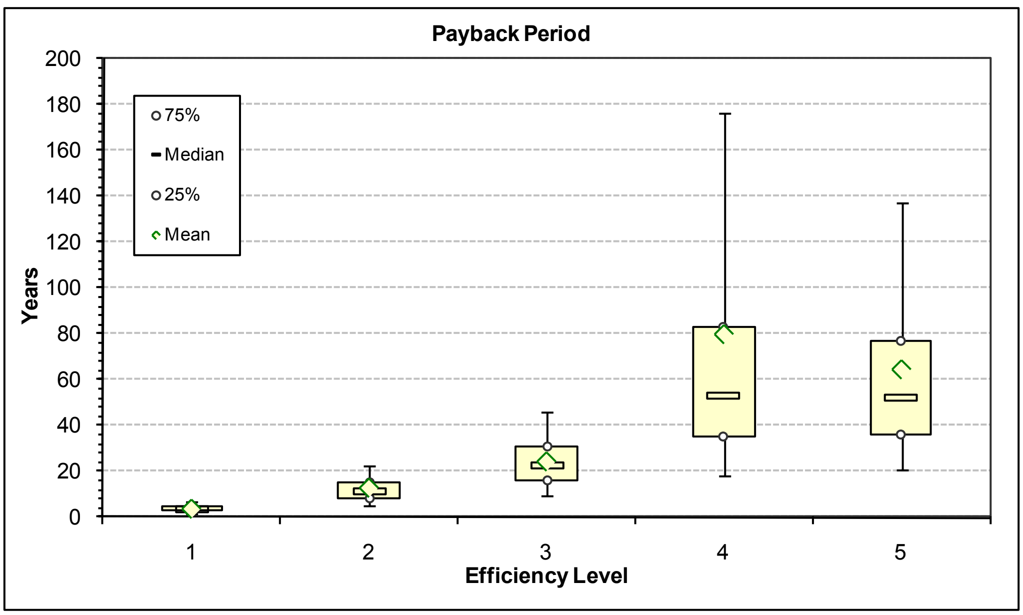


Figure 8.4.28 Product Class 5-BI, Built-In Bottom-Mount Refrigerator-Freezers: Range of Payback Periods by Efficiency Level

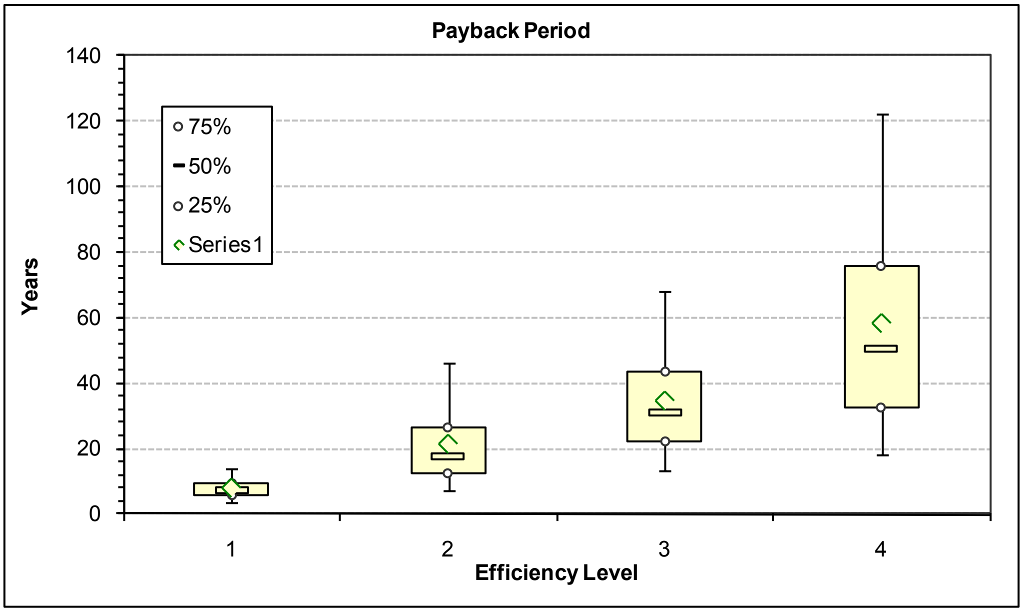


Figure 8.4.29 Product Class 7-BI, Built-In Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: Range of Payback Periods by Efficiency Level

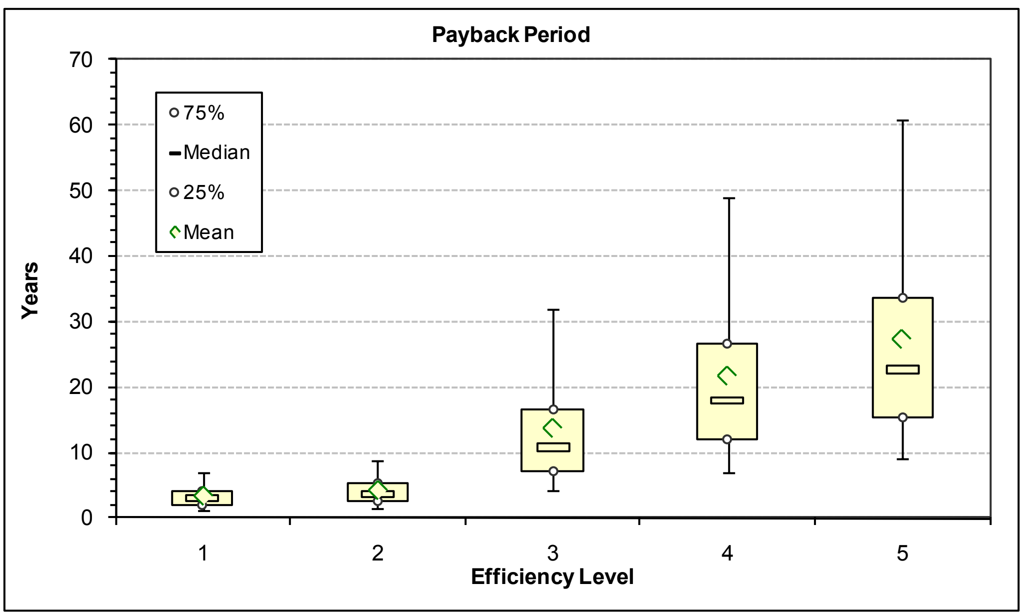


Figure 8.4.30 Product Class 9-BI, Built-In Upright Freezers: Range of Payback Periods by Efficiency Level

8.5 REBUTTABLE PAYBACK PERIOD

DOE presents rebuttable PBPs to provide information for considering the legally established rebuttable presumption that an energy efficiency standard is economically justified if the additional product costs attributed to the standard are less than three times the value of the first-year savings in energy costs. (42 U.S.C. §6295 (o)(2)(B)(iii))

The basic equation for rebuttable PBP is the same as that shown in section 8.3, Inputs to Analysis of Payback Period. Unlike the analyses described in sections 8.2 and 8.3, however, the rebuttable PBP is not based on the use of household samples and probability distributions. Rather, it is based on discrete, single-point values. For example, although DOE uses a probability distribution of regional energy prices in the-analysis of payback period, it uses only the national average energy price to determine the rebuttable PBP. DOE calculated rebuttable PBPs for each standard level relative to the purchase and operating costs of an average baseline product.

Other than the use of single-point values, the key difference between the distribution PBP and the rebuttable PBP is the latter's reliance on the DOE test procedure to determine a product's annual energy consumption.

8.5.1 Results

Table 8.5.1 through Table 8.5.4 present the rebuttable PBPs for each group of refrigeration products.

Table 8.5.1 Standard-Size Refrigerator-Freezers: Rebuttable Payback Periods

Product Class 3: Top-Mount Refrigerator-Freezer		**Product Class 5: Bottom-Mount Refrigerator-Freezer**		**Product Class 7: Side-by-Side Refrigerator-Freezer with TTD***	
Efficiency Level (*% less than baseline energy use*)	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***
1 (10)	2.4	1 (10)	2.1	1 (10)	1.3
2 (15)	2.6	2 (15)	2.3	2 (15)	1.7
3 (20)	7.3	3 (20)	3.1	3 (20)	2.9
4 (25)	8.5	4 (25)	5.8	4 (25)	5.1
5 (30)	12.0	5 (30)	9.5	5 (30)	9.4
6 (36)	16.0	6 (36)	13.2	6 (33)	12.1

*Through-the-door ice service.

Table 8.5.2 Standard-Size Freezers: Rebuttable Payback Periods

Product Class 9: Upright Freezer		Product Class 10: Chest Freezer	
Efficiency Level (*% less than baseline energy use*)	**PBP** *years*	**Efficiency Level** (*% less than baseline energy use*)	**PBP** *years*
1 (10)	1.9	1 (10)	1.8
2 (15)	3.3	2 (15)	2.7
3 (20)	3.8	3 (20)	3.4
4 (25)	4.6	4 (25)	6.9
5 (30)	5.1	5 (30)	7.4
6 (35)	6.7	6 (35)	10.1
7 (40)	8.7	7 (39)	15.1
8 (43)	13.8		

Table 8.5.3 Compact Refrigeration Products: Rebuttable Payback Periods

Product Class 11: Compact Refrigerator		Product Class 18: Compact Freezer	
Efficiency Level (*% less than baseline energy use*)	**PBP** *years*	**Efficiency Level** (*% less than baseline energy use*)	**PBP** *years*
1 (10)	1.7	1 (10)	2.0
2 (15)	2.1	2 (15)	3.8
3 (20)	2.5	3 (20)	9.0
4 (25)	3.5	4 (25)	8.4
5 (30)	3.9	5 (30)	10.0
6 (35)	5.8	6 (35)	9.2
7 (40)	5.7	7 (42)	12.9
8 (45)	7.3		
9 (50)	7.7		
10 (59)	10.0		

Table 8.5.4 Built-In Refrigeration Products: Rebuttable Payback Periods

Product Class 3A-BI: Built-in All Refrigerator		**Product Class 5-BI: Built-In Bottom-Mount Refrigerator-Freezer**		**Product Class 7-BI: Built-In Side-by-Side Refrigerator-Freezer with TTD***		**Product Class 9-BI: Built-In Upright Freezer**	
Efficiency Level (*% less than baseline energy use*)	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***
1 (10)	1.5	1 (10)	3.9	1 (10)	7.4	1 (10)	2.6
2 (15)	2.6	2 (15)	10.3	2 (15)	11.8	2 (15)	3.1
3 (20)	13.0	3 (20)	15.0	3 (20)	20.2	3 (20)	8.3
4 (25)	22.3	4 (25)	21.4	4 (22)	24.8	4 (25)	14.2
5 (29)	27.2	5 (27)	24.5			5 (27)	18.3

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CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Estimates of future product shipments are a necessary input to calculations of the national energy savings (NES) and net present value (NPV), as well as to the manufacturer impact analysis (MIA). This chapter describes the data and methods the U.S. Department of Energy (DOE) used to forecast annual product shipments and presents results for each of the refrigeration product classes being considered in this analysis.

DOE defined four refrigeration product types, and developed models to estimate shipments for each type. The four types are: (1) standard-size refrigerator-freezers, (2) standard-size freezers, (3) compact refrigerators, and (4) compact freezers. Each model considers specific market segments to estimate shipments of each product type. The results from these segments are aggregated to estimate total shipments for each product type. DOE then used various data and assumptions to disaggregate total shipments into the product classes considered in this rulemaking. Note that built-in refrigeration products are initially included in the models for standard-size refrigerator-freezers and standard-size freezers, and then are separated out from the forecast.

To estimate the effects of potential standard levels on product shipments, each shipments model accounts for the combined effects on consumer purchase decisions of changes in product price, annual operating cost, and household income.

The shipments models were developed as Microsoft Excel spreadsheets that are accessible on the Internet (http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers.html). Appendix 10-A discusses how to access and utilize the shipments model spreadsheets, which are integrated into spreadsheets for the National Impact Analysis. The rest of this chapter explains the shipments models in more detail. Section 9.2 presents methodology behind the models; section 9.3 describes the data inputs and calibration of each model; section 9.4 discusses impacts on shipments from standards; section 9.5 discusses the affected stock; and section 9.6 presents the shipments forecast for different energy conservation standard levels.

9.2 SHIPMENTS MODEL GENERAL METHODOLOGY

DOE developed a model of the national stock of in-service appliances for estimating annual shipments for each of the product types considered for this standards rulemaking. Rather than simply extrapolating a shipments trend, the shipments models used in this rulemaking take an accounting approach, tracking the vintage of units in the existing stock.

9.2.1 Stock Accounting Approach

Stock accounting provides an estimate of the age distribution of product stocks for all years, using product shipments, a retirement function, and initial product stock as inputs. The age distribution of product stocks is a key input to both the NES and NPV calculations because the operating costs for any year depend on the age distribution of the stock. Older, less efficient units may have higher operating costs, while younger, more-efficient units have lower operating costs.

DOE calculates the total stock of each product by integrating historical shipments data beginning with a specific year. The start year depends on the historical data available for the product. As units are added to the stock, some of the older ones retire and exit the stock. To estimate future shipments, DOE developed a series of equations that define the dynamics and accounting of stocks. For new units, the equation is:

$$Stock(j, age = 1) = Ship(j - 1)$$

Where:

Stock(j, age) = number of units of a particular age,
j = year for which the stock is being estimated, and
Ship (j) = number of units purchased in year *j*.

The above equation states that the number of one-year-old units is simply equal to the number of new units purchased the previous year. Slightly more complicated equations, such as the following equation, describe how the model accounts for the existing stock of units.

$$Stock(j+1, age+1) = Stock(j, age) \times \left[1 - prob_{Rtr}(age)\right]$$

In this equation, as the year is incremented from *j* to *j+1*, the age is also incremented from *age* to *age+1*. Over time, a fraction of the stock is removed; that fraction is determined by a retirement probability function, $prob_{Rtr}(age)$, which is described below.

9.2.2 Market Segments

The model considers specific market segments in developing a shipments forecast. The two primary market segments are replacements and installations in new homes.

For common appliances that have been used by U.S. consumers for a long time, replacements typically constitute the majority of shipments. To estimate shipments of replacement units, the models utilize shipments data from previous years and estimates of the lifetime of each product. Estimated shipments of replacement units in a given year are equal to the total stock of the appliance minus those units shipped in previous years that remain in the stock. DOE determines the useful service life of each product class to estimate the number of years products are likely to remain in the stock. The following equation shows how DOE estimates shipments of replacement units.

$$Rpl_p(j) = Stock_p(j-1) - \sum_{age=0}^{ageMax} \sum_{j=N}^{j-1} Ship_j \times prob_{Rtr}(age)$$

Where:

$Stock_p (j-1)$ = total stock of appliances in year *j-1*,
$prob_{Rtr} (age)$ = probability that an appliance of a particular *age* will be retired, and
N = year in which the model begins its stock accounting.

To forecast annual shipments for the new construction market, the model uses forecasts of new housing and the saturation of the product in new housing. The forecast of market shares involves knowledge of historical trends, as well as the important drivers of consumer choice and their relative impacts.

For many products, DOE models a third market segment. For standard-size refrigerator-freezers, DOE estimated purchases driven by the conversion of an existing unit from first to second refrigerator. For standard-size freezers, DOE estimated purchases driven by existing households who enter the market as new owners.

9.3 PRODUCT-SPECIFIC MODELS

This section describes the models used to forecast shipments of the four refrigeration product types described in section 9.1. For each model, the section describes the sources for historical shipments data, the market segments considered, the approach for disaggregating total shipments into the appropriate product classes, and presents the forecast of base case shipments.

Forecasts of new housing are used in the shipments models. New housing includes newly constructed single- and multi-family units, termed "new housing completions," and mobile home placements. For new housing completions and mobile home placements, DOE used recorded data through 2007, and adopted the projections from the DOE Energy Information Administration (EIA)'s *Annual Energy Outlook 2010* (*AEO2010*) for the period 2008–2035.[1] Figure 9.3.1 presents historical and forecasted new housing starts. For 2031−2043, DOE kept completions at the 2035 level.

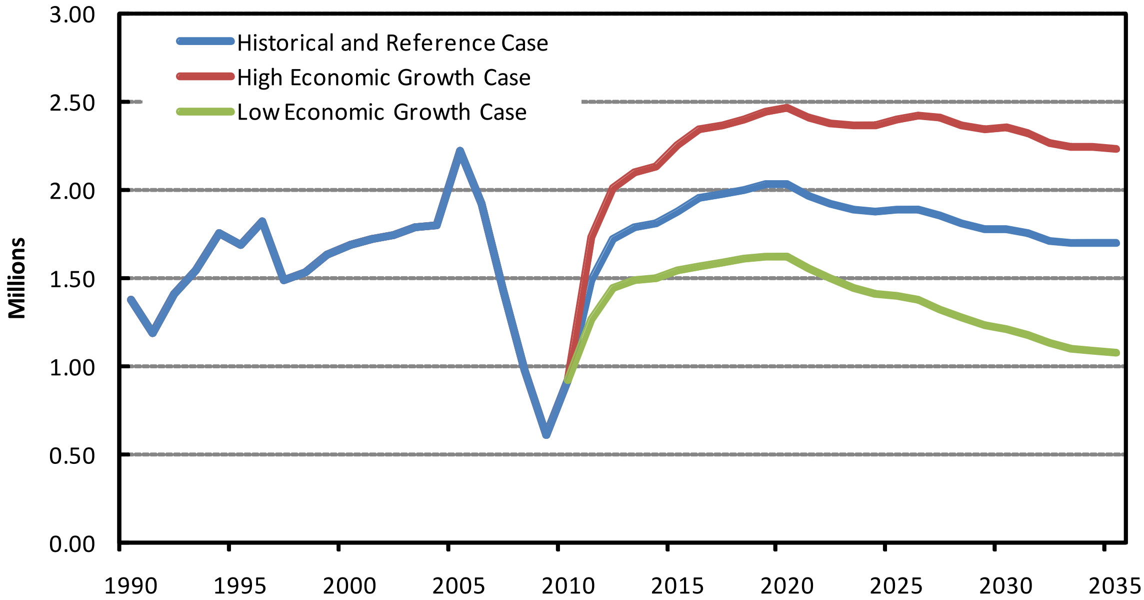

Figure 9.3.1 Historical and Forecasted U.S. Housing Starts

9.3.1 Standard-Size Refrigerator-Freezers

DOE's shipments model uses the aggregate shipments of standard-size refrigerator-freezers as the basis for its forecasts. For the shipments analysis, the category "standard-size refrigerator-freezers" includes built-in refrigerator-freezers. DOE used various data and assumptions to disaggregate total shipments of standard-size refrigerator-freezers into the product classes of standard-size refrigerator-freezers and built-in refrigerator-freezers considered in its analysis.

To start, DOE used the following sources to establish historical shipments for standard-size refrigerator-freezers: *Appliance* magazine's Statistical Review,[2,3,4] AHAM Factbooks,[5,6] and an Association of Home Appliance Manufacturers (AHAM) data submittal related to this rulemaking.[7] The shipments data from 1990 onward are shown in Figure 9.3.2 below. (The complete historical time series may be found in the shipments model spreadsheet for standard-size refrigerator-freezers.)

9.3.1.1 Market Segments

The market for standard-size refrigerator-freezers is primarily comprised of units for new construction, replacement units for products that have been retired, and additional refrigerator purchases driven by conversion of a first refrigerator to a second refrigerator. Total shipments are represented by the following equation:

$$Ship_{SRRF}(j) = Rpl_{SRRF}(j) + NH_{SRRF}(j) + Conv_{SRRF}(j)$$

Where:

$Ship_{SRRF}(j)$ =	total shipments of standard-size refrigerator-freezers in year *j*,
$Rpl_{SRRF}(j)$ =	replacement shipments in year *j*,
$NH_{SRRF}(j)$ =	shipments to new homes in year *j*, and
$Conv_{SRRF}(j)$=	shipments due to additional refrigerator purchase (conversion of first to second refrigerator) in year *j*.

The following sections discuss these three market segments in further detail.

Replacements. DOE determined refrigerator-freezer shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. Over time, some units are retired and removed from the stock, thereby triggering the shipment of replacement units. A certain percentage of units will fail each year and need to be replaced. To determine when a unit fails, DOE used a survival function based on a product lifetime distribution with an average value of 17.1 years. Chapter 8 provides a discussion of product lifetime. Figure 9.3.2 shows the survival and retirement functions that DOE used to estimate replacement shipments for standard-size refrigerator-freezers.

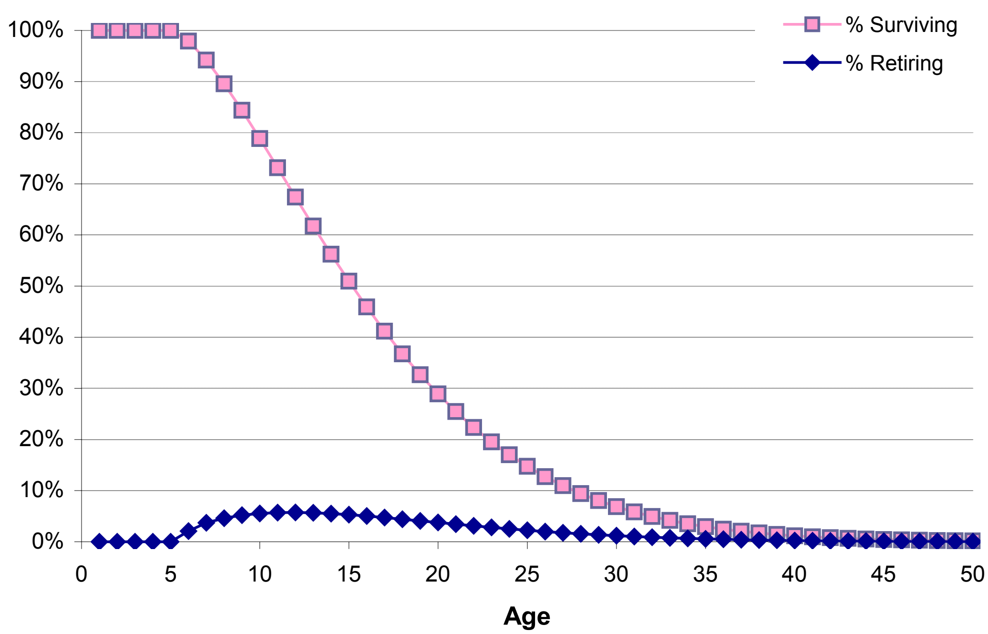

Figure 9.3.2 Standard-size Refrigerator-Freezers: Survival and Retirement Functions

New Construction Shipments. To estimate shipments for new residential construction, DOE multiplied the housing starts forecast for each year by the estimated saturation of standard-size refrigerator-freezers in new housing. DOE estimated the saturation in 2008 to be 1.3 per new home based on the calculated appliance stock from shipments data and the retirement function. DOE used the 2008 saturation for the entire forecast period. The following equation describes the method used for calculating saturation for new construction:

$$Sat_{NC}(j) = Stock(j) / HStock(j)$$

$$Sat_{NC}(j) = Sat_{NC}(2008) \forall j > 2008$$

Where:

$Sat_{NC}(j)$ = market saturation of standard-size refrigerator-freezers in the new housing market segment in year *j*,
$Stock(j)$ = total stock of standard-size refrigerator-freezers in year *j*,
$HStock(j)$ = total number of housing units in year *j*, and
$Sat_{NC}(2008)$ = market saturation of standard-size refrigerator-freezers in the new housing market segment in 2008.

Shipments Due to Additional Refrigerator Purchase. DOE included a market segment corresponding to purchases of additional standard-size refrigerator-freezers that are not intended as replacements. Because such purchases involve converting a first unit to a second refrigerator, DOE estimated shipments to this market segment by applying the probability of conversion (developed in chapter 8) to the stock of surviving refrigerators. To determine when a household converts a first refrigerator to a second one, DOE used a conversion function based on the total installed stock of refrigerators of a certain age. Chapter 8 provides a detailed discussion of the conversion function. The following equation shows how DOE calculated shipments to this market segment.

$$SNew_{SRRF}(j) = C_j \times \sum_{age=0}^{ageMax} \sum_{j=N}^{j-1} Stock(age)_j \times prob_{conv}(age)$$

Where:

$SNew_{SRRF}(j)$= shipments due to additional refrigerator purchase (conversion of first to second refrigerator) in year *j*,
C_j = a calibration factor, equal to the ratio of new shipments in year *j* to the installed stock in that year, and
$Prob_{conv}(age)$ = probability that the refrigerator has been converted at a given *age*

Shipments Forecast by Market Segment. Figure 9.3.3 shows the forecasted shipments in the base case (without new energy conservation standards) and the historical shipments (through 2008). The figure presents shipments due to retirements, shipments to new housing, and shipments due to conversion from first to second units.

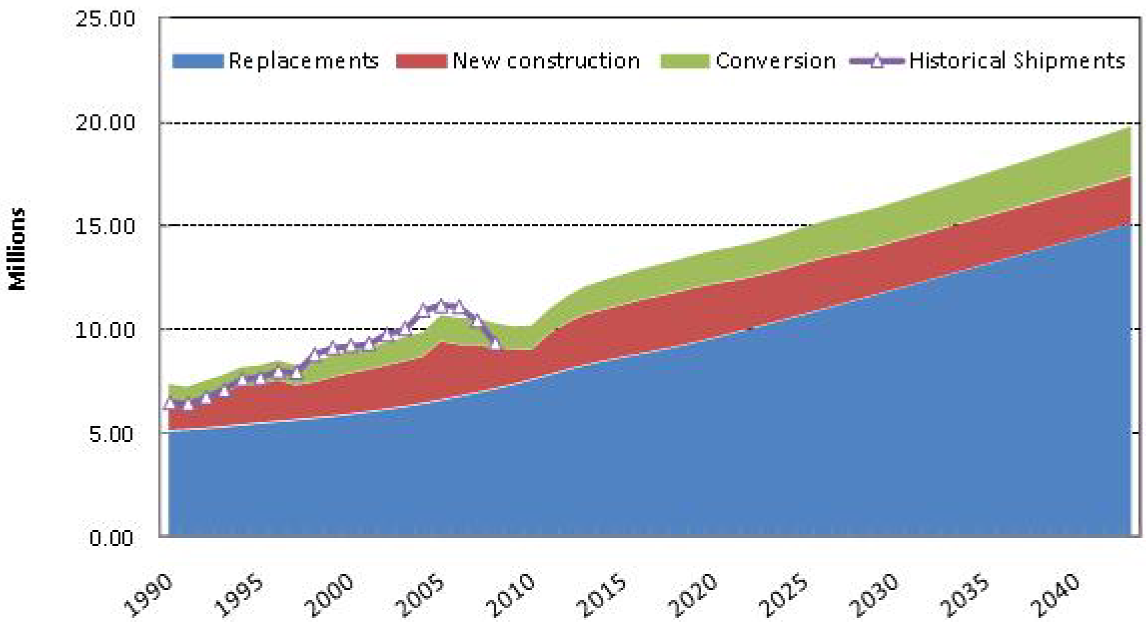

Figure 9.3.3 Standard-Size Refrigerator-Freezers: Historical and Base Case Shipments Forecast by Market Segment

9.3.1.2 Disaggregation into Refrigerator-Freezer Product Classes

DOE examined the historical trends in the market shares of various refrigerator-freezer configurations to disaggregate the total shipments of refrigerator-freezers into shipments to each of the three considered refrigerator-freezer product categories (top-mount, bottom-mount and side-by-side configurations). The market share of side-by-side refrigerator-freezers models has grown significantly during the past two decades. Bottom-freezer models historically had a small market share, but that share has grown in recent years. To forecast the market share for these three configurations throughout the 30-year analysis period (beginning in 2014), DOE built a simple model of aggregate consumer behavior, fit its model to the historical growth in side-by-side market share, and then used its model to estimate future market shares for all three configurations.

DOE assumed that bottom-freezer models were an insignificant portion of the market prior to 2005, and that consumer behavior related to these models in the future would mirror behavior regarding side-by-side models. Therefore, DOE forecast the combined market share for side-by-side and bottom-freezer products, and assumed that the ratio between the market shares of bottom-mount and side-by-side products would remain fixed at its 2008 value.

DOE based its model on the market share of each product category as reported by households in the Energy Information Administration's Residential Energy Consumption Survey[8] (RECS) and as reported by AHAM.[7] RECS reports whether a household owns a side-by-side refrigerator, but does not distinguish between top- and bottom-mount units. For the purpose of this model, DOE assumed that all recently-purchased top-or-bottom-mount refrigerators reported in the RECS surveys conducted in 1990, 1993, 1997, 2001, and 2005 are top-mount units.

DOE used RECS data first to estimate the maximum ("limiting") market share that side-by-side and bottom-mount product classes would attain in the future. RECS reports the income of each household in its sample. DOE assumed that households that have annual incomes greater than $100,000 and that own their own homes are able to select the appliance that best meets their needs and preferences. The market share of side-by-side units in these households is significantly higher than the current overall market share of side-by-side products. DOE determined market shares for recent purchases from RECS by considering only households which reported purchasing their appliance within two years prior to the survey. The market share of side-by-side refrigerator purchases in the selected household group from each RECS survey is shown in Table 9.3.3. Over time, DOE assumed that all homeowners will be free to choose the product of their choice, as DOE assumed high-income homeowners can today. As a result, DOE assumed that market share of side-by-side units among all homeowners will increase until it equals the mean market share among high-income home-owning households, 66.4 percent.

Table 9.3.1 Market Shares of Side-by-Side Refrigerator-Freezers

RECS Survey Year	Market Share of Side-by-Side Units for High-Income Homeowners (%)
1990	57.7
1993	71.7
1997	73.4
2001	61.6
2005	67.5
Mean	**66.4**

Source: EIA, Residential Energy Consumption Survey, for the years listed.

DOE used RECS to determine what percent of side-by-side units is sold to home-owners in order to convert a limiting market share among home-owning households into a market share for all shipments. This percentage was roughly constant in the five most recent RECS surveys, and DOE assumed that it would remain equal to their mean, 90.9 percent, throughout the forecast period. DOE also assumed that the percent of American households that own their home would return to its historical level of roughly 65 percent by 2025. (Home ownership ranged between 63 percent and 66 percent from 1962 to 1997, peaked at 69 percent in 2004, and fell to 67.8 percent in 2008.)

DOE combined the three factors (the observed preference of high-income consumers, percent of side-by-side refrigerator-freezers purchased by homeowners, and homeownership) to predict the limiting market share for the side- and bottom-freezer product classes. This limit is

$$MS_{SF-LIM} = \frac{MS_{HO-LIM} \times HO_{LIM}}{SF_{HO}} = 47.45\%$$

Where:

$MS_{SF\text{-}LIM}$ = limiting market share for side-by-side and bottom-mount product classes,
$MS_{HO\text{-}LIM}$ = limiting market share for side-by-side and bottom- mount product classes among homeowners (66.4 percent),
HO_{LIM} = DOE's assumed value for the eventual percentage of households that will own their own home (65 percent), and
SF_{HO} = the percentage of side-by-side and bottom-mount products sold to homeowners (90.9 percent).

DOE modeled the approach to this limiting value as a logistic curve, and fit the model parameters to data from RECS and AHAM in order to determine the rate at which the market will approach the limit. RECS micro-data enabled DOE to determine the approximate market share of side-by-side products among all homeowners in the years preceding each RECS survey (1989, 1992, 1996, 2000, and 2004). DOE also calculated the market share among homeowners from the AHAM data by multiplying by 90.9 percent (SF_{HO}) and dividing by the homeownership (*HO*) for each year. The resulting estimates for market shares of side-by-side products among homeowners are shown in Table 9.3.2.

Table 9.3.2 Modeled Homeowner Side-by-Side Market Share

Survey	Year	Market Share
AHAM	1998	41.0%
	1999	41.9%
	2000	42.2%
	2001	43.0%
	2002	43.9%
	2003	45.9%
	2004	46.2%
	2005	49.1%
	2006	59.8%
	2007	61.4%
	2008	65.1%
RECS	1989	32.5%

Survey	Year	Market Share
	1992	31.9%
	1996	41.1%
	2000	48.9%
	2004	53.0%

DOE fit a logistic curve to the data in Table 9.3.2, approaching the limiting value MS_{SF-LIM}:

$$MS_{HO-year} = \frac{MS_{HO-LIM}}{1 + e^{\alpha(\beta - year)}},$$

Where:

$MS_{HO-year}$ = market share of side-by-side and bottom-mount refrigerator-freezers among all homeowners in a given *year*,
α, β = fit parameters, and
MS_{HO-LIM} = limiting market share for side- and bottom-freezer product classes among homeowners (66.4 percent).

The best fit parameters are: $\alpha = 0.10504$ and $\beta = 1992.38$.

The R-squared value for the fit is 0.795, indicating that the model is a relatively good fit. DOE multiplied the best-fit estimate of $MS_{HO-year}$ by homeownership in each year, and then divided by SF_{HO} to account for side- and bottom-mount refrigerators sold to non-homeowners. The results are estimated market shares of side-by-side or bottom-mount products throughout the analysis period. This estimate, along with the markets shares derived from the RECS and AHAM data, is shown in Figure 9.3.4.

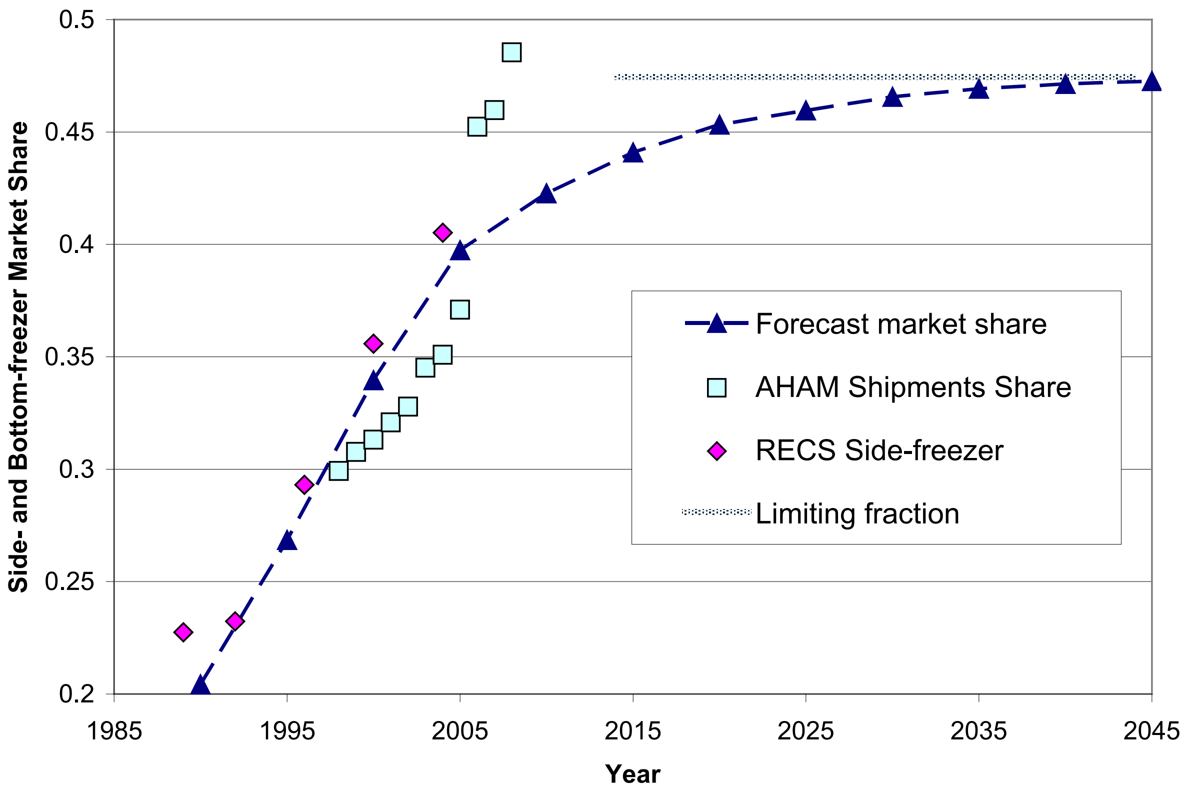

Figure 9.3.4 Projected Market Share of Side- and Bottom-Freezer Product Classes

DOE disaggregated the side and bottom-mount freezer classes into their respective product classes based on the AHAM data submittal for 2005-2008. For future years, DOE maintained the market shares of the product classes within each considered category of side-by-side and bottom-mount, and top-mount refrigerator-freezer as they existed in 2008.

For built-in product classes, DOE assumed that the market shares will move in step with market shares of the closest corresponding conventional product class (e.g., product class 3A-BI follows conventional product class 3), and it maintained the ratios between built-in and conventional products found in 2008.

Table 9.3.3 presents the market share forecast DOE used to disaggregate total standard-size refrigerator-freezer shipments.

Projected Product Class Market Shares of Standard-Size Refrigerator-Freezers

Year	PC3 (Top)	PC1+PC2 +PC6 (Top)	PC4 (S/S)	PC7 (S/S)	PC5 (Bottom)	PC5A (Bottom)	PC4-BI+ PC7-BI (Built-in S/S)	PC3A-BI+ PC5-BI (Built-in)
2008	50.6%	0.7%	0.8%	26.9%	12.5%	5.7%	1.6%	1.2%
2009	54.5%	0.7%	0.8%	24.7%	11.5%	5.2%	1.5%	1.1%
2010	58.0%	0.8%	0.7%	22.8%	10.6%	4.8%	1.3%	1.0%
2011	57.7%	0.8%	0.7%	23.0%	10.7%	4.9%	1.3%	1.0%
2012	57.5%	0.8%	0.7%	23.1%	10.8%	4.9%	1.4%	1.1%
2013	57.2%	0.8%	0.7%	23.3%	10.8%	4.9%	1.4%	1.1%
2014	56.9%	0.8%	0.7%	23.4%	10.9%	5.0%	1.4%	1.1%
2015	56.6%	0.8%	0.7%	23.6%	11.0%	5.0%	1.4%	1.1%
2016	56.4%	0.8%	0.7%	23.7%	11.1%	5.0%	1.4%	1.1%
2017	56.1%	0.8%	0.7%	23.9%	11.1%	5.1%	1.4%	1.1%
2018	55.9%	0.8%	0.7%	24.0%	11.2%	5.1%	1.4%	1.1%
2019	55.7%	0.8%	0.7%	24.1%	11.2%	5.1%	1.4%	1.1%
2020	55.4%	0.7%	0.7%	24.2%	11.3%	5.1%	1.4%	1.1%
2021	55.3%	0.7%	0.7%	24.3%	11.3%	5.2%	1.4%	1.1%
2022	55.1%	0.7%	0.7%	24.4%	11.4%	5.2%	1.4%	1.1%
2023	55.0%	0.7%	0.8%	24.5%	11.4%	5.2%	1.4%	1.1%
2024	54.8%	0.7%	0.8%	24.6%	11.4%	5.2%	1.4%	1.1%
2025	54.7%	0.7%	0.8%	24.7%	11.5%	5.2%	1.4%	1.1%
2026	54.5%	0.7%	0.8%	24.8%	11.5%	5.2%	1.5%	1.1%
2027	54.3%	0.7%	0.8%	24.8%	11.6%	5.3%	1.5%	1.1%
2028	54.2%	0.7%	0.8%	24.9%	11.6%	5.3%	1.5%	1.1%
2029	54.0%	0.7%	0.8%	25.0%	11.7%	5.3%	1.5%	1.1%
2030	53.9%	0.7%	0.8%	25.1%	11.7%	5.3%	1.5%	1.1%
2031	53.7%	0.7%	0.8%	25.2%	11.7%	5.3%	1.5%	1.1%
2032	53.6%	0.7%	0.8%	25.2%	11.8%	5.3%	1.5%	1.1%
2033	53.5%	0.7%	0.8%	25.3%	11.8%	5.4%	1.5%	1.1%
2034	53.4%	0.7%	0.8%	25.4%	11.8%	5.4%	1.5%	1.1%
2035	53.3%	0.7%	0.8%	25.4%	11.8%	5.4%	1.5%	1.1%
2036	53.2%	0.7%	0.8%	25.5%	11.9%	5.4%	1.5%	1.1%
2037	53.1%	0.7%	0.8%	25.5%	11.9%	5.4%	1.5%	1.1%
2038	53.0%	0.7%	0.8%	25.6%	11.9%	5.4%	1.5%	1.1%
2039	52.9%	0.7%	0.8%	25.6%	11.9%	5.4%	1.5%	1.1%
2040	52.8%	0.7%	0.8%	25.7%	12.0%	5.4%	1.5%	1.1%
2041	53.1%	0.7%	0.8%	25.5%	11.9%	5.4%	1.5%	1.1%
2042	52.8%	0.7%	0.8%	25.7%	12.0%	5.4%	1.5%	1.1%
2043	52.7%	0.7%	0.8%	25.8%	12.0%	5.5%	1.5%	1.1%

Shipments Forecast by Market Segment. Figure 9.3.5 presents forecasted refrigerator-freezer shipments disaggregated by product class group.

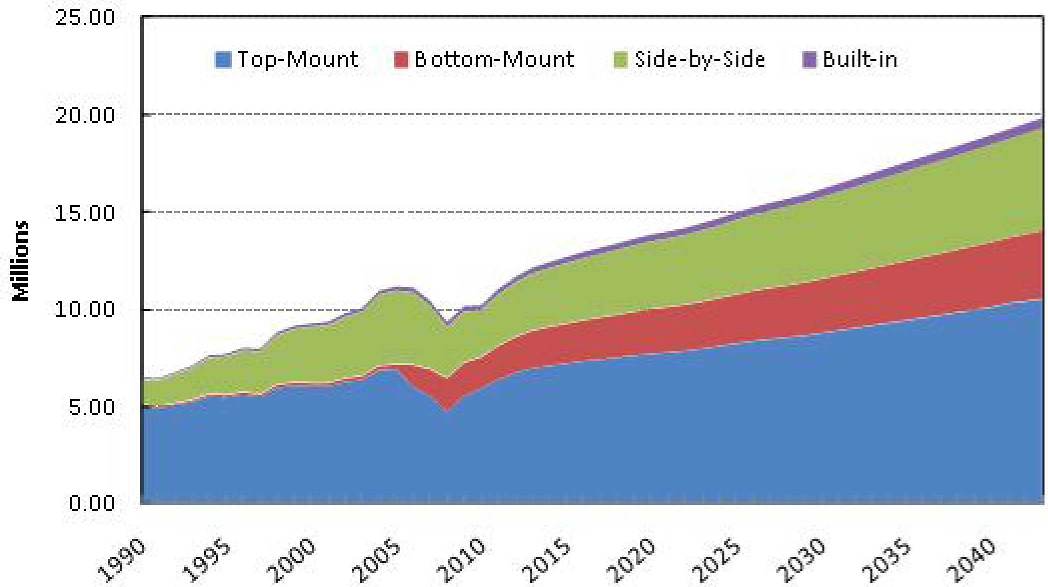

Figure 9.3.5 Standard-size Refrigerator-Freezers: Base Case Shipments Forecast by Product Class Group

9.3.2 Standard-Size Freezers

DOE's shipments model uses the aggregate shipments of standard-size freezers as the basis for its forecasts. For the shipments analysis, the category "standard-size freezers" includes built-in freezers. DOE used various data and assumptions to disaggregate total shipments of standard-size freezers into the product classes of standard-size freezers and built-in freezers considered in its analysis.

To start, DOE used data on historical shipments (i.e., domestic shipments and imports) from *Appliance* magazine's Statistical Review,[9] AHAM Factbook,[5] and an AHAM data submittal[7] to populate and calibrate its shipments model. The shipments data from 1990 onward are shown in Figure 9.3.7 below. (The complete historical time series may be found in the shipments model spreadsheet for standard-size freezers.)

9.3.2.1 Market Segments

The shipments market for standard-size freezers is primarily comprised of replacement units for products that have been retired and units in new homes. DOE's shipments model also assumes that some households enter the market as new freezer owners. Total shipments are represented by the following equation:

$$Ship_{SF}(j) = Rpl_{SF}(j) + NH_{SF}(j) + EHA_{SF}(j)$$

Where:

$Ship_{SF}(j)$ =	total shipments of standard-size freezers in year *j*,
$Rpl_{SF}(j)$ =	replacement shipments in year *j*,
$NH_{SF}(j)$ =	shipments to new households in year *j*, and
$EHA_{SF}(j)$=	shipments to existing households without the appliance in year *j*.

The following sections discuss all three of these markets in further detail.

Replacements. DOE determined shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. Over time, some units are retired and removed from the stock, triggering the shipment of a replacement unit. A certain percentage (depending on the age) of units will fail each year and need to be replaced. To determine when a unit fails, DOE used a survival function based on a product lifetime distribution that had an average value of 22.7 years. Chapter 8 describes the derivation of the lifetime of standard-size freezers. Figure 9.3.6 shows the survival and retirement functions that DOE used to estimate shipments of replacement freezers.

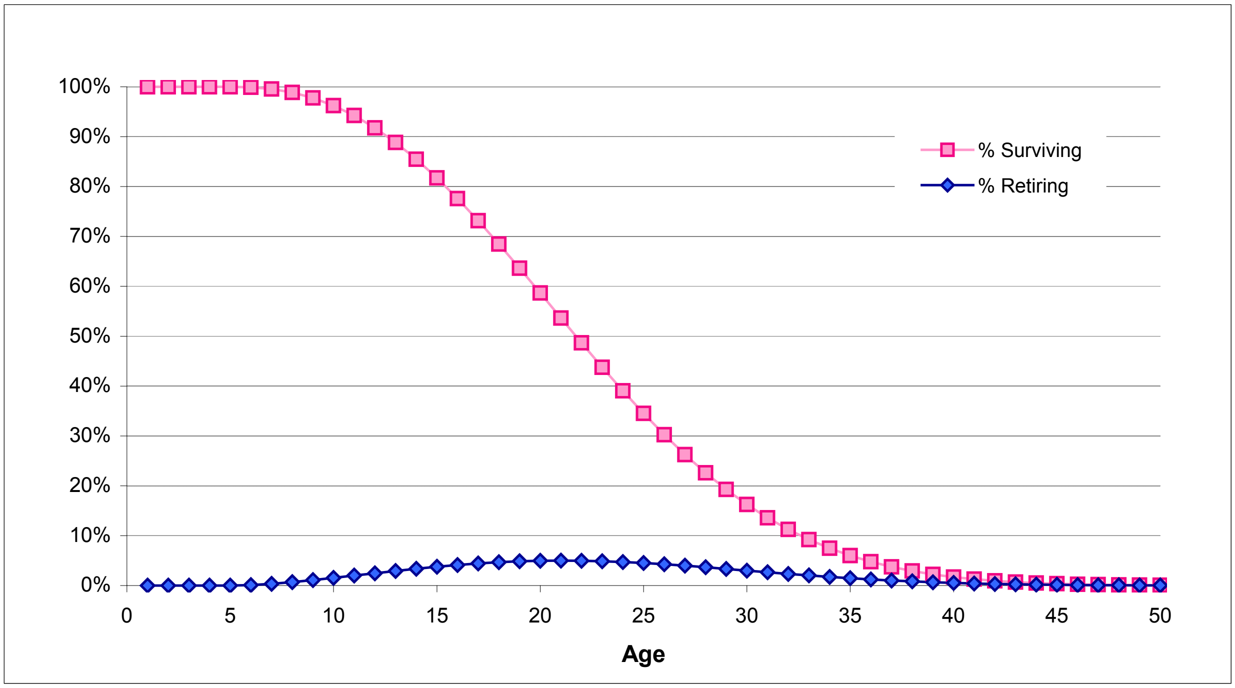

Figure 9.3.6 Standard-size Freezers: Survival and Retirement Functions

New Construction. To forecast the shipments of standard-size freezers for new construction for any given year, DOE multiplied the forecasted housing starts by the forecasted saturation of standard-size freezers for new housing. DOE determined the saturation in new homes by using a sample of RECS household records whose home is less than 5 years old, with freezers of age less than 5 years. DOE used the growth in saturation between the 2001 and 2005 RECS surveys[8] to estimate saturation in 2007 new homes of 12%. It used that level for the entire forecast period.

New Owners. DOE introduced a third market segment that consists of households that currently do not own a freezer. DOE estimated historical shipments to this market segment as the residual shipments after modeled shipments for new housing and replacements were subtracted from total actual shipments. DOE used a moving average of the previous 3 years of the percent of households who purchase freezers as new owners to estimate the percent for each year in 2008-2043. The following equation illustrates the calculations.

$$EHA_{SF}(j) = (1 - StockSat_j) \times HStock_j \times EHAfrac_j$$

Where:

$EHA_{SF}(j)$ = number of freezers shipped to existing households without the appliance in year j,
$StockSat_j$ = stock saturation of freezers in year j,
$HStock_j$ = housing stock in year j, and
$EHAfrac_j$ = fraction of housing units without the appliance who obtain a freezer in year j.

Shipments Forecast by Market Segment. Figure 9.3.7 shows the forecasted shipments of standard-size freezers in the base case (without amended energy conservation standards), disaggregated into the three modeled market segments, and the historical shipments, which DOE used to calibrate the forecast.

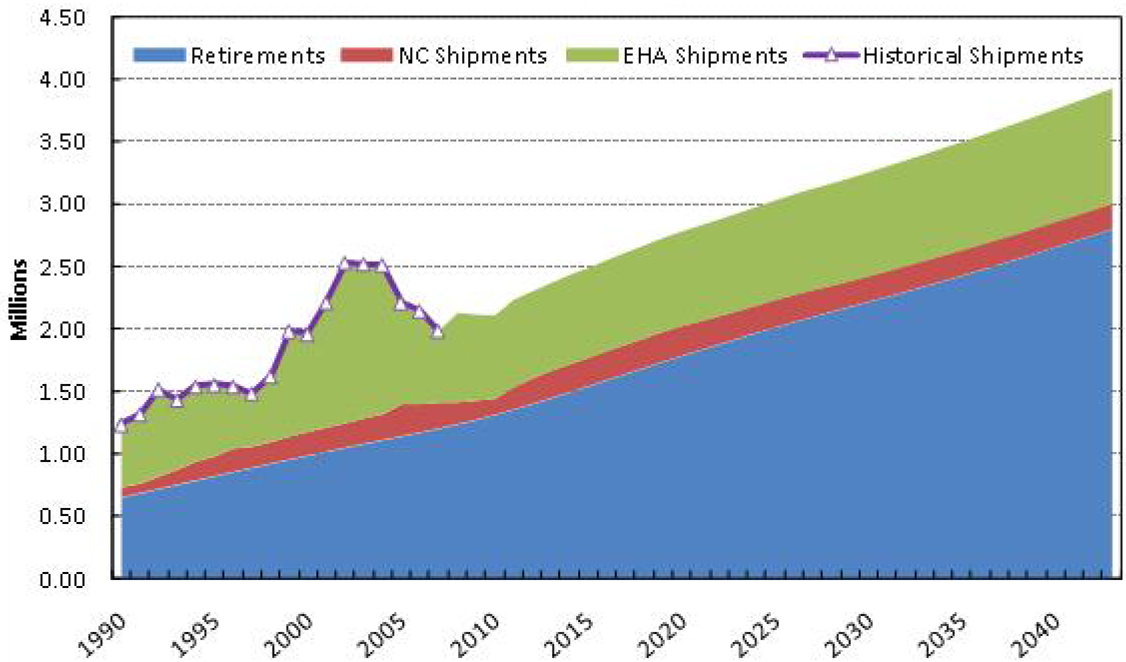

Figure 9.3.7 Standard-Size Freezers: Historical and Base Case Shipments Forecast by Market Segment

9.3.2.2 Disaggregation into Freezer Product Classes

To disaggregate the total shipments of standard-size freezers into shipments of each of the freezer product classes, DOE used the market share information submitted by AHAM.[7] These data provided an aggregated market share in 2007 of 50.6 percent for product classes 8, 10 and 10A. Using data from the 2005 AHAM Fact Book[5] and *Appliance* magazine,[2] DOE concluded that the market shares for product classes 8 and 10A are near zero. Therefore, DOE attributed the combined market share of product classes 8, 10 and 10A from the AHAM data submittal (50.6 percent) entirely to product class 10. The remainder, 49.4 percent, is comprised of shipments of upright freezers with auto defrost. Based on the AHAM data submittal, DOE estimated that built-in freezers (product class 9-BI) account for 2.2% of total shipments of upright freezers with auto defrost.

Table 9.3.4 presents the market shares used for disaggregating modeled shipments of standard-size freezers. Because a reliable method for projecting market share changes was lacking, DOE used these estimated market shares throughout the forecast period.

Table 9.3.3 Product Class Market Shares for Standard-size Freezers

PC8	PC9 + PC9I	PC10	PC10A	PC9-BI + PC9I-BI
0.0%	48.3%	50.6%	0.0%	1.1

9.3.3 Compact Refrigerators

DOE's shipments model uses the aggregate shipments of compact refrigerators as the basis for its forecasts. DOE used various data and assumptions to disaggregate total shipments into the five product classes of compact refrigerators considered in this analysis.

To start, DOE developed historical shipments data (domestic shipments and imports) based on data submitted by AHAM[7] and various issues of *Appliance* magazine.[2,9] These data are shown in Figure 9.3.9 below.

9.3.3.1 Market Segments

The market for compact refrigerators is primarily comprised of units that replace products that have been retired from service, and units installed in new housing, new lodging in the commercial sector (such as hotel rooms and dormitories), and in other new construction in the commercial sector. Total compact refrigerator shipments are represented by the following equation:

$$Ship_{CRRF}(j) = Rpl_{CRRF}(j) + NH_{CRRF}(j) + NLodg_{CRRF}(j) + NOthComm_{CRRF}(j)$$

Where:

$Ship_{CRRF}(j)$ = total shipments of compact refrigerators in year j,
$Rpl_{CRRF}(j)$ = replacement shipments in year j,
$NH_{CRRF}(j)$ = shipments to new households in year j,
$NLodg_{CRRF}(j)$ = shipments to new lodging units in year j, and
$NOthComm_{CRRF}(j)$ = shipments to other new commercial establishments in year j.

The following sections discuss these markets.

Replacements. DOE determined shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. Over time, some of the units are retired and removed from the stock, triggering the shipment of a new unit. A certain percentage of units will fail each year and need to be replaced. To determine when a compact refrigerator fails, DOE used a product survival function based on a lifetime distribution with an average value of 5.6 years. Chapter 8 presents a more thorough discussion of product lifetimes for compact refrigerators. Figure 9.3.8 shows the survival and retirement functions that DOE used to estimate replacement shipments.

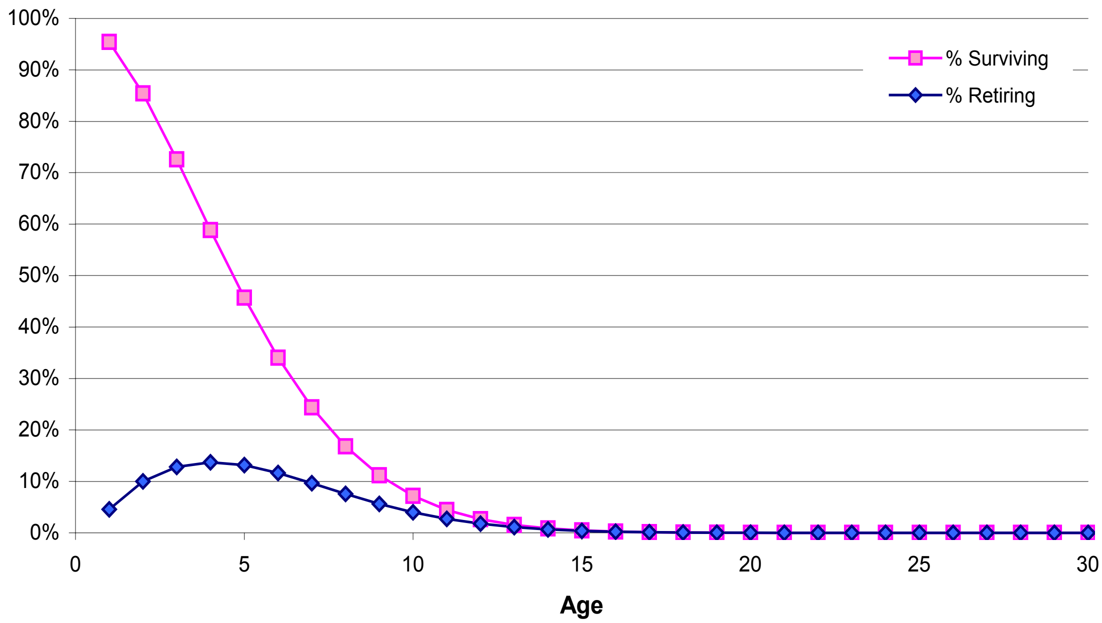

Figure 9.3.8 Compact Refrigerators: Survival and Retirement Functions

New Housing. To estimate shipments to new housing in each year, DOE multiplied forecasted housing starts by the estimated saturation of compact refrigerators in new housing units. DOE estimated market saturation for this segment using the saturation of compact refrigerators in newly-built homes in RECS 2001 and RECS 2005 (2.7 percent and 3.2 percent, respectively). For years beyond 2005, DOE maintained the growth in new housing saturation measured between 2001 and 2005.

New Lodging and Other Commercial New Construction. To estimate shipments to new commercial establishments, DOE used forecasts of new construction in lodging and other commercial establishments coupled with saturation data (in terms of units per building). DOE used total-stock saturation data from the American Lodging Association (ALA)[10] and the EIA's Commercial Building Energy Consumption Survey (CBECS).[11] For lodging, DOE used saturations from ALA for the years 1998, 2003, and 2008. For future years, DOE maintained the growth in saturation rates seen between 2003 and 2008. For other commercial applications, DOE used saturations from CBECS for the years 1999 and 2003. DOE maintained the growth in saturation seen between 1999 and 2003 for subsequent years.

Figure 9.3.9 presents the forecast for saturation of compact refrigerators (in terms of percent of new buildings with 1 or more units) for the three market segments for new construction.

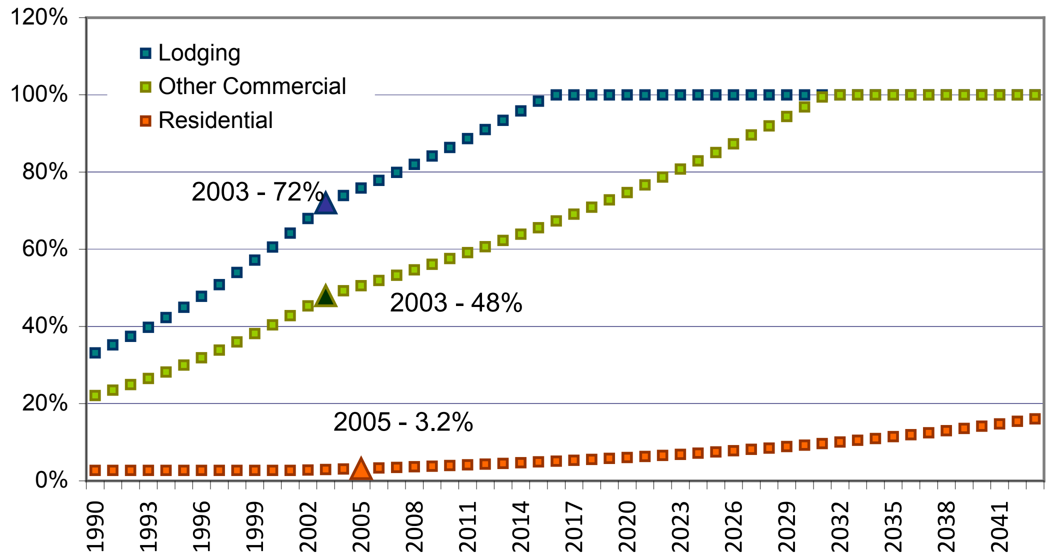

Figure 9.3.9 Forecast of Saturation of Compact Refrigerators in New Construction Market Segments

Model Calibration. To better match modeled shipments with the historical shipments data, DOE first estimated the compact refrigerator stock (number of units) for 2003. DOE estimated the 2003 residential stock from various years of RECS. As mentioned earlier, DOE obtained the compact refrigerator saturation data for the lodging sector from the ALA. For other commercial applications, DOE utilized saturations from CBECS for the years 1999 and 2003. CBECS data does not specify the size of the residential style refrigerators in commercial establishments. In order to put an upper bound on the saturations, DOE considered the case wherein all residential style refrigerators in these establishments are compact refrigerators. This upper bound determined the maximum possible stock of compact refrigerators in other commercial establishments.

Using the above stock estimate, DOE estimated the maximum average life of a compact refrigerator to be 5.6 years.[a] In the absence of additional information, DOE made the conservative assumption of 5.6 years as the average life of a compact refrigerator. This lifetime provides a better match between modeled and historical shipments (see figure below).

Based on the above sources, DOE estimated that in 2003 the compact refrigerator stock was split 30 percent, 18 percent, and 52 percent between residential, lodging, and other commercial sectors, respectively.

Shipments Forecast by Market Segment. Figure 9.3.10 shows the forecasted shipments of compact refrigerators in the base case, disaggregated into modeled market segments, along with the historical shipments. DOE did not attempt to match its total modeled shipments with the spike in historical shipments seen in 2003-2006.

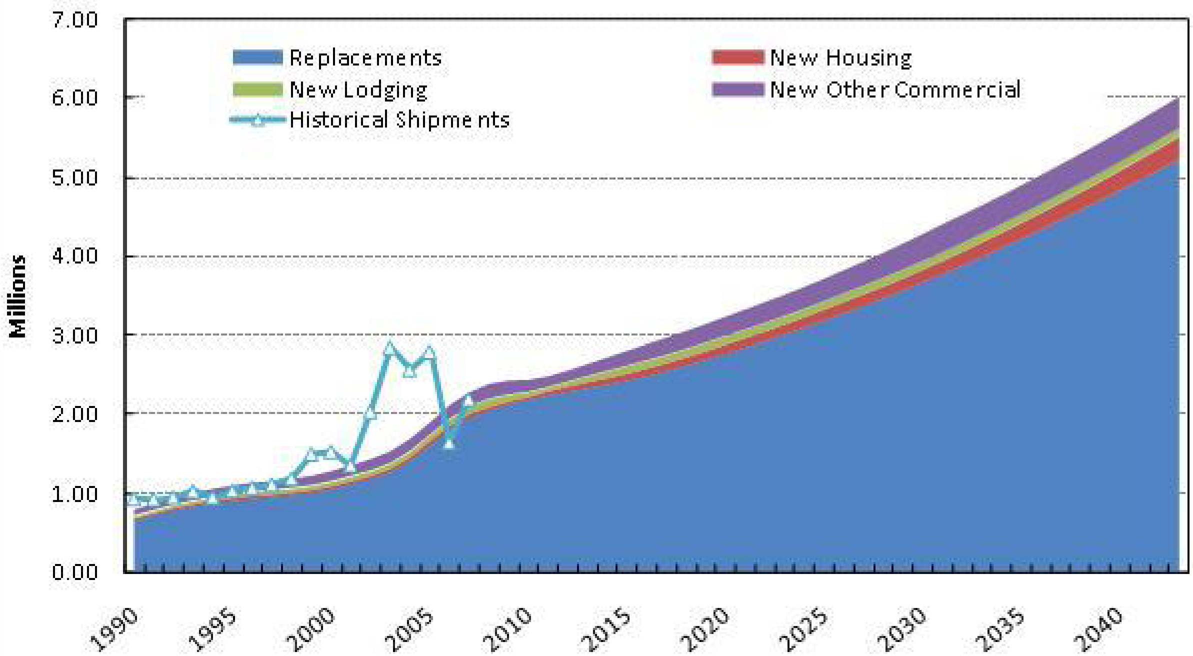

Figure 9.3.10 Compact Refrigerators: Base Case Shipments Forecast by Market Segment

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[a] In DOE's stock accounting model based on historical shipments and stock in residential and lodging sectors, a lower saturation of compacts in other commercial establishments would imply a shorter average life for a compact refrigerator.

9.3.3.2 Disaggregation into Compact Refrigerator Product Classes

DOE based its product class market shares for compact refrigerators on data submitted by AHAM[7] and California Energy Commission (CEC) data[12] on available compact refrigerator models. Table 9.3.5 presents the market share forecast used for disaggregating total modeled shipments. DOE used these estimated market shares throughout the forecast period.

Table 9.3.4 Product Class Market Shares of Compact Refrigerators

Year	PC11 + PC11A	PC12	PC13 + PC13I	PC13A	PC14 + PC14I	PC15 + PC15I
2008	84.4%	5.9%	0.9%	8.1%	0.3%	0.3%

9.3.4 Compact Freezers

DOE's shipments model uses the aggregate shipments of compact freezers as the basis for its forecasts. DOE used various data and assumptions to disaggregate total shipments into the three product classes of compact freezers considered in this analysis.

To start, DOE developed historical shipments data (domestic shipments and imports) based on data submitted by AHAM[7] and various issues of *Appliance* magazine.[2,9] These data are shown in Figure 9.3.12 below.

9.3.4.1 Market Segments

The market for compact freezers is primarily comprised of replacement units for products that have been retired from service and units purchased by new owners (not just new construction) in both residential and commercial sectors. Total compact freezer shipments are represented by the following equation:

$$Ship_{CF}(j) = Rpl_{CF}(j) + NR_{CF}(j) + NC_{CF}(j)$$

Where:

$Ship_{CF}(j)$ = total shipments of compact freezers in year *j*,
$Rpl_{CF}(j)$ = replacement shipments in year *j*,
$NR_{CF}(j)$ = shipments to new residential owners in year *j*, and
$NC_{CF}(j)$ = shipments to new commercial owners in year *j*.

The following sections discuss these markets in further detail.

Replacements. DOE determined shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. DOE integrated historical shipments to estimate each year's stock of compact freezers by vintage. Over time, some units are retired and removed from the stock, triggering the shipment of a replacement unit. A certain percentage of units will fail each year and need to be replaced. To determine when a compact freezer fails, DOE used a product survival function based on a lifetime distribution with an average value of 7.5 years. Chapter 8 provides a more thorough discussion of product lifetimes for compact freezers. Figure 9.3.11 shows the survival and retirement functions that DOE used to estimate shipments of replacement units.

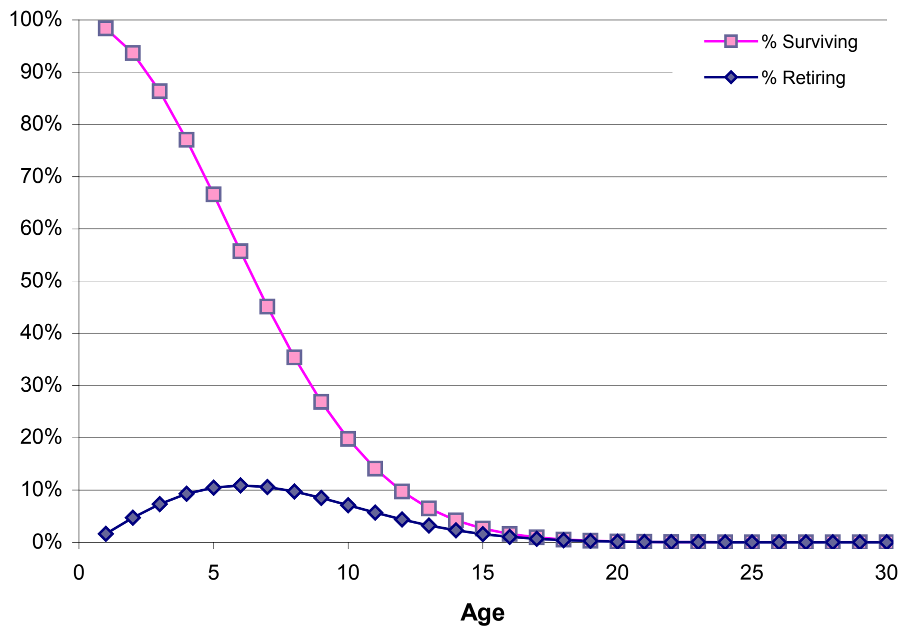

Figure 9.3.11 Compact Freezers: Survival and Retirement Functions

New Owners. In the absence of data on saturation of compact freezers in homes or commercial applications, DOE estimated historical shipments to new owners based on the difference between total historical shipments of compact freezers and estimated replacement shipments. DOE forecast new owner shipments in each year using a 3-year moving average method. DOE assumed an even split between residential and commercial new owners for this segment.

Shipments Forecast by Market Segment. Figure 9.3.12 shows the forecasted shipments of compact freezers in the base case (without amended energy conservation standards), disaggregated into modeled market segments, along with the historical shipments.

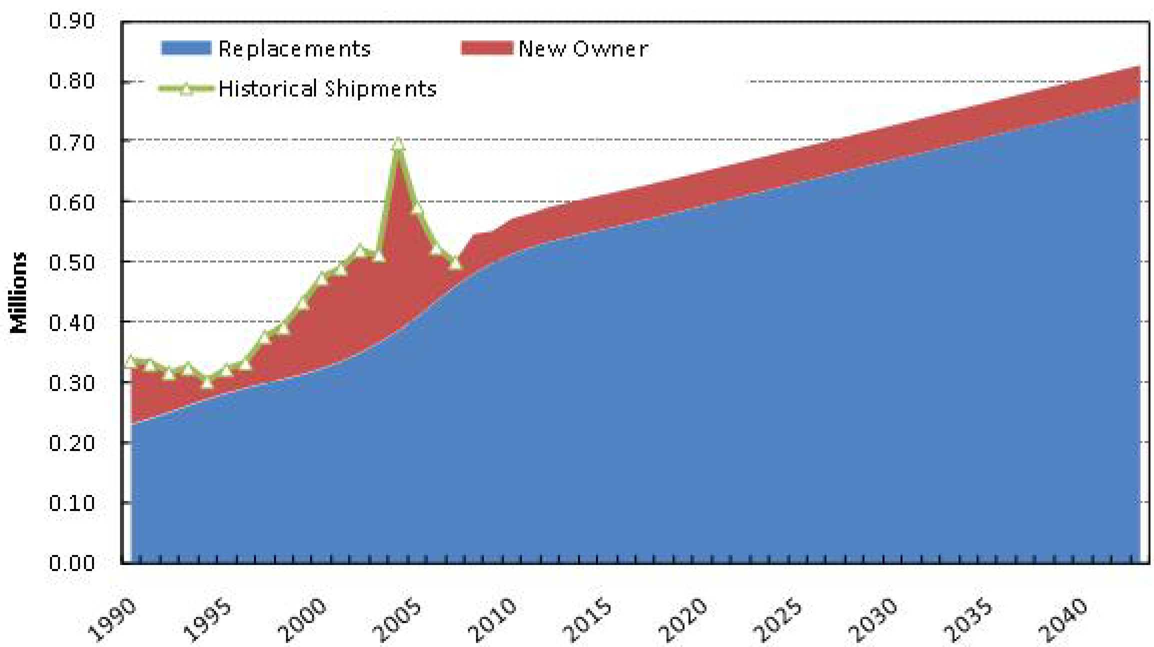

Figure 9.3.12 Compact Freezers: Historical and Base Case Shipments Forecast by Market Segment

9.3.4.2 Disaggregation into Compact Freezer Product Classes

DOE used CEC data on the number of available freezer models[13] to estimate market shares of product classes 16, 17, and 18. Table 9.3.6 presents the market share forecast used throughout the forecast period for disaggregating total modeled shipments.

Table 9.3.5 Product Class Market Shares of Compact Freezers

PC16	PC17	PC18
50.0%	30.0%	20.0%

9.4 IMPACT OF ENERGY CONSERVATION STANDARDS ON SHIPMENTS

DOE projects that appliance standards often result in an increase in the price of the product. Economic theory suggests that, all else being equal, an increase in the price of a normal good would lead to a decrease in demand for it. DOE conducted a literature review and an analysis of appliance price and efficiency data to estimate the effects on product shipments from increases in product price. DOE also considered the decreases in operating costs from higher energy efficiency and changes over time in household income. Appendix 9-A provides a detailed explanation of the methodology DOE used to quantify the impacts of these variables on shipments.

In the literature, DOE found only a few studies of appliance markets that are relevant to the issue at hand. DOE identified no studies that use time-series data of product price and shipments data after 1980. The information that can be summarized from the literature suggests that the demand for appliances is price-inelastic. Other information in the literature suggests that appliances are a normal good, such that rising incomes increase the demand for appliances. Finally, the literature suggests that market behavior indicates relatively high "implicit discount rates" when comparing appliance prices and appliance operating costs.[b]

DOE found insufficient data on product purchase price and operating cost to perform a thorough analysis of dynamic changes in the appliance market. Instead, it used purchase price and efficiency data specific to residential refrigerators, clothes washers, and dishwashers over the period 1980–2002 to evaluate broad market trends and conduct simple regression analyses. These data indicate that there has been a rise in appliance shipments and a decline in appliance purchase price and operating costs over the time period. Household income has also risen during this time.

To simplify the analysis, DOE combined the available economic information into one variable, termed the *relative price*, and used this variable in an analysis of market trends, as well as to conduct a regression analysis. The *relative price* is defined with the following expression:

$$RP = \frac{TP}{Income} = \frac{PP + PVOC}{Income}$$

[b] A high implicit discount rate with regard to operating costs means that, based on market behavior, consumers appear to put relatively low economic value on the operating cost savings realized from more-efficient appliances. A high value may indicate lack of information, risk aversion and other factors as well as the value consumers place on savings accrued in the future.

Where:

RP =	Relative price,
TP =	Total price,
Income =	Household income,
PP =	Appliance purchase price, and
PVOC =	Present value of operating cost.

DOE used an "implicit discount rate" of 37 percent to determine the present value of operating costs. This value is an average from values derived by several studies described in a 1985 journal article.[14]

DOE's regression analysis yields a *relative price* elasticity of demand, averaged over the three appliances, of -0.34. For example, a *relative price* increase of 10 percent results in a 3.4 percent decrease in shipments. Note that because the *relative price* elasticity incorporates the impacts from three effects (i.e., purchase price, operating cost, and household income), the impact from any single effect is somewhat mitigated by changes from the other two effects.

The *relative price* elasticity of -0.34 is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using simple statistical analysis. More importantly, the measure is based on an assumption that economic variables, including purchase price, operating costs, and household income, explain most of the trend in appliances per household in the United States since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but DOE did not account for them in this analysis. Despite these uncertainties, DOE believes that its estimate of the relative price elasticity of demand provides a reasonable assessment of the impact that purchase price, operating cost, and household income have on product shipments.

DOE considers the *relative price* elasticity provided by the preceding analysis to be a short-run value. Because DOE's forecasts of shipments and national impacts due to standards is over a 30-year time period, it needed to consider how the *relative price* elasticity is affected once a new standard takes effect. It was unable to identify sources specific to household durable goods, such as appliances, to indicate how short-run and long-run price elasticities differ. To estimate how the *relative price* elasticity changes over time, DOE relied on a study pertaining to automobiles.[15] This study shows that the automobile price elasticity of demand changes in the years following a purchase price change. With increasing years after the purchase price change, the price elasticity becomes smaller (more inelastic) until it reaches a terminal value around the tenth year after the price change. Table 9.4.7 shows the relative change in the price elasticity of demand for automobiles over time. DOE developed a time series of *relative price* elasticities for home appliances based on the relative change in the automobile price elasticity of demand. For years not shown in the table, DOE performed a linear interpolation to obtain the *relative price* elasticity.

Table 9.4.1 Change in Relative Price Elasticity Following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Change in Elasticity Relative to 1st year	1.00	0.78	0.63	0.46	0.35	0.33
Relative Price Elasticity	-0.34	-0.26	-0.21	-0.16	-0.12	-0.11

9.4.1 Application of Relative Price Elasticity

DOE estimated shipments in each standards case using the *relative price* elasticities described above, along with the change in the *relative price* between a standards case and the base case. Because household income is the same in the standards case and the base case, it does not figure into the calculation of the change in the *relative price.* Note that in the following equation, the *relative price* and the *relative price* elasticity are functions of the year because both change with time.[c]

$$Ship_{STD\_p}(j) = \left(Rpl_{BASE\_p}(j) + NI_{BASE\_p}(j) + M_{BASE\_p}(j)\right) \times \left(1 - e_{RP}(j) \times \Delta RP(j)\right)$$

Where:

$Ship_{STD\_p}(j)$ = total shipments under the standards case of product p in year j,
$Rpl_{BASE\_p}(j)$ = units of product p under the base case retired and replaced in year j,
$NI_{BASE\_p}(j)$ = number of new construction installations under the base case of product p in year j,
$M_{BASE\_p}(j)$ = units installed in market M under the base case of product p in year j (M represents purchases for existing homes for standard-size freezers, and purchase of an additional refrigerator for standard-size refrigerators),
$e_{RP}(j)$= *relative price* elasticity in year j (equals -0.34 for year 1), and
$\Delta RP(j)$= change in *relative price* due to a standard level in year j.

9.5 AFFECTED STOCK

In addition to the forecast of product shipments under both the base case and the standards case, the affected stock is a key output of DOE's shipments models. The affected stock (stock that is affected by a standards level) consists of those in-service units that are purchased in or after the year the standard has taken effect, as described by the following equation:

$$Aff\ Stock_p(j) = Ship_p(j) + \sum_{age=1}^{j - Std\_yr} Stock_p(age)$$

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[c] The *relative price* changes slightly over time because the lifetime operating costs are different for each vintage in the forecast period. Operating costs change slightly because forecasted energy prices are changing.

Where:

$Aff\ Stock_p(j)$ = affected stock of units of product p of all vintages that are in service in year j,
$Ship_p(j)$ = shipments of product p in year j,
$Stock_p(j)$ = stock of units of product p of all vintages that are in service in year j,
age = age of the units (years), and
Std_yr = effective date of the standard.

For its analysis, DOE assumed that amended energy conservation standards will become effective in 2014. Thus, all appliances purchased starting in 2014 are affected by the standard level.

9.6 SHIPMENTS FORECASTS IN STANDARDS CASES

This section presents the shipments forecasts for the trial standard levels that DOE considered for each of the refrigeration product types, as well as for the base case. The TSLs, which consist of a combination of specific efficiency levels for each product class, are described in chapter 10. The differences between the base case and standards case shipments forecasts represent the annual shipments reductions attributable to the standard levels.

Figure 9.6.1 shows the standard-size refrigerator-freezer shipment forecasts for the base case and the considered TSLs.

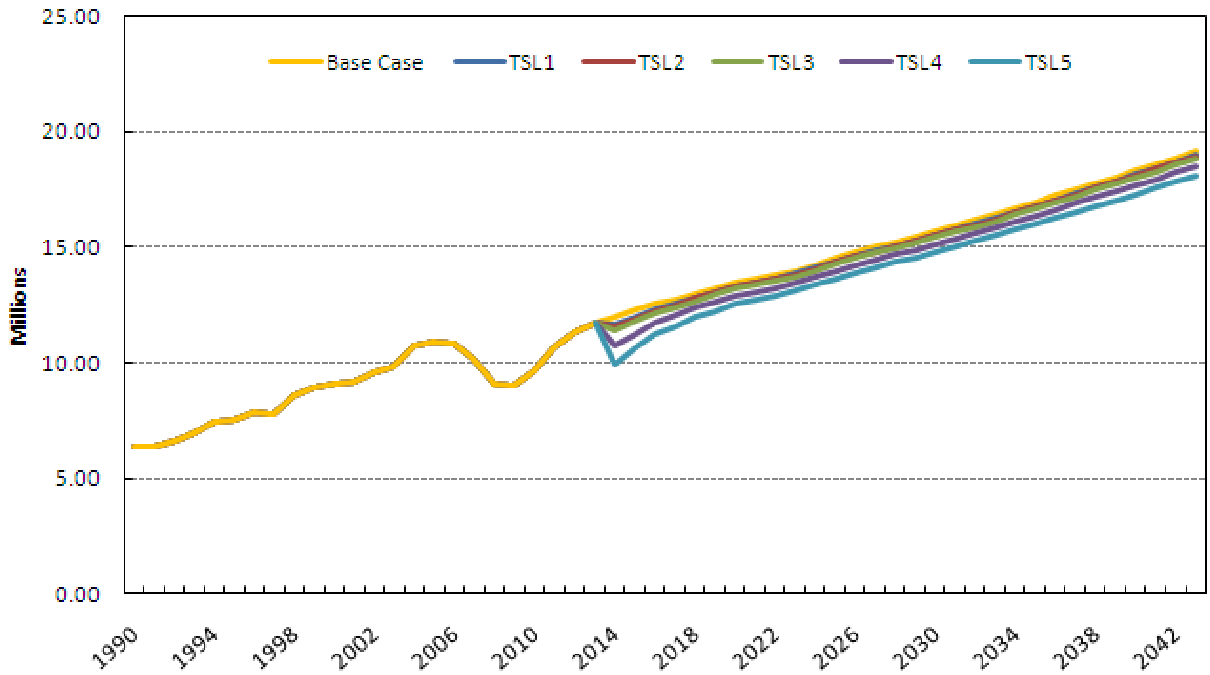

Figure 9.6.1 Standard-Size Refrigerator-Freezers: Base Case and Standards Case Shipments Forecasts

Figure 9.6.2 shows the standard-size freezer shipment forecasts for the base case and the considered TSLs.

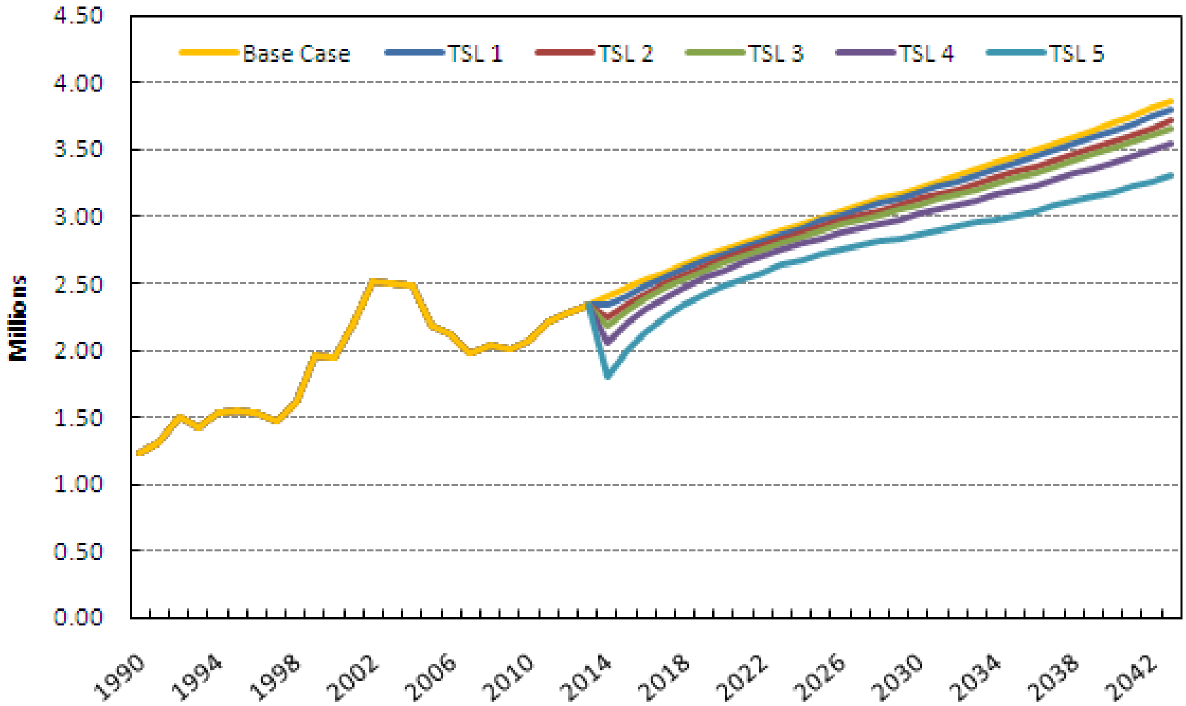

Figure 9.6.2 Standard-size Freezers: Base Case and Standards Case Shipments Forecasts

Figure 9.6.3 shows the compact refrigerator shipment forecasts for the base case and the considered TSLs.

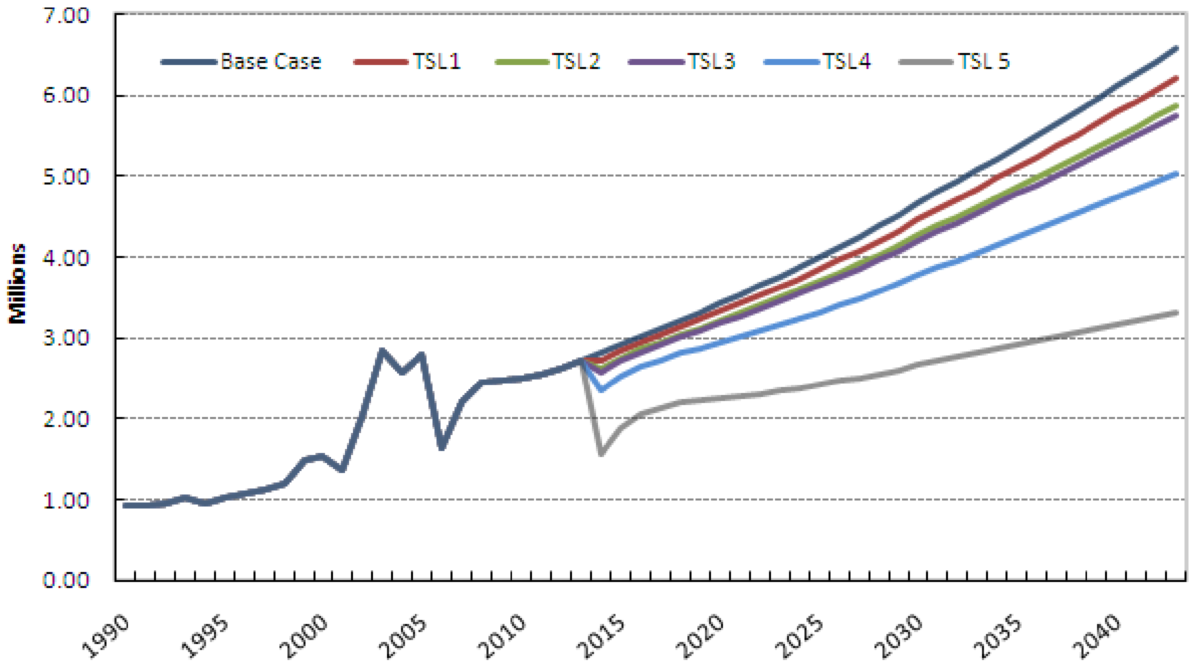

Figure 9.6.3 Compact Refrigerators: Base Case and Standards Case Shipments Forecasts

Figure 9.6.4 shows the compact freezer shipment forecasts for the base case and the considered TSLs.

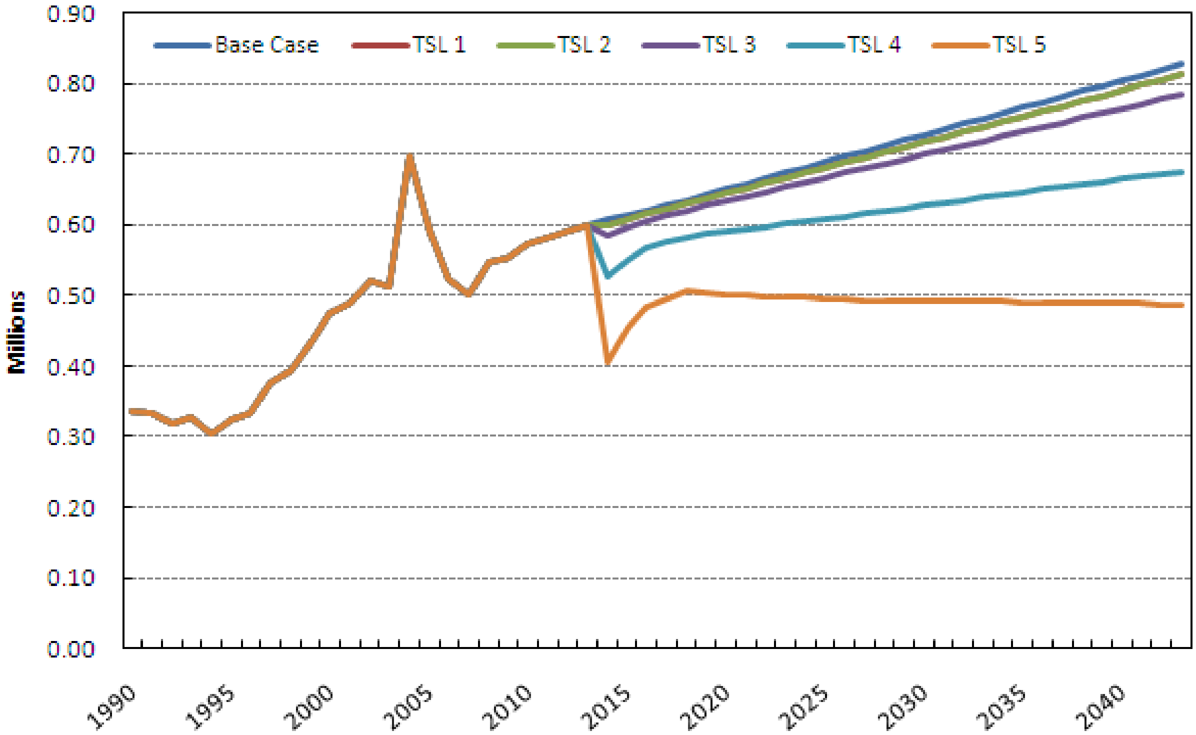

Figure 9.6.4 Compact Freezers: Base Case and Standards Case Shipments Forecasts

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CHAPTER 10: NATIONAL IMPACT ANALYSIS

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CHAPTER 10. NATIONAL IMPACT ANALYSIS

10.1 INTRODUCTION

This chapter describes the method the U.S. Department of Energy (DOE) used to conduct a national impacts analysis (NIA) of potential standard levels for residential refrigeration products. DOE evaluated the following impacts: (1) national energy savings (NES) attributable to each possible standard, (2) monetary value of those energy savings to consumers of the considered products, (3) increased total installed cost of the products because of standards, and (4) net present value (NPV) of energy savings (the difference between the value of energy savings and increased total installed cost).

DOE determined both the NES and NPV for all the efficiency levels considered for residential refrigeration products. DOE performed all calculations for each considered product using a Microsoft Excel spreadsheet model, which is accessible on the Internet. <www.eere.energy.gov/buildings/appliance_standards/> The spreadsheets combine the calculations for determining the NES and NPV for each considered product with input from the appropriate shipments model. As discussed in chapter 16, the NIA model also performs the calculations for the Regulatory Impact Analysis. Details and instructions for using the NIA model are provided in appendix 10-A.

Chapter 9 provides a detailed description of the shipments models that DOE used to forecast future purchases of the considered products. Chapter 9 includes a description of the sensitivity of shipments to total installed cost and operating cost, and how DOE captured those sensitivities within the model.

In its NOPR and final rule analysis, DOE studied 11 representative product classes in detail. For the NIA, each of these classes represents a product category that also contains other product classes. DOE assigned each of the product classes to one of these 11 product categories. To estimate the national impacts of potential standards for all the product classes considered in this rulemaking, DOE applied the product cost and annual energy consumption of each representative product class to all product classes within its category. The following list indicates which product classes are associated with each product category for purposes of analysis. In each case, the cost curve for the representative product class provided the best match for the other classes with which it is associated.

- Top-mount refrigerator-freezers: product classes 1, 1A, 2, 3, 3A, 3I and 6; represented by product class 3.
- Bottom-mount refrigerator-freezers: product classes 5, 5A and 5I; represented by product class 5.
- Side-by-side refrigerator-freezers: product classes 4, 4I and 7; represented by product class 7.

- Upright freezers: product class 9 and 9I, represented by product class 9.
- Chest freezers: product classes 8,[a] 10, and 10A; represented by product class 10.
- Compact refrigerators: product classes 11, 11A, and 12; represented by product class 11.
- Compact freezers: product classes 16, 17, and 18, and also 13, 13I, 13A, 14, 14I, 14 and 15I[b]; represented by product class 18.
- Built-in all refrigerators: product class 3A-BI only.
- Built-in bottom-mount refrigerator-freezers: product classes 5-BI and 5I-BI; represented by product class 5-BI.
- Built-in side-by-side refrigerator-freezers: product classes 4-BI, 4I-BI and 7-BI; represented by product class 7-BI.
- Built-in upright freezers: product class 9-BI and 9I-BI, represented by product class 9-BI.

In the presentation of NIA results, DOE groups the product classes according to type of refrigeration product and door style. That is, upright freezers are all grouped together, as are compact refrigerators.

10.1.1 Alternative Scenarios

The results in this chapter were calculated using selected inputs from the Reference case in EIA's *Annual Energy Outlook 2010* (*AEO 2010*).[1] DOE also calculated NIA results using inputs from the High Economic Growth case and the Low Economic Growth case in *AEO 2010.* Appendix 10-B presents the NIA results in the alternative economic growth cases.

10.2 FORECASTED EFFICIENCIES FOR BASE AND STANDARDS CASES

A key factor in estimating NES and NPV is the trend in energy efficiency forecasted for the base case (without new standards) and each of the standards cases. In calculating the NES, per-unit annual energy consumption is a direct function of product efficiency. For the NPV, two inputs depend on efficiency. The first input, the per-unit total installed cost, is a direct function of efficiency. The per-unit annual operating cost, because it is a function of the per-unit annual consumption, is indirectly dependent on product efficiency. This section describes the method DOE used to forecast the energy efficiency distribution of the considered products under the base case and each of the potential standards cases.

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[a] Product class 8, "upright freezers with manual defrost," is grouped with the "chest freezer" category because products in this class are more technologically similar to chest freezers.

[b] Product classes 13, 13I, 13A, 14, 14I, 15 and 15I (compact refrigerators and refrigerator-freezers) are grouped with the "compact freezer" category because products in this class are more technologically similar to compact freezers.

10.2.1 Method and Assumptions

10.2.1.1 Base Case

The base-case efficiency distribution projected for 2014 was described in chapter 8. The distribution was largely based on ENERGY STAR market shares for each product class. To project the distribution after 2014, DOE considered the potential for changes in ENERGY STAR qualification levels. DOE assumed that, in the absence of a new standard, the ENERGY STAR program would consider revision of its qualification levels regardless of the market share in 2014. The ENERGY STAR program uses several criteria when setting a minimum product efficiency level for qualification. One important factor is that the average payback period compared to the current standard level should not exceed 5 years. Using the payback period calculation described in chapter 8, DOE applied this criterion to all product classes in order to evaluate whether the current ENERGY STAR efficiency levels might be increased in the future.

Tables 10.2.1, 10.2.2 and 10.2.3 show the payback period relative to the baseline efficiency level (current standard). For standard-sized refrigerator-freezers, the highest efficiency level with a payback period of 5 years or less corresponds to the current ENERGY STAR level for product classes 5 and 7, but for product class 3, it corresponds to the 15% efficiency level, which is lower than the current ENERGY STAR level. Because it is unlikely that the ENERGY STAR program would reduce its qualifying efficiency level, DOE assumed the efficiency level would not be reduced (from 20% less than baseline) for product class 3. Thus, for standard-sized refrigerator-freezers, DOE assumed no change in the ENERGY STAR levels in the base case.

Table 10.2.1 Standard-Size Refrigerator-Freezers: Average Payback Period Relative to Current Standard Level by Efficiency Level

	Payback period (years)		
Efficiency Level ***(% less than baseline energy use***	**Product Class 3: Top-Mount Refrigerator-Freezer**	**Product Class 5: Bottom-Mount Refrigerator-Freezer**	**Product Class 7: Side-by-Side Refrigerator-Freezer with TTD**
1 (10)	2.5	2.3	1.4
2 (15)	**2.8**††	2.5	2.2
3 (20)*	10.1	**4.6**††	**4.6**††
4 (25)	10.9	16.7	11.0
5 (30)	15.1	24.4	18.4
6 (36/36/33)†	19.9	28.0	21.8

* Meets current ENERGY STAR criteria.
† Energy savings relative to baseline varies with product class.
†† Indicates maximum efficiency level with payback period of 5 years or less.

For standard-sized freezers, DOE found that an efficiency level of 20% below baseline was justified using the 5-year payback criterion, higher than the current ENERGY STAR level of 10%. Thus, for standard-sized freezers, DOE assumed the ENERGY STAR efficiency level would increase to level 3 starting in 2014.

For compact refrigeration products, DOE found that for product class 11, an efficiency level of 30% below baseline was justified using the 5-year payback criterion, higher than the current 20% qualifying level. For product class 18, an efficiency level of only 15% was justified. However, as for product class 3 above, DOE assumed the ENERGY STAR level for product class 18 would not be reduced from the current 20% level. Thus, DOE assumed the ENERGY STAR efficiency level will increase to level 5 for product class 11, but will not change for product class 18.

Table 10.2.2 Standard-Size Freezers: Average Payback Period Relative to Current Standard Level by Efficiency Level

	Payback period (years)	
Efficiency Level ***(% less than baseline energy use***	**Product Class 9: Upright Freezer**	**Product Class 10: Chest Freezer**
1 (10)*	2.2	2.3
2 (15)	4.4	3.8
3 (20)	**4.8****	**4.6****
4 (25)	5.7	9.5
5 (30)	6.2	9.8
6 (35)	8.3	14.6
7 (40/41)†	11.1	21.2
8 (44)	17.4	n/a

* Meets current ENERGY STAR criteria.
** Indicates maximum efficiency level with payback period of 5 years or less.
† Energy savings relative to baseline varies with product class

Table 10.2.3 Compact Refrigeration Products: Average Payback Period Relative to Current Standard Level by Efficiency Level

	Payback period (years)	
Efficiency Level ***(% less than baseline energy use)***	**Product Class 11: Compact Refrigerators**	**Product Class 18: Compact Freezers**
1 (10)	1.7	2.2
2 (15)	2.0	**4.3****
3 (20)*	2.4	10.0
4 (25)	3.4	9.2
5 (30)	**3.8****	11.6
6 (35)	5.9	10.5
7 (40/42) †	5.7	14.5
8 (45)	7.5	n/a
9 (50)	7.9	n/a
10 (59)	10.1	n/a

* Meets current ENERGY STAR criteria.
**Indicates maximum efficiency level with payback period of 5 years or less.
† Energy savings relative to baseline varies with product class

In projecting the market shares for ENERGY STAR standard-sized refrigerator-freezers beyond 2014, DOE examined historical trends, and estimated that ENERGY STAR market shares would reach the 2007 levels (at the older ENERGY STAR efficiency level) by 2021, except in the case of product class 7, where the projected 2014 market share exceeds the 2007 market share. In the latter case, DOE assumed no change in ENERGY STAR market shares. The projected shares are given in Table 10.2.4.

Table 10.2.4 Standard-Size Refrigerator-Freezers: Base-Case Efficiency Distributions

Efficiency Level ***(% less than baseline energy use)***	**Product Class 3: Top-Mount Refrigerator-Freezer**			**Product Class 5: Bottom-Mount Refrigerator-Freezer**			**Product Class 7: Side-by-Side Refrigerator-Freezer with TTD***		
	Market Share %			**Market Share %**			**Market Share %**		
	2007	**2014**	**2021**	**2007**	**2014**	**2021**	**2007**	**2014**	**2021**

Baseline	80.6	78.2	80.6	11.8	13.0	11.8	25.0	21.7	21.7
1 (10)	5.9	4.2	5.9	0.1	0.1	0.1	43.0	26.4	26.4
2 (15)	13.2	9.4	0.1	69.8	19.3	0.0	30.3	15.0	15.0
3 (20)	**0.2**†	**8.3**†	**13.4**†	**18.3**†	**67.7**†	**88.1**†	**1.7**†	**37.0**†	**37.0**†
4 (25)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 and higher	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* Through-the-door ice service.
† Meets current (2008) ENERGY STAR criteria.

For standard-sized freezers, DOE assumed there would be a linear increase in ENERGY STAR market share, reaching in 2021 the average of the 2007 shares (at the older ENERGY STAR efficiency level) and the projected new ENERGY STAR market share levels in 2014. See Table 10.2.5.

Table 10.2.5 Standard-Size Freezers: Base-Case Efficiency Distributions

Efficiency Level ***(% less than baseline energy use)***	**Product Class 9: Upright Freezer**			**Product Class 10: Chest Freezer**		
	Market Share %			**Market Share %**		
	2007	**2014**	**2021**	**2007**	**2014**	**2021**
Baseline	81.5	81.5	81.5	84.6	84.6	84.6
1 (10)	**17.0***	17.0	8.5	**14.3***	14.3	7.2
2 (15)	1.0	1.0	0.5	0.8	0.8	0.4
3 (20)	0.1	**0.1**†	**9.1**†	0.0	**0.0**†	**7.6**†
4 (25)	0.2	0.2	0.2	0.0	0.0	0.0
5 (30)	0.2	0.2	0.2	0.0	0.0	0.0
6 (35)	0.0	0.0	0.0	0.4	0.4	0.4
7 and higher	0.0	0.0	0.0	0.0	0.0	0.0

* Meets current ENERGY STAR criteria.
† Meets projected new ENERGY STAR criteria.

For compact refrigeration products, for product class 11, DOE assumed there would be only a slight increase in ENERGY STAR market share between 2014 and 2021 because of the relatively high ENERGY STAR level (30% below baseline). For product class 18, DOE assumed no change in market share beyond 2014. See Table 10.2.6.

Table 10.2.6 Compact Refrigeration Products: Base-Case Efficiency Distributions

Efficiency Level *(% less than baseline energy use)*	**Product Class 11: Compact Refrigerator**			**Product Class 18: Compact Freezer**		
	Market Share %			**Market Share %**		
	2007	**2014**	**2021**	**2007**	**2014**	**2021**
Baseline	97.1	98.5	98.5	95.4	95.4	95.4
1 (10)	0.3	0.3	0.3	4.6	4.6	4.6
2 (15)	0.0	0.0	0.0	0.0	0.0	0.0
3 (20)	**0.9***	0.5	0.2	**0.0***	**0.0***	**0.0***
4 (25)	0.2	0.1	0.1	0.0	0.0	0.0
5 (30)	1.5	**0.8** †	**1.0** †	0.0	0.0	0.0
6 and higher	0.0	0.0	0.0	0.0	0.0	0.0

* Meets current ENERGY STAR criteria.
† Meets projected new ENERGY STAR criteria.

For all product classes, rather than make long-run projections based on limited information, DOE assumed there would be no further change in market shares between 2021 and the end of the forecast period. DOE recognizes that some change in shares is likely to occur in reality. However, since DOE uses the same assumption in the standards cases, the accuracy of the assumption makes no difference to the analysis of energy savings.

10.2.1.2 Standards Cases

To determine efficiency distributions for cases in which a potential standard applies for 2014 and beyond, DOE assumed that product efficiencies in the base case that did not meet the standard under consideration would roll up to meet the new standard in 2014. DOE further assumed that the ENERGY STAR program will continue to promote high-efficiency appliances after revised standards are introduced in 2014, and that product market shares above a given standard level may shift.

As it did for the base case, DOE assumed that in the case of amended standards, the ENERGY STAR program would re-evaluate its qualifying levels for all product classes in 2014 using the 5-year payback period criterion. For each candidate standard level (CSL), DOE identified the maximum efficiency level with a payback of 5 years or less, relative to the lowest efficiency level at each CSL. If such a level was below the current ENERGY STAR level, DOE maintained the current level. At higher CSLs, there becomes a point at which no efficiency level has a payback period of less than 5 years. DOE assumed that the ENERGY STAR program would be suspended with standards at higher CSLs on a product-class specific basis. This occurs for all product classes at CSL 3 and above; for product classes 9 and 10, it occurs at lower CSLs.

In projecting ENERGY STAR market shares beyond 2014, DOE used a similar approach as described above for the base case. To maintain consistency with the base case, for the standards cases DOE assumed that after 2021 the market shares at each efficiency level would remain constant at the 2021 values.

Tables 10.2.7 through 10.2.12 show the efficiency distributions for 2014 and 2021 that DOE used for the standard-size refrigerator-freezer product classes under each standards case. The tables include the shipment-weighted energy use factor (SWEUF) associated with each standards case.

Table 10.2.7 Top-Mount Refrigerator-Freezers: Efficiency Distributions in 2014 for Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %						
		Base Case	Standard at Efficiency Level:					
			1	2	3	4	5	6
Baseline	1.00	78.2	-	-	-	-	-	-
1 (10)	0.90	4.2	82.3	-	-	-	-	-
2 (15)	0.85	9.4	9.4	91.7	-	-	-	-
3 (20)	0.80	8.3	8.3	8.3	100.0	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (36)	0.64	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.965	0.887	0.846	0.800	0.750	0.700	0.640

Table 10.2.8 Top-Mount Refrigerator-Freezers: Efficiency Distributions in 2021 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %						
		Base Case	Standard at Efficiency Level:					
			1	2	3	4	5	6
Baseline	1.00	80.6			-	-	-	-
1 (10)	0.90	5.9	86.5		-	-	-	-
2 (15)	0.85	0.1	0.1	86.6	-	-	-	-
3 (20)	0.80	13.4	13.4	13.4	100.0	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (36)	0.64	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SWEUF		0.967	0.887	0.843	0.800	0.750	0.700	0.640

Table 10.2.9 Bottom-Mount Refrigerator-Freezers: Efficiency Distributions in 2014 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %						
		Base Case	Standard at Efficiency Level:					
			1	2	3	4	5	6
Baseline	1.00	13.0	-	-	-	-	-	-
1 (10)	0.90	0.1	13.1	-	-	-	-	-
2 (15)	0.85	19.3	19.3	32.4	-	-	-	-
3 (20)	0.80	67.7	67.7	67.7	100.0	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (36)	0.64	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SWEUF		0.836	0.823	0.816	0.800	0.750	0.700	0.640

Table 10.2.10 Bottom-Mount Refrigerator-Freezers: Efficiency Distributions in 2021 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %						
			Standard at Efficiency Level:					
		Base Case	1	2	3	4	5	6
Baseline	1.00	11.8			-	-	-	-
1 (10)	0.90	0.1	11.9		-	-	-	-
2 (15)	0.85	0.0	0.0	11.9	-	-	-	-
3 (20)	0.80	88.1	88.1	88.1	100.0	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (36)	0.64	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.824	0.812	0.806	0.800	0.750	0.700	0.640

Table 10.2.11 Side-by Side Refrigerator-Freezers: Efficiency Distributions in 2014 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %						
			Standard at Efficiency Level:					
		Base Case	1	2	3	4	5	6
Baseline	1.00	21.7	-	-	-	-	-	-
1 (10)	0.90	26.4	48.1	-	-	-	-	-
2 (15)	0.85	15.0	15.0	63.1	-	-	-	-
3 (20)	0.80	37.0	37.0	37.0	100.0	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (33)	0.67	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.877	0.856	0.832	0.800	0.750	0.700	0.670

Table 10.2.12 Side-by Side Refrigerator-Freezers: Efficiency Distributions in 2021 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %						
			Standard at Efficiency Level:					
		Base Case	1	2	3	4	5	6
Baseline	1.00	21.7	-	-	-	-	-	-
1 (10)	0.90	26.4	48.1	-	-	-	-	-
2 (15)	0.85	15.0	15.0	63.1	-	-	-	-
3 (20)	0.80	37.0	37.0	37.0	100.0	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (33)	0.67	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.877	0.856	0.832	0.800	0.750	0.700	0.670

Tables 10.2.13 through 10.2.16 show the efficiency distributions in 2014 and 2021 that DOE used for each standards case for the standard-sized freezer product classes. The tables include the shipment-weighted energy use factor (SWEUF) associated with each standards case.

Table 10.2.13 Upright Freezers: Efficiency Distributions in 2014 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
			Standard at Efficiency Level:							
		Base Case	1	2	3	4	5	6	7	8
Baseline	1.00	81.5	-	-	-	-	-	-	-	-
1 (10)	0.90	17.0	98.5	-	-	-	-	-	-	-
2 (15)	0.85	1.0	1.0	99.5	-	-	-	-	-	-
3 (20)	0.80	0.1	0.1	0.1	99.6	-	-	-	-	-
4 (25)	0.75	0.2	0.2	0.2	0.2	99.8	-	-	-	-
5 (30)	0.70	0.2	0.2	0.2	0.2	0.2	100.0	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (44)	0.56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.980	0.899	0.849	0.800	0.750	0.700	0.650	0.600	0.560

Table 10.2.14 Upright Freezers: Efficiency Distributions in 2021 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standard at Efficiency Level:							
			1	2	3	4	5	6	7	8
Baseline	1.00	81.5								
1 (10)	0.90	8.5	98.5							
2 (15)	0.85	0.5	1.0	99.5						
3 (20)	0.80	9.1	0.1	0.1	99.6					
4 (25)	0.75	0.2	0.2	0.2	0.2	99.8				
5 (30)	0.70	0.2	0.2	0.2	0.2	0.2	100.0			
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0		
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	
8 (44)	0.56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SWEUF		0.971	0.899	0.849	0.800	0.750	0.700	0.650	0.600	0.560

Table 10.2.15 Chest Freezers: Efficiency Distributions in 2014 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %							
		Base Case	Standard at Efficiency Level:						
			1	2	3	4	5	6	7
Baseline	1.00	84.6							
1 (10)	0.90	14.3	98.9						
2 (15)	0.85	0.8	0.8	99.7					
3 (20)	0.80	0.0	0.0	0.0	99.7				
4 (25)	0.75	0.0	0.0	0.0	0.0	99.7			
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	99.7		
6 (35)	0.65	0.4	0.4	0.4	0.4	0.4	0.4	100.0	
7 (41)	0.59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SWEUF		0.983	0.899	0.849	0.799	0.750	0.700	0.650	0.590

Table 10.2.16 Chest Freezers: Efficiency Distributions in 2021 for Candidate Standard Levels

Efficiency Level (% less than	Energy Use Factor	Market Share %							
		Base Case	Standard at Efficiency Level:						
			1	2	3	4	5	6	7

baseline energy use)									
Baseline	1.00	84.6							
1 (10)	0.90	7.2	98.8						
2 (15)	0.85	0.4	0.8	99.6					
3 (20)	0.80	7.6	0.0	0.0	99.6				
4 (25)	0.75	0.0	0.0	0.0	0.0	99.6			
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	99.6		
6 (35)	0.65	0.4	0.4	0.4	0.4	0.4	0.4	100.0	
7 (41)	0.59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SWEUF		0.976	0.899	0.849	0.799	0.750	0.700	0.650	0.590

Tables 10.2.17 and 10.2.18 show the efficiency distributions in 2014 and 2021 that DOE used for all potential standards cases for compact refrigeration product classes. The tables include the shipment-weighted energy use factor (SWEUF) associated with each standards case.

Table 10.2.17 Compact Refrigerators: Efficiency Distributions in 2014 and 2021 for Candidate Standard Levels

Efficiency Level (% less than baseline energy use)	**Energy Use Factor**	**Market Share (%)**										
			Standard at Efficiency Level:									
		Base Case	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Baseline	1.00	98.5	-	-	-	-	-	-	-	-	-	-
1 (10)	0.90	0.3	98.7	-	-	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	98.7	-	-	-	-	-	-	-	-
3 (20)	0.80	0.5	0.5	0.5	99.2	-	-	-	-	-	-	-
4 (25)	0.75	0.1	0.1	0.1	0.1	99.3	-	-	-	-	-	-
5 (30)	0.70	0.8	0.8	0.8	0.8	0.8	100.0	-	-	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
9 (50)	0.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
10 (59)	0.41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SWEUF		0.996	0.898	0.849	0.799	0.750	0.700	0.650	0.600	0.550	0.500	0.410

Table 10.2.18 Compact Freezers: Efficiency Distributions in 2014 and 2021 for Candidate Standard Levels

Efficiency	**Energy**	**Market Share %**

Level (% less than baseline energy use)	Use Factor	Base Case	Standard at Efficiency Level:						
			1	2	3	4	5	6	7
Baseline	1.00	95.4	-	-	-	-	-	-	-
1 (10)	0.90	4.6	100.0	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	100.0	-	-	-	-	-
3 (20)	0.80	0.0	0.0	0.0	100.0	-	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
7 (42)	0.58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.995	0.900	0.850	0.800	0.750	0.700	0.650	0.580

10.3 NATIONAL ENERGY SAVINGS

DOE calculated the national energy savings associated with the difference between the base case and the case associated with each potential standard for the refrigeration products considered herein. DOE calculated cumulative energy savings throughout the forecast period, which extends from 2014 to 2043.

10.3.1 Definition

The following equation shows that DOE calculated annual national energy savings (NES) as the difference between two projections: a base case (without new standards) and a standards case. Positive values of NES represent energy savings (that is, national annual energy consumption (AEC) under a standard is less than in the base case).

$$\boldsymbol{NES_y = AEC_{BASE} - AEC_{STD}}$$

Cumulative energy savings are the sum of annual national energy savings throughout the forecast period, which extends from the assumed effective date of new standards (2014) to 30 years after that date (through 2043).

DOE calculated the national annual site energy consumption by multiplying the number or stock of each product class (by vintage) by its unit energy consumption (UEC; also by vintage). The calculation of national annual energy consumption is represented by the following equation.

$$AEC_y = \sum STOCK_V \times UEC_V$$

DOE defined the quantities for the above expressions as follows.

AEC = national annual energy consumption each year in quadrillion British thermal units (quads), summed over vintages of the product stock, $STOCK_V$;
NES = annual national energy savings (quads);
$STOCK_V$ = stock of product (millions of units) of vintage *V* that survive in the year for which DOE calculated annual energy consumption;
UEC_V = annual energy consumption per product in kilowatt-hours (kWh);
V = year in which the product was purchased as a new unit; and
y = year in the forecast.

Electricity consumption is converted from site energy to source energy (quads) by applying a time-dependent conversion factor.

The stock of a product depends on annual shipments and the lifetime of the product. As described in chapter 9, DOE projected product shipments under the base case and the standards cases. DOE projected that shipments under the standards cases would be slightly lower than under the base case, because DOE believes that the higher purchase cost of more efficient products would cause some consumers to forego purchasing new products.

To avoid including savings attributable to shipments displaced because of standards, DOE used the projected standards-case shipments and, in turn, the standards-case stock, to calculate the annual energy consumption for the base case.

10.3.2 Inputs

The inputs to the calculation of national energy savings (NES) are:

- Shipments;
- product stock ($STOCK_V$);
- annual energy consumption per unit (*UEC*);
- national annual energy consumption (*AEC*); and
- site-to-source conversion factor (*src_conv*).

10.3.2.1 Shipments

DOE forecasted shipments of each considered product class under the base case and all standards cases. Several factors affect forecasted shipments, including purchase cost, operating cost, and household income. As noted earlier, the increased cost of more efficient products causes some consumers to forego buying the products. Consequently, shipments forecasted under the standards cases are lower than under the base case. The method DOE used to calculate and generate the shipments forecasts for each considered product class is described in detail in Chapter 9, Shipments Analysis.

10.3.2.2 Equipment Stock

The equipment stock in a given year is the number of products shipped from earlier years that survive in that year. The NIA model tracks the number of units shipped each year. DOE assumes that products have an increasing probability of retiring as they age. The probability of survival as a function of years since purchase is the survival function. Chapter 9 provides additional details on the survival functions that DOE used for each product.

10.3.2.3 Annual Energy Consumption per Unit

DOE used the shipment-weighted energy use factors (SWEUFs) presented in section 10.2 for the base case and standards cases, along with the data on annual energy consumption presented in chapters 7 and 8, to estimate the shipment-weighted average annual per-unit energy consumption under the base and each standards case. The average annual per-unit energy consumption projected for 2014 for each product category is shown in Tables 10.3.1 through 10.3.3.

Table 10.3.1 Standard-Size Refrigerator-Freezers: Shipment-Weighted Average Annual Energy Use in 2014 for Base and Standards Cases

	Base Case	**Standard at Efficiency Level:**					
		1	2	3	4	5	6
Top-Mount							
SWEUF	0.965	0.887	0.846	0.800	0.750	0.700	0.640
Avg. Energy Use (kWh)*	520	478	456	431	404	377	347
Bottom-Mount							
SWEUF	0.836	0.823	0.816	0.800	0.750	0.700	0.640
Avg. Energy Use (kWh)*	556	548	543	533	499	466	425
Side-by-Side							
SWEUF	0.877	0.856	0.832	0.800	0.750	0.700	0.670
Avg. Energy Use (kWh)*	716	698	679	653	612	571	547

SWEUF = shipment-weighted energy use factor
* Before applying UAF correction (which varies with product age).

Table 10.3.2 Standard-Size Freezers: Shipment-Weighted Average Annual Energy Consumption in 2014 for Base and Standards Cases

	Base Case	Standard at Efficiency Level:							
		1	2	3	4	5	6	7	8
Upright									
SWEUF	0.980	0.899	0.849	0.800	0.750	0.700	0.650	0.600	0.560
Avg. Energy Use (kWh)	671	615	582	548	514	479	445	411	386
Chest									
SWEUF	0.983	0.899	0.849	0.799	0.750	0.700	0.650	0.590	-
Avg. Energy Use (kWh)	394	360	340	320	300	280	260	235	-

SWEUF = shipment-weighted energy use factor

Table 10.3.3 Compact Refrigeration Products: Shipment-Weighted Average Energy Consumption in 2014 for Base and Standards Cases

	Base Case	Standard at Efficiency Level:									
		1	2	3	4	5	6	7	8	9	10
Refrigerator											
SWEUF	0.996	0.898	0.849	0.799	0.750	0.700	0.650	0.600	0.550	0.500	0.410
Avg. Energy Use (kWh)	326	294	278	262	246	229	213	197	180	164	135
Freezer											
SWEUF	0.995	0.900	0.850	0.800	0.750	0.700	0.650	0.580	-	-	-
Avg. Energy Use (kWh)	311	281	266	250	235	219	203	182	-	-	-

SWEUF = shipment-weighted energy use factor

10.3.2.4 National Annual Energy Consumption

The national annual energy consumption (AEC) is the product of the annual energy consumption per unit and the number of units of each vintage. This method of calculation accounts for differences in unit energy consumption from year to year. In determining national annual energy consumption, DOE first calculated annual energy consumption at the site, then applied a conversion factor, described below, to calculate primary energy consumption.

10.3.2.5 Site-to-Source Conversion Factors

In determining national annual energy consumption, DOE initially calculated the annual energy consumption at the site (for electricity, the energy in kWh consumed at the household or establishment). It then used site energy consumption to calculate primary (source) energy consumption by applying a conversion factor to account for losses associated with the generation, transmission, and distribution of electricity. The site-to-source conversion factor is a multiplicative factor used to convert site energy consumption into primary or source energy consumption, expressed in quads (quadrillion Btu's). DOE used annual site-to-source conversion factors based on the version of the National Energy Modeling System (NEMS)[c] that corresponds to *AEO 2010*. The factors are marginal values, which represent the response of the system to an incremental decrease in consumption. For electricity, the conversion factors change over time in response to projected changes in generation sources (*i.e.,* the types of power plants projected to provide electricity to the Nation). The values derived from the *AEO2010* NEMS end in 2035. DOE assumed that conversion factors remain at the 2035 values throughout the rest of the forecast.

10.4 NET PRESENT VALUE

DOE calculated the net present value (NPV) of the increased product cost and reduced operating cost associated with the difference between the base case and each potential standards case for the considered refrigeration products.

10.4.1 Definition

The NPV is the value in the present of a time-series of costs and savings. The NPV is described by the equation:

$$\boldsymbol{NPV = PVS - PVC}$$

Where:

PVS = present value of savings in operating cost, and
PVC = present value of increased total product cost to consumers.

DOE determined the *PVS* and *PVC* according to the following expressions.

$$PVS = \sum OCS_y \times DF_y$$

$$PVC = \sum TIC_y \times DF_y$$

[c] For more information on NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000), March 2000. EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on EIA assumptions, DOE refers to the model by the name NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work has been performed). NEMS-BT was previously called NEMS-BRS.

Where:

OCS = total annual savings in operating cost each year summed over vintages of the product stock, $STOCK_V$;
TIC = total annual increases in product cost each year summed over years of the product shipments, $SHIP_y$;
DF = discount factor in each year; and
y = year in the forecast.

DOE calculated the total annual consumer savings in operating cost by multiplying the number or stock of a given product class (by vintage) by its per-unit operating cost savings (also by vintage). DOE calculated the total annual increases in consumer product cost by multiplying the number or shipments of the given product class (by vintage) by its per-unit increase in consumer product cost (also by vintage). The calculation of total annual operating cost savings and total annual product cost increases is represented by the following equations.

$$OCS_y = \sum STOCK_V \times UOCS_V$$

$$TIC_y = \sum SHIP_y \times UTIC_y$$

Where:

$STOCK_V$ = stock of products of vintage V that survive in the year for which DOE calculated annual energy consumption,
$UOCS_V$ = annual per-unit savings in operating cost,
V = year in which the product was purchased as a new unit,
$SHIP_y$ = shipments of products in year y, and
$UTIC_y$ = annual per-unit increase in installed product cost in year y.

DOE determined the total increased product cost for each year from the effective date of a potential standard to 2043. It determined the present value of operating cost savings for each year from the effective date of the standard to the year when all units purchased by 2043 have been retired. DOE calculated costs and savings as the difference between a standards case and a base case without new standards.

DOE developed a discount factor from the national discount rate and the number of years between the present (*i.e.*, year to which the sum is being discounted) and the year in which the costs and savings occur. The NPV is the sum over time of the discounted net savings.

10.4.2 Inputs

The inputs to calculation of the net present value (NPV) are:

- Average annual product cost;
- average annual savings in operating cost;
- total annual increases in product cost;
- total annual savings in operating cost;
- discount factor;
- present value of costs; and
- present value of savings.

The increase in total annual product cost is equal to the annual change in the average annual product cost (difference between base case and standards case) multiplied by the shipments forecasted in the standards case. As with the calculation of the NES, DOE did not calculate total annual product costs using base-case shipments. To avoid including savings due to displaced shipments (by consumers deciding not to buy higher-cost products), DOE used the standards-case projection of shipments and, in turn, the standards-case stock, to calculate product costs.

The total annual savings in operating cost are equal to the change in annual operating cost (difference between base case and standards case) per unit multiplied by the shipments forecasted in the standards case.

10.4.2.1 Average Annual Product Cost

The average annual product cost is directly dependent on efficiency. DOE therefore used the efficiency distributions presented in section 10.2 for the base case and each standards case, along with the product costs at various efficiency levels (presented in chapter 8), to estimate the shipment-weighted average annual product cost under the base and standards cases.

Table 10.4-1 Standard-Size Refrigerator-Freezers: Shipment-Weighted Average Product Cost in 2014 for Base Case and Candidate Standard Levels

	Base Case	**Standard at Efficiency Level:**					
		1	2	3	4	5	6
Top-Mount							
SWEUF	0.965	0.887	0.846	0.800	0.750	0.700	0.640
Avg. Prod Cost (2009$)	$ 492	$503	$510	$566	$604	$688	$809
Bottom-Mount							
SWEUF	0.836	0.823	0.816	0.800	0.750	0.700	0.640
Avg. Prod Cost (2009$)	$861	$863	$864	$870	$929	$1,027	$1,162

Side-by-Side							
SWEUF	0.877	0.856	0.832	0.800	0.750	0.700	0.670
Avg. Prod Cost (2009$)	$1,044	$1,047	$1,052	$1,069	$1,128	$1,256	$1,356

Table 10.4-2 Standard-Size Freezers: Shipment-Weighted Average Product Cost in 2014 for Base Case and Candidate Standard Levels

	Base Case	Standard at Efficiency Level:							
		1	2	3	4	5	6	7	8
Upright									
SWEUF	0.980	0.899	0.849	0.800	0.750	0.700	0.650	0.600	0.560
Avg. Prod Cost (2009$)	$507	$518	$537	$554	$581	$605	$659	$734	$901
Chest									
SWEUF	0.983	0.899	0.849	0.799	0.750	0.700	0.650	0.590	-
Avg. Prod Cost (2009$)	$369	$375	$385	$395	$439	$458	$512	$623	-

Table 10.4-3 Compact Refrigerators and Freezers: Shipment-Weighted Average Product Cost in 2014 for Base Case and Candidate Standard Levels

	Base Case	Standard at Efficiency Level:									
		1	2	3	4	5	6	7	8	9	10
Refrigerator											
SWEUF	0.996	0.898	0.849	0.799	0.750	0.700	0.650	0.600	0.550	0.500	0.410
Avg. Prod Cost (2009$)	$132	$137	$141	$147	$158	$167	$193	$200	$231	$248	$309
Freezer											
SWEUF	0.995	0.900	0.850	0.800	0.750	0.700	0.650	0.580	-	-	-
Avg. Prod Cost (2009$)	$183	$190	$202	$243	$253	$283	$290	$362	-	-	-

In the NOPR analysis, DOE assumed that the manufacturer costs and retail prices of products meeting various efficiency levels remain fixed, in real terms, after 2009 (the year for which the engineering analysis estimated costs) and throughout the period of the analysis. As discussed in chapter 8, examination of historical price data for certain appliances and equipment that have been subject to energy conservation standards indicates that the assumption of constant real prices and costs may, in many cases, over-estimate long-term appliance and equipment price trends.

For the final rule, DOE applied the default product price trend based on an experience curve derived using historical data on shipments and refrigeration equipment PPI (described in chapter 8) to forecast the prices of refrigeration products sold in each year in the forecast period (2014-2043). For each type of refrigeration product, DOE applied the same values to forecast prices for each product class at each considered efficiency level. The average annual rate of price decline in the default case is 1.87 percent.

For the NIA, DOE also analyzed two sensitivity cases that use a price trend based on an exponential in time extrapolation of refrigeration equipment PPI data. DOE selected a high price decline case and a low price decline case from among a number of price trends that it analyzed (see appendix 8E of the final rule TSD). The high price decline case is based on the upper end of the 95 percent confidence interval for an exponential fit to the inflation-adjusted PPI series in 1991-2010. The low price decline case is based on the lower end of the 95 percent confidence interval for an exponential fit to the nominal PPI series in 1976-2010. The annual rate of price decline is 3.12 percent in the high price decline case and 1.14 percent in the low price decline case. Appendix 10-C presents NPV results using these price trend forecasts.

10.4.2.2 Annual Operating Cost Savings per Unit

The average annual operating cost includes the costs for energy, repair, and maintenance. As described in chapter 8, for all the considered products DOE assumed that potential standards would produce no increase in maintenance or repair costs. For all the considered products, therefore, DOE determined the per-unit annual savings in operating cost based only on the savings in energy costs attributable to a standard. DOE determined the per-unit annual savings in operating cost by multiplying the per-unit annual savings in energy consumption developed for each product class by the appropriate energy price. As described in chapter 8, DOE forecasted energy prices based on EIA's *AEO2010*.

10.4.2.3 Total Annual Increases in Product Cost

The total annual increase in product cost for any given standards case is the product of the average cost increase per unit due to the standard and the number of units of each vintage shipped. This method accounts for differences in product cost from year to year. The equation for determining the total annual increase in product cost for a given standards case, which was shown in section 10.4.1, is repeated here.

$$TIC_y = \sum SHIP_y \times UTIC_y$$

As with the calculation of the NES, DOE did not calculate total annual product costs using base-case shipments. To avoid including savings due to displaced shipments (by consumers deciding not to buy higher-cost products), DOE used the standards-case projection of shipments and, in turn, the standards-case stock, to calculate product costs.

10.4.2.4 Total Annual Savings in Operating Cost

The total annual savings in operating cost for any given standards case is the product of the annual savings in operating cost per unit attributable to the standard and the number of units of each vintage. This method accounts for differences in annual savings in operating cost from year to year. The equation for determining the total annual savings in operating cost for a given standards case, which was presented in section 10.4.1, is repeated here.

$$OCS = \sum STOCK_V \times UOCS_V$$

10.4.2.5 Discount Factor

DOE multiplied monetary values in future years by a discount factor to determine the present value. The discount factor (DF) is described by the equation:

$$\boldsymbol{DF} = \frac{1}{(1+\boldsymbol{r})^{(y-yp)}}$$

Where:

r = discount rate,
y = year in which the monetary value exists, and
y_P = year in which the present value is being determined.

Although DOE used consumer discount rates to determine the life-cycle cost of refrigeration products (chapter 8), it used national discount rates to calculate national NPV. DOE estimated NPV using both a 3-percent and a 7-percent real discount rate, in accordance with the Office of Management and Budget's guidance to Federal agencies on the development of regulatory analysis, particularly section E therein: *Identifying and Measuring Benefits and Costs*.[2] DOE defined the present year as 2010.

10.4.2.6 Present Value of Costs

The present value of increased product costs is the annual total cost increase in each year (the difference between a standards case and the base case), discounted to the present and summed throughout the period in which DOE is considering the installation of products (2014 through 2043). DOE calculated annual increases in installed cost as the difference in total product cost for new appliances purchased each year, multiplied by the shipments in the standards case.

10.4.2.7 Present Value of Savings

The present value of savings in operating cost is the annual savings on operating cost (the difference between the base case and a standards case), discounted to the present and summed from the effective date to the time when the last unit installed in 2043 is retired from service. Savings are decreases in operating cost associated with the higher energy efficiency of products purchased in the standards case compared to the base case. Total annual savings in operating cost are the savings per unit multiplied by the number of units of each vintage that survive in a particular year.

10.5 NES AND NPV RESULTS

The NIA model produces estimates of the NES and NPV attributable to a given candidate standard level. The inputs to the NIA model were discussed in sections 10.3.2 (inputs to NES) and 10.4.2 (inputs to NPV). DOE generated the NES and NPV results using a Microsoft Excel spreadsheet, which is accessible on the Internet <www.eere.energy.gov/buildings/appliance_standards/> Details regarding and instructions for using the spreadsheet are provided in appendix 10-A.

Appendix 10-B presents the NIA results calculated using inputs from the High Economic Growth case and the Low Economic Growth case from *AEO 2010*.

10.5.1 Summary of Inputs

Table 10.5.1 summarizes the inputs to the NIA model.

Table 10.5.1 Inputs to Calculation of National Energy Savings and Net Present Value

Input	Description
Shipments	Annual shipments from shipments model. (See chapter 9.)
Compliance date of standard	2014.
Base-case forecasted efficiencies	See section 10.2.
Standards-case efficiencies	See section 10.2.
Annual energy consumption per unit	Annual weighted-average values are a function of SWEUF. (See section 10.3.2.1.)
Total installed cost per unit	Annual weighted-average values are a function of the efficiency distribution. (See section 10.4.2.1.)
Energy cost per unit	Annual weighted-average values are a function of annual energy consumption per unit and energy prices. (See chapter 8 for energy prices.)
Repair and maintenance costs per unit	Annual weighted-average values are a function of the efficiency distribution.
Forecast of energy prices	Energy prices: EIA *AEO2010* forecasts (to 2035) and extrapolation thereafter. (See chapter 8.)
Site-to-source conversion factor	A time-series conversion factor that includes electric generation, transmission, and distribution losses. Conversion, which changes yearly, is generated by DOE-EIA's NEMS* program.
Discount rates	3% and 7% real.
Present year	Future expenses are discounted to 2010.

* Chapter 13, Utility Impact Analysis, provides more detail on the National Energy Modeling System (NEMS).

10.5.2 Annual Costs and Savings

Figure 10.5.1 illustrates the basic inputs to the calculation of net present value (NPV) by showing the non-discounted annual increases in product cost and annual savings in operating cost at the national level for efficiency level 3 for product class 3 (refrigerator-freezers–automatic defrost with top-mounted freezer and without through-the-door ice service). The figure also shows the net savings, which is the difference between the savings and costs for each year. The annual increase in product cost is the total cost for products purchased each year in the forecast period. The annual savings in operating cost applies to products operating in each year. The NPV is the difference between the cumulative annual discounted savings and cumulative annual discounted costs. DOE could create figures like Figure 10.5.1 for each of the considered efficiency levels for each product class.

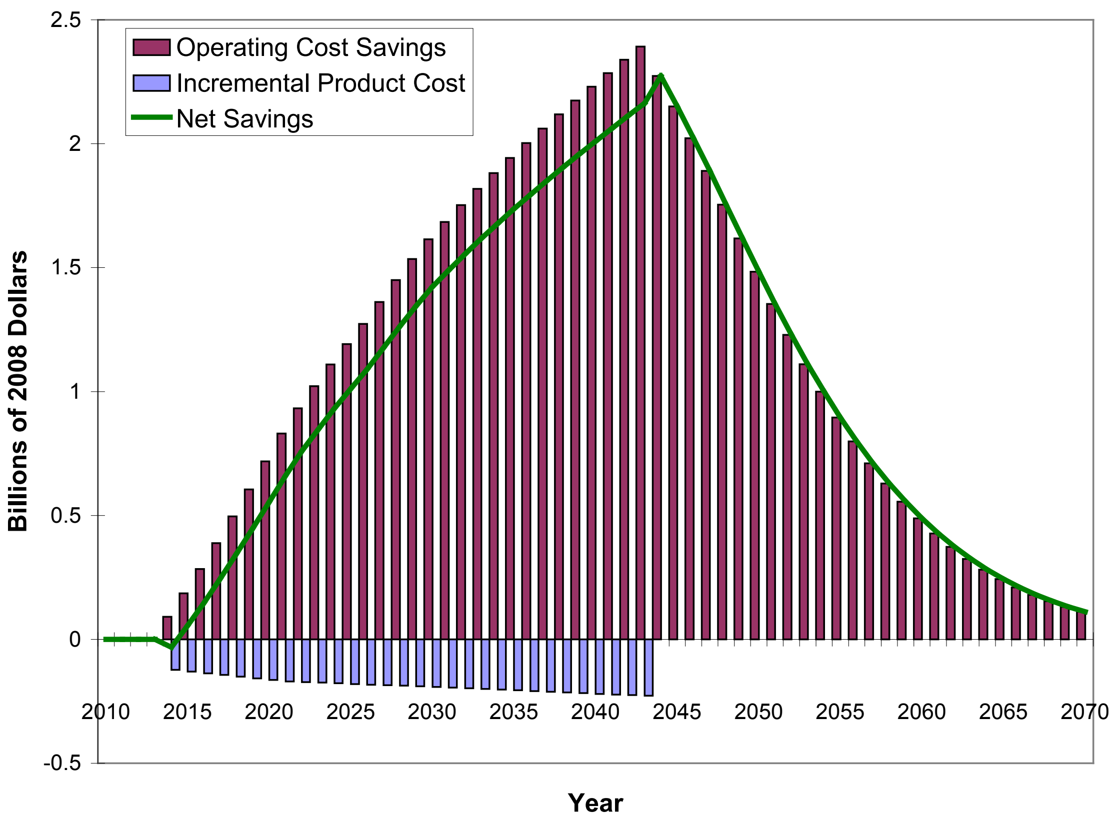

Figure 10.5.1 Non-Discounted Annual Increases in Installed Cost and Savings in Operating Cost for Product Class 3 at Efficiency Level 3

10.6 NES AND NPV RESULTS BY TRIAL STANDARD LEVEL

10.6.1 Trial Standard Levels

In considering amended standards for the NOPR, DOE created trial standard levels (TSLs) that combine specific efficiency levels across product classes. DOE analyzed the benefits and burdens of a number of TSLs for the refrigeration products that are the subject of this rulemaking. A description of each TSL DOE analyzed is provided below. DOE attempted to limit the number of TSLs considered for the NOPR by excluding efficiency levels that do not exhibit significantly different economic and/or engineering characteristics from the efficiency levels already selected as a TSL.

Table 10.6.1 presents the TSLs and the corresponding product class efficiencies for standard-size refrigerator-freezers. TSL 1 consists of those efficiency levels that meet current ENERGY STAR criteria. TSL 2 consists of the highest efficiency levels for which the consumer NPV is positive, using a 7-percent discount rate. TSL 3 consists of the highest efficiency levels for which the consumer NPV is positive, using a 3-percent discount rate, as well as the levels recommended in the Joint Comments.[d] TSL 4 consists of those efficiency levels that yield energy use 30 percent below the baseline products. TSL 5 consists of the max-tech efficiency levels.

Table 10.6.1 Trial Standard Levels for Standard-Size Refrigerator-Freezers

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	**Product classes 5, 5A, and 5I**	**Product classes 4, 4I, and 7**
	Efficiency Level (% less than baseline energy use)		
1	3 (20)	3 (20)	3 (20)
2	3(20)	3 (20)	4 (25)
3	4 (25)*	3 (20)	4 (25)
4	5 (30)	5 (30)	5 (30)
5	6 (36)	6 (36)	6 (33)

* Level for product classes 1, 1A, and 2 is 20%.

[d] DOE received comment from a group of refrigerator manufacturers, electric utilities, and energy conservation advocates (referred to as the "Joint Comments") who, acting on its own initiative, negotiated intensively for several months to develop a common recommendation for an energy conservation standard that meets the EPCA requirements for refrigerators, refrigerator-freezers and freezers.

Table 10.6.2 presents the TSLs and the corresponding product class efficiencies for standard-size freezers. TSL 1 consists of those efficiency levels that yield energy use 20 percent below the baseline products. TSL 2 consists of the levels recommended in the Joint Comments. TSL 3 consists of incrementally higher efficiency levels than the preceding TSL. TSL 4 consists of the efficiency levels for which the consumer NPV is positive, using a 7-percent discount rate. TSL 5 consists of the max-tech efficiency levels, which are also the efficiency levels for which the consumer NPV is positive, using a 3-percent discount rate.

Table 10.6.2 Trial Standard Levels for Standard-Size Freezers

Trial Standard Level	Upright Freezers		Chest Freezers
	Product classes 9 and 9I	Product class 8	Product classes 10 and 10A
	Efficiency Level (% less than baseline energy use)		
1	3 (20)	3 (20)	3 (20)
2	5 (30)	4 (25)	4 (25)*
3	6 (35)	5 (30)	5 (30)
4	7 (40)	6 (35)	6 (35)
5	8 (44)	7 (41)	7 (41)

* Level for product class 10A is 30%.

Table 10.6.3 presents the TSLs and the corresponding product class efficiencies for compact refrigeration products. TSL 1 consists of efficiency levels that meet current ENERGY STAR criteria for some compact refrigerators (product classes 11, 11A, and 12), and efficiency levels that are 10 percent below the baseline energy use for other compact refrigerators (product classes 13, 13I, 13A, 14, 14I, 15 and 15I) and compact freezers (product classes 16, 17, and 18). TSL 2 consists of the levels recommended in the Joint Comments. TSL 3 consists of the highest efficiency levels for which the consumer NPV is positive, using both a 3-percent and a 7-percent discount rate. TSL 4 consists of incrementally higher efficiency levels than TSL 3. TSL 5 consists of the max-tech efficiency levels.

Table 10.6.3 Trial Standard Levels for Compact Refrigeration Products

Trial Standard Level	Compact Refrigerators and Refrigerator-Freezers		Compact Freezers
	Product classes 11, 11A, 12	Product classes 13, 13I, 13A, 14, 14I, 15, 15I	Product classes 16, 17, 18
	Efficiency Level (% less than baseline energy use)		
1	3 (20)	1 (10)	1 (10)
2	4 (25)	2 (15)*	1 (10)
3	5 (30)	2 (15)	2 (15)
4	7 (40)	4 (25)	4 (25)
5	10 (59)	7 (42)	7 (42)

* Level for product class 13A is 25 percent, and for product classes 14 and 14I, 20 percent.

Table 10.6.4 presents the TSLs and the corresponding product class efficiencies for built-in refrigeration products. TSL 1 consists of the efficiency levels that are 10 percent better than the current standard. TSL 2 consists of the highest efficiency levels for which the consumer NPV is positive, using both a 3-percent and a 7-percent discount rate. TSL 3 consists of the levels recommended in the Joint Comments. TSL 4 consists of incrementally higher efficiency levels than TSL 3. TSL 5 consists of the max-tech efficiency levels.

Table 10.6.4 Trial Standard Levels for Built-in Refrigeration Products

Trial Standard Level	Built-in All-Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
	Efficiency Level (% less than baseline energy use)			
1	1 (10)	1 (10)	1 (10)	1 (10)
2	2 (15)	2 (15)	1 (10)	3 (20)
3	3 (20)	2 (15)	3 (20)	4 (25)
4	4 (25)	4 (25)	3 (20)	4 (25)
5	5 (29)	5 (27)	4 (22)	5 (27)

10.6.2 National Energy Savings Results by Trial Standard Level

The tables below show the cumulative national energy savings associated with standards at the considered TSLs for each group of refrigeration products.

Table 10.6.5 Standard-Size Refrigerator-Freezers: Cumulative National Energy Savings in Quads

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	Product classes 5, 5A, and 5I	Product classes 4, 4I, and 7
1	1.73	0.10	0.58
2	1.73	0.10	0.95
3	2.22	0.10	0.95
4	2.67	0.48	1.30
5	3.11	0.70	1.50

Table 10.6.6 Standard-Size Freezers: Cumulative National Energy Savings in Quads

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
1	0.49	0.31
2	0.75	0.38
3	0.87	0.46
4	0.98	0.53
5	1.01	0.60

Table 10.6.7 Compact Refrigeration Products: Cumulative National Energy Savings in Quads

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
1	0.28	0.03
2	0.35	0.03
3	0.39	0.04
4	0.48	0.07
5	0.51	0.09

Table 10.6.8 Built-In Refrigeration Products: Cumulative National Energy Savings in Quads

Trial Standard Level	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
1	0.00	0.00	0.01	0.00
2	0.01	0.00	0.01	0.01
3	0.01	0.00	0.03	0.01
4	0.01	0.02	0.03	0.01
5	0.01	0.02	0.04	0.02

10.6.3 Consumer Net Present Value Results by Trial Standard Level

The tables below show the consumer NPV associated with standards at the considered TSLs for each group of refrigeration products. The results here reflect the default learning rate for product costs, which is 44.6 percent.

Table 10.6.9 Cumulative Net Present Value of Consumer Benefits for Standard-Size Refrigerator-Freezers, 3-Percent Discount Rate

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	**Product classes 5, 5A, and 5I**	**Product classes 4, 4I, and 7**
	billion 2009 dollars		
1	11.45	0.94	5.43
2	11.45	0.94	6.34
3	12.91	0.94	6.34
4	9.11	(0.47)	3.52
5	1.87	(2.52)	0.83

* Values in parentheses are negative values.

Table 10.6.10 Cumulative Net Present Value of Consumer Benefits for Standard-Size Refrigerator-Freezers, 7-Percent Discount Rate

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	**Product classes 5, 5A, and 5I**	**Product classes 4, 4I, and 7**
	billion 2009 dollars		
1	2.99	0.34	1.88
2	2.99	0.34	1.67
3	2.81	0.34	1.67
4	(0.31)	(1.17)	(0.60)
5	(5.28)	(2.74)	(2.53)

* Values in parentheses are negative values.

Table 10.6.11 Cumulative Net Present Value of Consumer Benefits for Standard-Size Freezers, 3-Percent Discount Rate

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
	billion 2009 dollars	
1	5.03	3.25
2	7.37	3.33
3	7.69	3.94
4	7.51	3.52
5	5.17	2.42

* Values in parentheses are negative values.

Table 10.6.12 Cumulative Net Present Value of Consumer Benefits for Standard-Size Freezers, 7-Percent Discount Rate

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
	billion 2009 dollars	
1	1.70	1.11
2	2.38	0.96
3	2.30	1.12
4	1.96	0.75
5	0.56	(0.04)

* Values in parentheses are negative values.

Table 10.6.13 Cumulative Net Present Value of Consumer Benefits for Compact Refrigeration Products, 3-Percent Discount Rate

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
	billion 2009 dollars	
1	1.61	0.20
2	1.42	0.20
3	1.62	0.21
4	0.81	(0.01)
5	(1.86)	(0.48)

* Values in parentheses are negative values.

Table 10.6.14 Cumulative Net Present Value of Consumer Benefits for Compact Refrigeration Products, 7-Percent Discount Rate

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
	billion 2009 dollars	
1	0.67	0.09
2	0.51	0.09
3	0.59	0.08
4	0.08	(0.07)
5	(1.44)	(0.36)

* Values in parentheses are negative values.

Table 10.6.15 Cumulative Net Present Value of Consumer Benefits for Built-In Refrigeration Products, 3-Percent Discount Rate

Trial Standard Level	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
	billion 2009 dollars			
1	0.04	0.02	0.06	0.05
2	0.05	0.01	0.06	0.07
3	0.02	0.01	(0.17)	0.05
4	(0.04)	(0.20)	(0.17)	0.05
5	(0.08)	(0.31)	(0.43)	0.02

* Values in parentheses are negative values.

Table 10.6.16 Cumulative Net Present Value of Consumer Benefits for Built-In Refrigeration Products, 7-Percent Discount Rate

Trial Standard Level	Built-in All Refrigerators (3A-BI)	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers (9-BI)
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
	billion 2009 dollars			
1	0.01	0.01	0.02	0.02
2	0.02	0.00	0.02	0.02
3	0.00	0.00	(0.16)	0.00
4	(0.04)	(0.14)	(0.16)	0.00
5	(0.07)	(0.21)	(0.32)	(0.02)

* Values in parentheses are negative values.

REFERENCES

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2. Office of Management and Budget. *OMB Circular A-4, Regulatory Analysis*. 2003. OMB: Washington, D.C. September 17, 2003. <www.whitehouse.gov/omb/assets/omb/circulars/a004/a-4.pdf>

CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

11.1 INTRODUCTION

The consumer subgroup analysis evaluates impacts on any identifiable groups or customers who may be disproportionately affected by any national energy conservation standard. DOE evaluates impacts on particular sub-groups of consumers primarily by analyzing the LCC impacts and PBP for those particular consumers from alternative standard levels. For the NOPR and for the final rule, DOE analyzed the impacts of the considered standard levels on low-income consumers and senior citizens for standard-size refrigerator-freezers and freezers. DOE did not estimate impacts for compact refrigeration products because the household sample sizes were not large enough to yield meaningful results.

DOE determines the impact on consumer subgroups using the LCC Spreadsheet Model. Chapter 8 explains in detail the inputs to the model used in determining LCC impacts and PBPs.

This chapter describes the subgroup identification in further detail and gives the results of the LCC and PBP analyses for the considered subgroups.

11.2 SUBGROUPS DESCRIPTION

11.2.1 Senior-Only Households

Senior-only households have occupants who are all at least 65 years of age. Based on the DOE Energy Information Administration (EIA)'s Residential Energy Consumption Survey of 2005 (RECS), senior-only households comprise 17 percent of the country's households.[1]

11.2.2 Low-Income Households

As defined in the RECS survey, low-income households are considered to be those at or below the "poverty line." The "poverty line" varies with household size, head of household age, and family income. Table 11.2.1 summarizes the income level baselines for selecting low-income households from the RECS sample. The RECS survey classifies 15 percent of the country's households as low-income.

Table 11.2.1 RECS 2005 Definitions of Low-Income Households by Yearly Income

	Average Income in $		
Household Size	**48 Contiguous States and D.C.**	**Alaska**	**Hawaii**
1	9,570	11,950	11,010
2	12,830	16,030	14,760
3	16,090	20,100	18,510
4	19,350	24,190	22,260
5	22,610	28,270	26,010
6	25,870	32,350	29,760
7	29,130	36,430	33,510
8	32,390	40,510	37,260
9	35,650	44,590	41,010
10	38,910	48,670	44,760
11	42,170	52,750	48,510
12	45,430	56,830	52,260
13	48,690	60,910	56,010
14	51,950	64,990	59,760
15	55,210	69,070	63,510

11.2.3 Subgroup Populations

Table 11.2.2 summarizes the subgroup populations for standard-size refrigerator-freezers and freezers, while Table 11.2.3 summarizes the average annual energy use for the households analyzed in the consumer subgroup analyses. These values are compared against the average values for the national sample.

Table 11.2.2 Household Population Data for Refrigeration Products

	Standard-Size Refrigerator-Freezers		**Standard-Size Freezers**	
	Count	Weight	Count	Weight
All Households	3329	84,886,289	616	15,329,541
Senior Only	505	10,526,643	162	3,045,340
Senior Only %	15%	12%	26%	20%
Low Income	535	8,606,765	83	1,589,276
Low Income %	16%	10%	13%	10%

Table 11.2.3 Average Annual Energy Use for Baseline Refrigeration Products

	Standard-Size Top-Mount Refrigerator-Freezers* (kWh)	Standard-Size Upright Freezers (kWh)
Senior Only	403	600
Low Income	443	575
All Households	444	600

* In first year of operation.

11.3 RESULTS

11.3.1 Standard-Size Refrigerator-Freezers

Tables 11.4.1 through 11.4.6 summarize the LCC and PBP results for low-income consumers and senior citizens for the standard-size refrigerator-freezer representative product classes. Table 11.4.7 compares the average LCC savings at each efficiency level for the two consumer subgroups with the average LCC savings for the entire sample for each representative product class.

Table 11.3.1 Product Class 3, Top-Mount Refrigerator-Freezers: LCC and PBP Results for Senior-Only Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
					% of Households that Experience			
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
Baseline	$490	$738	$1,228					
1 (10)	$501	$684	$1,185	$43	0.55%	19.62%	79.83%	2.5
2 (15)	$508	$656	$1,164	$64	1.11%	15.23%	83.66%	3.1
3 (20)	$566	$627	$1,193	$36	39.89%	5.57%	54.54%	8.7
4 (25)	$604	$594	$1,198	$31	50.25%	0.00%	49.75%	10.2
5 (30)	$688	$560	$1,248	-$20	68.91%	0.00%	31.09%	14.3
6 (36)	$808	$525	$1,333	-$105	82.75%	0.00%	17.25%	19.0

Table 11.3.2 Product Class 5, Bottom-Mount Refrigerator-Freezers: LCC and PBP Results for Senior-Only Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
					% of Households that Experience			
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
Baseline	$860	$904	$1,763					
1 (10)	$862	$895	$1,756	$9	0.09%	86.28%	13.63%	2.3
2 (15)	$863	$890	$1,753	$13	0.11%	86.22%	13.67%	2.6
3 (20)	$869	$877	$1,746	$21	3.70%	65.78%	30.52%	4.6
4 (25)	$928	$840	$1,768	-$1	71.69%	0.00%	28.31%	16.4
5 (30)	$1,026	$804	$1,830	-$63	85.63%	0.00%	14.37%	23.1
6 (36)	$1,160	$758	$1,919	-$151	91.43%	0.00%	8.57%	27.3

Table 11.3.3 Product Class 7, Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: LCC and PBP Results for Senior-Only Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
					% of Households that Experience			
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
Baseline	$1,043	$1,175	$2,218					
1 (10)	$1,045	$1,152	$2,197	$22	0.00%	76.99%	23.01%	1.4
2 (15)	$1,051	$1,126	$2,177	$42	0.12%	49.10%	50.78%	2.2
3 (20)	$1,068	$1,093	$2,161	$59	5.28%	33.48%	61.24%	4.3
4 (25)	$1,127	$1,044	$2,172	$48	43.83%	0.00%	56.17%	9.7
5 (30)	$1,256	$996	$2,251	-$31	73.20%	0.00%	26.80%	16.6
6 (33)	$1,356	$964	$2,320	-$100	82.90%	0.00%	17.10%	20.3

Table 11.3.4 Product Class 3, Top-Mount Refrigerator-Freezers: LCC and PBP Results for Low-Income Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
Baseline	$490	$811	$1,301					
1 (10)	$501	$751	$1,252	$49	0.38%	19.34%	80.28%	2.3
2 (15)	$509	$720	$1,228	$73	0.78%	15.01%	84.21%	2.6
3 (20)	$567	$687	$1,254	$48	34.56%	5.30%	60.14%	7.9
4 (25)	$605	$650	$1,255	$47	44.44%	0.02%	55.54%	9.3
5 (30)	$689	$613	$1,302	$0	63.89%	0.00%	36.11%	13.0
6 (36)	$809	$573	$1,383	-$81	78.02%	0.00%	21.98%	17.3

Table 11.3.5 Product Class 5, Bottom-Mount Refrigerator-Freezers: LCC and PBP Results for Low-Income Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
Baseline	$861	$969	$1,830					
1 (10)	$863	$959	$1,822	$10	0.02%	86.21%	13.77%	2.1
2 (15)	$864	$954	$1,818	$15	0.06%	86.14%	13.80%	2.4
3 (20)	$871	$939	$1,809	$24	2.98%	65.28%	31.74%	4.2
4 (25)	$930	$898	$1,827	$6	66.89%	0.00%	33.11%	14.8
5 (30)	$1,027	$858	$1,886	-$52	82.61%	0.00%	17.39%	20.9
6 (36)	$1,162	$807	$1,970	-$136	89.03%	0.00%	10.97%	24.6

Table 11.3.6 Product Class 7, Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: LCC and PBP Results for Low-Income Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
					% of Households that Experience			
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
Baseline	$1,042	$1,209	$2,251					
1 (10)	$1,045	$1,183	$2,228	$23	0.00%	76.16%	23.84%	1.3
2 (15)	$1,051	$1,156	$2,206	$46	0.04%	46.76%	53.20%	2.2
3 (20)	$1,069	$1,119	$2,189	$64	5.12%	30.32%	64.56%	4.3
4 (25)	$1,128	$1,069	$2,197	$56	41.33%	0.00%	58.67%	9.3
5 (30)	$1,257	$1,019	$2,275	-$23	70.88%	0.00%	29.12%	15.9
6 (33)	$1,357	$986	$2,343	-$91	80.84%	0.00%	19.16%	19.5

Table 11.3.7 Standard-Size Refrigerator-Freezers: Comparison of Average LCC Savings for Consumer Subgroups and All Households

Efficiency Level (% less than baseline energy use)	Top-Mount Refrigerator-Freezers (PC 3)			Bottom-Mount Refrigerator-Freezers (PC 5)			Side-by-Side Refrigerator-Freezers (PC 7)		
	Senior	Low-Income	All	Senior	Low-Income	All	Senior	Low-Income	All
1 (10)	$43	$49	$46	$9	$10	$9	$22	$23	$22
2 (15)	$64	$73	$69	$13	$15	$14	$42	$46	$44
3 (20)	$36	$48	$43	$21	$24	$22	$59	$64	$62
4 (25)	$31	$47	$41	-$1	$6	$5	$48	$56	$57
5 (30)	-$20	$0	-$7	-$63	-$52	-$54	-$31	-$23	-$18
6 (36/36/33)	-$105	-$81	-$89	-$151	-$136	-$137	-$100	-$91	-$85

11.3.2 Standard-Size Freezers

Tables 11.4.8 through 11.4.11 summarize the LCC and PBP results for low-income consumers and senior citizens for the standard-size freezer representative product classes. Table 11.4.12 compares the average LCC savings at each efficiency level for the two consumer subgroups with the average LCC savings for the entire sample for each representative product class.

Table 11.3.8 Product Class 9, Upright Freezers: LCC and PBP Results for Senior-Only Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
					% of Households that Experience			
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
Baseline	$507	$1,041	$1,548					
1 (10)	$518	$962	$1,479	$69	0.35%	19.03%	80.62%	2.1
2 (15)	$537	$914	$1,451	$98	5.98%	1.63%	92.39%	3.8
3 (20)	$554	$865	$1,419	$130	7.24%	0.58%	92.18%	4.3
4 (25)	$581	$815	$1,395	$153	11.01%	0.42%	88.57%	5.2
5 (30)	$605	$764	$1,369	$179	13.03%	0.21%	86.76%	5.6
6 (35)	$659	$720	$1,378	$170	24.73%	0.00%	75.27%	7.5
7 (40)	$734	$676	$1,410	$139	38.00%	0.00%	62.00%	10.0
8 (44)	$901	$639	$1,540	$8	62.71%	0.00%	37.29%	15.7

Table 11.3.9 Product Class 10, Chest Freezer: LCC and PBP Results for Senior-Only Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
					% of Households that Experience			
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
Baseline	$369	$644	$1,013					
1 (10)	$375	$593	$968	$45	0.23%	15.83%	83.94%	1.9
2 (15)	$384	$562	$947	$66	2.70%	1.16%	96.14%	3.1
3 (20)	$395	$532	$927	$86	4.74%	0.22%	95.04%	3.8
4 (25)	$439	$501	$940	$74	26.11%	0.22%	73.67%	7.9
5 (30)	$458	$470	$928	$85	28.14%	0.22%	71.64%	8.2
6 (35)	$512	$447	$959	$54	46.54%	0.00%	53.46%	11.7
7 (41)	$623	$408	$1,031	-$18	68.23%	0.00%	31.77%	17.4

Table 11.3.10 Product Class 9, Upright Freezers: LCC and PBP Results for Low-Income Households

Efficiency Level *(% less than baseline energy use)*	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
Baseline	$508	$1,041	$1,549					
1 (10)	$518	$962	$1,480	$69	0.24%	19.07%	80.69%	2.0
2 (15)	$537	$914	$1,451	$98	5.46%	1.60%	92.94%	3.8
3 (20)	$555	$865	$1,420	$129	6.49%	0.58%	92.93%	4.2
4 (25)	$581	$815	$1,396	$153	10.59%	0.42%	88.99%	5.1
5 (30)	$605	$765	$1,370	$179	12.38%	0.21%	87.41%	5.5
6 (35)	$659	$720	$1,379	$170	23.89%	0.00%	76.11%	7.4
7 (40)	$735	$676	$1,411	$139	37.37%	0.00%	62.63%	9.8
8 (44)	$902	$640	$1,541	$8	62.07%	0.00%	37.93%	15.4

Table 11.3.11 Product Class 10, Chest Freezer: LCC and PBP Results for Low-Income Households

Efficiency Level *(% less than baseline energy use)*	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
Baseline	$370	$609	$978					
1 (10)	$376	$561	$936	$42	0.30%	16.05%	83.65%	2.0
2 (15)	$385	$532	$917	$61	3.36%	1.19%	95.45%	3.3
3 (20)	$396	$504	$899	$79	5.41%	0.23%	94.36%	4.0
4 (25)	$439	$475	$914	$65	28.41%	0.23%	71.36%	8.3
5 (30)	$458	$445	$904	$75	30.28%	0.23%	69.49%	8.7
6 (35)	$513	$424	$937	$42	50.16%	0.00%	49.84%	12.4
7 (41)	$624	$387	$1,011	-$32	70.88%	0.00%	29.12%	18.4

Table 11.3.12 Standard-Size Freezers: Comparison of Average LCC Savings for Consumer Subgroups and All Households

Efficiency Level (% less than baseline energy use)	Upright Freezers (PC 9)			Chest Freezers (PC 10)		
	Senior	Low-Income	All	Senior	Low-Income	All
1 (10)	$69	$69	$73	$45	$42	$43
2 (15)	$98	$98	$105	$66	$61	$63
3 (20)	$130	$129	$139	$86	$79	$82
4 (25)	$153	$153	$166	$74	$65	$68
5 (30)	$179	$179	$195	$85	$75	$79
6 (35)	$170	$170	$189	$54	$42	$47
7 (40/41)	$139	$139	$160	-$18	-$32	-$26
8 (44)	$8	$8	$32			

11.3.3 Built-In Refrigeration Products

Tables 11.4.13 through 11.4.20 summarize the LCC and PBP results for low-income consumers and senior citizens for the built-in refrigeration product representative product classes. Table 11.4.21 compares the average LCC savings at each efficiency level for the two consumer subgroups with the average LCC savings for the entire sample for each representative product class.

Table 11.3.13 Product Class 3A-BI, Built-In All Refrigerators: LCC and PBP Results for Senior-Only Households

Efficiency Level *(% less than baseline energy use)*	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
					% of Households that Experience			
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
Baseline	$4,324	$65	$5,080					
1 (10)	$4,330	$60	$5,032	$48	0.04%	19.39%	80.57%	1.6
2 (15)	$4,342	$58	$5,016	$65	1.49%	15.01%	83.50%	2.9
3 (20)	$4,465	$55	$5,106	-$25	69.11%	5.43%	25.46%	15.2
4 (25)	$4,639	$53	$5,250	-$170	93.02%	0.00%	6.98%	27.6
5 (29)	$4,771	$51	$5,360	-$280	96.54%	0.00%	3.46%	34.2

Table 11.3.14 Product Class 5-BI, Built-In Bottom-Mount Refrigerator-Freezers: LCC and PBP Results for Senior-Only Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
Baseline	$4,980	$77	$5,868					
1 (10)	$4,984	$77	$5,864	$7	0.99%	86.08%	12.93%	4.2
2 (15)	$4,994	$76	$5,881	$0	8.79%	86.03%	5.18%	12.6
3 (20)	$5,027	$75	$5,900	-$19	30.56%	65.59%	3.85%	24.6
4 (25)	$5,183	$73	$6,029	-$148	98.61%	0.00%	1.39%	60.8
5 (27)	$5,273	$71	$6,100	-$219	99.10%	0.00%	0.90%	59.4

Table 11.3.15 Product Class 7-BI, Built-In Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: LCC and PBP Results for Senior-Only Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
Baseline	$7,150	$117	$8,559					
1 (10)	$7,164	$115	$8,555	$8	7.60%	77.09%	15.31%	8.1
2 (15)	$7,208	$114	$8,583	-$15	41.13%	49.24%	9.63%	19.9
3 (20)	$7,335	$111	$8,675	-$107	63.60%	33.19%	3.21%	34.4
4 (22)	$7,443	$109	$8,767	-$199	98.27%	0.00%	1.73%	53.8

Table 11.3.16 Product Class 9-BI, Built-In Upright Freezers: LCC and PBP Results for Senior-Only Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience			Median
					Net Cost	No Impact	Net Benefit	
Baseline	$3,943	$74	$4,950					
1 (10)	$3,959	$68	$4,889	$61	2.09%	18.91%	79.00%	3.1
2 (15)	$3,973	$65	$4,858	$93	5.19%	1.60%	93.21%	3.9
3 (20)	$4,058	$62	$4,903	$47	46.81%	0.53%	52.66%	11.5
4 (25)	$4,193	$58	$4,990	-$39	72.10%	0.46%	27.44%	19.1
5 (27)	$4,296	$57	$5,069	-$119	82.05%	0.24%	17.71%	24.2

Table 11.3.17 Product Class 3A-BI, Built-In All Refrigerators: LCC and PBP Results for Low-Income Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience			Median
					Net Cost	No Impact	Net Benefit	
Baseline	$4,329	$71	$5,157					
1 (10)	$4,336	$66	$5,102	$54	0.04%	18.98%	80.98%	1.4
2 (15)	$4,348	$63	$5,083	$74	1.15%	14.54%	84.31%	2.6
3 (20)	$4,472	$60	$5,170	-$14	64.81%	4.75%	30.44%	14.0
4 (25)	$4,646	$57	$5,311	-$155	90.62%	0.00%	9.38%	25.3
5 (29)	$4,778	$55	$5,419	-$263	94.66%	0.00%	5.34%	31.1

Table 11.3.18 Product Class 5-BI, Built-In Bottom-Mount Refrigerator-Freezers: LCC and PBP Results for Low-Income Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
Baseline	$4,987	$84	$5,950					
1 (10)	$4,991	$83	$5,944	$8	0.66%	85.94%	13.40%	3.9
2 (15)	$5,001	$83	$5,961	$2	7.88%	85.89%	6.23%	11.4
3 (20)	$5,035	$81	$5,979	-$17	30.06%	65.07%	4.87%	22.3
4 (25)	$5,191	$79	$6,103	-$141	97.89%	0.00%	2.11%	52.3
5 (27)	$5,281	$77	$6,173	-$210	98.45%	0.00%	1.55%	52.0

Table 11.3.19 Product Class 7-BI, Built-In Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: LCC and PBP Results for Low-Income Households

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median
Baseline	$7,147	$120	$8,584					
1 (10)	$7,162	$118	$8,579	$9	7.58%	75.92%	16.50%	8.0
2 (15)	$7,208	$116	$8,607	-$14	42.39%	46.85%	10.76%	19.2
3 (20)	$7,341	$113	$8,702	-$109	66.39%	30.05%	3.56%	33.0
4 (22)	$7,449	$111	$8,794	-$201	98.03%	0.00%	1.97%	50.4

Table 11.3.20 Product Class 9-BI, Built-In Upright Freezers: LCC and PBP Results for Low-Income Households

Efficiency Level *(% less than baseline energy use)*	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings				Payback Period (years)
					% of Households that Experience			
	Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	Net Cost	No Impact	Net Benefit	Median
Baseline	$3,946	$73	$4,946					
1 (10)	$3,961	$67	$4,885	$61	1.81%	18.99%	79.20%	3.1
2 (15)	$3,975	$64	$4,854	$92	5.11%	1.63%	93.26%	3.9
3 (20)	$4,061	$61	$4,900	$46	46.80%	0.54%	52.66%	11.6
4 (25)	$4,195	$58	$4,987	-$41	72.27%	0.47%	27.26%	19.0
5 (27)	$4,298	$56	$5,067	-$121	82.77%	0.25%	16.98%	24.2

Table 11.3.21 Built-In Refrigeration Products: Comparison of Average LCC Savings for Consumer Subgroups and All Households

Efficiency Level (% less than baseline energy use)	Built-in All Refrigerators (PC 3A-BI)			Built-in Bottom-Mount Refrigerator-Freezers (PC 5-BI)			Built-in Side-by-Side Refrigerator-Freezers (PC 7-BI)			Built-in Upright Freezers (PC 9-BI)		
	Senior	Low-Income	All	Senior	Low-Income	All	Senior	Low-Income	All	Senior	Low-Income	All
1 (10)	$48	$54	$52	$7	$8	$8	$8	$9	$10	$61	$61	$66
2 (15)	$65	$74	$71	$0	$2	$2	-$15	-$14	-$9	$93	$92	$101
3 (20)	-$25	-$14	-$12	-$19	-$17	-$15	-$107	-$109	-$92	$47	$46	$58
4 (25/25/22/25)	-$170	-$155	-$152	-$148	-$141	-$139	-$199	-$201	-$183	-$39	-$41	-$24
5 (29/27/-/27)	-$280	-$263	-$260	-$219	-$210	-$208				-$119	-$121	-$102

CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

In determining whether a standard is economically justified, the U.S. Department of Energy (DOE) is required to consider "the economic impact of the standard on the manufacturers and on the consumers of the products subject to such a standard." (42 U.S.C. 6313(a)(6)(B)(i)) The law also calls for an assessment of the impact of any lessening of competition as determined in writing by the Attorney General. *Id*. DOE conducted a manufacturer impact analysis (MIA) to estimate the financial impact of amended energy conservation standards on manufacturers of residential refrigerators, freezers, and refrigerator-freezers, and assessed the impact of such standards on direct employment and manufacturing capacity.

The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA primarily relies on the Government Regulatory Impact Model (GRIM), an industry cash-flow model adapted for each product in this rulemaking. The GRIM inputs include information on industry cost structure, shipments, and pricing strategies. The GRIM's key output is the industry net present value (INPV). The model estimates the financial impact of more stringent energy conservation standards for each product by comparing changes in INPV between a base case and the various trial standard levels (TSLs) in the standards case. The qualitative part of the MIA addresses product characteristics, manufacturer characteristics, market and product trends, as well as the impact of standards on subgroups of manufacturers.

12.2 METHODOLOGY

DOE conducted the MIA in three phases. Phase I, "Industry Profile," consisted of preparing an industry characterization for the residential refrigerators, freezers, and refrigerator-freezers industry, including data on market share, sales volumes and trends, pricing, employment, and financial structure. In Phase II, "Industry Cash Flow," DOE used the GRIM to assess the impacts of amended energy conservation standards on four major product types for this rulemaking:

1) Standard-Size Refrigerator-Freezers
2) Standard-Size Freezers
3) Compact Refrigeration Products
4) Built-in Refrigeration Products

In Phase II, DOE created a GRIM for residential refrigeration products and an interview guide to gather information on the potential impacts on manufacturers. DOE presented the MIA results for standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products separately. Each of the four groups of product classes and results is based on a unique set of considered TSLs. These TSLs are described in Section 12.4.5 below.

In Phase III, "Subgroup Impact Analysis," DOE interviewed manufacturers representing more than 95 percent of standard-size refrigerator-freezer sales, approximately 95 percent of standard-size freezer sales, about 75 percent of compact refrigeration product sales, and more than 95 percent of built-in refrigeration products sales. Interviewees included large and small manufacturers with various market shares and market focus, providing a representative cross-section of the industries. During interviews, DOE discussed financial topics specific to each manufacturer and obtained each manufacturer's view of the industry. The interviews provided DOE with valuable information for evaluating the impacts of amended energy conservation standards on manufacturer cash flows, investment requirements, and employment.

DOE groups the MIA results by product classes that are made by the same manufacturers. As stated above, DOE presents separate results for standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products.

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE prepared a profile of the residential refrigeration industry that built upon the market and technology assessment prepared for this rulemaking. (See chapter 3 of this Technical Support Document (TSD).) Before initiating the detailed impact studies, DOE collected information on the present and past structure and market characteristics of each industry. This information included market share data, product shipments, manufacturer markups, and the cost structure for various manufacturers. The industry profile includes: (1) further detail on the overall market and product characteristics; (2) estimated manufacturer market shares; (3) financial parameters such as net plant, property, and equipment; selling, general and administrative (SG&A) expenses; cost of goods sold, *etc.;* and (4) trends in the number of firms, market, and product characteristics. The industry profile included a top-down cost analysis of residential refrigeration manufacturers that DOE used to derive preliminary financial inputs for the GRIM (*e.g.,* revenues, depreciation, SG&A, and research and development (R&D) expenses).

DOE also used public information to further calibrate its initial characterization of the residential refrigeration industry, including Securities and Exchange Commission (SEC) 10–K reports,[1] Standard & Poor's (S&P) stock reports,[2] corporate annual reports, and the U.S. Census Bureau's 2007 Annual Survey of Manufacturers (2007 ASM).[3] DOE also characterized these industries using information from its engineering analysis and the life-cycle cost analysis.

12.2.2 Phase II: Industry Cash-Flow Analysis and Interview Guide

Phase II focused on the financial impacts of potential amended energy conservation standards on manufacturers of standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products. More stringent energy conservation standards can affect manufacturer cash flows in three distinct ways: (1) create a need for increased investment, (2) raise production costs per unit, and (3) alter revenue due to higher per-unit prices and/or possible changes in sales volumes. To quantify these impacts, DOE used the GRIM to perform a cash-flow analysis for residential refrigerators, freezers, and refrigerator-freezers. In performing these analyses, DOE used the financial values derived during Phase I and the shipment scenarios used in the NIA. In Phase II, DOE performed these preliminary industry cash-flow analyses and prepared written guides for manufacturer interviews.

12.2.2.1 Industry Cash-Flow Analysis

The GRIM uses several factors to determine a series of annual cash flows from the announcement year of amended energy conservation standards until several years after the standards' compliance date. These factors include annual expected revenues, costs of sales, SG&A, taxes, and capital expenditures related to the amended standards. Inputs to the GRIM include manufacturing production costs, selling prices, and shipments forecasts developed in other analyses. DOE derived the manufacturing costs from the engineering analysis and information provided by the industry and estimated typical manufacturer markups from public financial reports and interviews with manufacturers. DOE developed alternative markup scenarios for each GRIM based on discussions with manufacturers. DOE's shipments analysis, presented in chapter 9 of this TSD, provided the basis for the shipment projections in the GRIM. The financial parameters were developed using publicly available manufacturer data and were revised with information submitted confidentially during manufacturer interviews. The GRIM results are compared to base case projections for the industry. The financial impact of amended energy conservation standards is the difference between the discounted annual cash flows in the base case and standards case at each TSL.

12.2.2.2 Interview Guides

During Phase III of the MIA, DOE interviewed manufacturers to gather information on the effects of amended energy conservation on revenues and finances, direct employment, capital assets, and industry competitiveness. Before the interviews, DOE distributed an interview guide for the residential refrigeration industry. The interview guide provided a starting point to identify relevant issues and help identify the impacts of amended energy conservation standards on individual manufacturers or subgroups of manufacturers. Most of the information DOE received from these meetings is protected by non-disclosure agreements and resides with DOE's contractors. Before each telephone interview or site visit, DOE provided company representatives with an interview guide that included the topics for which DOE sought input. The MIA interview topics included (1) key issues to this rulemaking; (2) a company overview and organizational characteristics; (3) engineering and life cycle cost analysis follow-up; (4)

manufacturer markups and profitability; (5) shipment projections and market shares; (6) financial parameters; (7) conversion costs; (8) cumulative regulatory burden; (9) impacts of potential HFC regulations; (10) direct employment impact assessment; (11) exports, foreign competition, and outsourcing; (12) consolidation; and (13) impacts on small business. The interview guides are presented in appendix 12-A.

12.2.3 Phase III: Subgroup Analysis

For its analysis, DOE presented the impacts on standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products separately. While conducting the MIA, DOE interviewed a representative cross-section of residential refrigeration manufacturers. The MIA interviews broadened the discussion to include business-related topics. DOE sought to obtain feedback from industry on the approaches used in the GRIMs and to isolate key issues and concerns. During interviews, DOE defined two manufacturer subgroups (small businesses and built-in refrigeration manufacturers) that could be disproportionately impacted by amended energy conservation standards. These subgroups are described in detail below.

12.2.3.1 Manufacturing Interviews

The information gathered in Phase I and the cash-flow analysis performed in Phase II are supplemented with information gathered from manufacturer interviews in Phase III. The interview process provides an opportunity for interested parties to express their views on important issues privately, allowing confidential or sensitive information to be considered in the rulemaking process.

DOE used these interviews to tailor the GRIM to reflect unique financial characteristics of each product group. Within each manufacturer group, DOE contacted companies from its database of manufacturers. Small and large companies, subsidiaries and independent firms, and public and private corporations were interviewed to provide a representation of the industry. Interviews were scheduled well in advance to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire was acceptable, DOE sought interactive interviews, which help clarify responses and identify additional issues. The resulting information provides valuable inputs to the GRIM developed for the product classes.

12.2.3.2 Revised Industry Cash-Flow Analysis

In Phase II of the MIA, DOE provided manufacturers with preliminary GRIM input financial figures for review and evaluation. During the interviews, DOE requested comments on the values it selected for the parameters. DOE revised its industry cash-flow models based on this feedback. Section 12.4.3 provides more information on how DOE calculated the parameters.

12.2.3.3 Manufacturer Subgroup Analysis

Using average cost assumptions to develop an industry-cash-flow estimate may not adequately assess differential impacts of amended energy conservation standards among manufacturer subgroups. For example, small manufacturers, niche players, or manufacturers exhibiting a cost structure that largely differs from the industry average could be more negatively affected. To address this possible impact, DOE used the results of the industry characterization analysis in Phase I to group manufacturers that exhibit similar characteristics. During the manufacturer interviews, DOE discussed financial topics specific to each manufacturer and obtained each manufacturer's view of the industry as a whole. As described in section 12.2.3, DOE presents the industry impacts by major product groupings. DOE presents the industry impacts by the major product types (standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products). These product groupings represent markets that are served by the same manufacturers. By segmenting the results into these product types, DOE is able to discuss how these subgroups of manufacturers will be impacted by amended energy conservation standards. Grouping these product categories reduced the need for a subgroup analysis to the consideration of built-in refrigeration product manufacturers because the impacts of each group are characterized by the MIA separately. DOE identified one small business manufacturer but did not analyze a separate subgroup of small business manufacturers for the reasons discussed below.

12.2.3.3.1 Small-Business Manufacturer Subgroup

DOE investigated whether small business manufacturers should be analyzed as a manufacturer subgroup. DOE used the Small Business Administration (SBA) small business size standards published on August 22, 2008, as amended, and the North American Industry Classification System (NAICS) code, presented in Table 12.2.1 , to determine whether any small entities would be affected by the rulemaking.[a] For the product classes under review, the SBA bases its small business definition on the total number of employees for a business, its subsidiaries, and its parent companies. An aggregated business entity with fewer employees than the listed limit is considered a small business.

Table 12.2.1 SBA and NAICS Classification of Small Businesses Potentially Affected by This Rulemaking

Industry Description	Revenue Limit	Employee Limit	NAICS
Household Refrigerator and Home Freezer Manufacturing	N/A	1,000	335222

DOE used the Association of Home Appliance Manufacturers[4] member directory to identify manufacturers of residential refrigeration products. DOE also reviewed public certification databases such as the Federal Trade Commission[5] database. DOE asked interested parties and industry representatives if they were aware of other small business manufacturers. Then, DOE consulted publicly available data, product databases like ENERGY STAR[6] and the California Energy Commission (CEC)[7], and manufacturers to determine which manufacturers meet SBA's definition of a small business.

[a] The size standards are available on the SBA's website at www.sba.gov/idc/groups/public/documents/sba_homepage/serv_sstd_tablepdf.pdf.

During its research, DOE identified only one company which manufactures products covered by this rulemaking and qualifies as small business per the applicable SBA definition. DOE contacted the small business to solicit feedback on the potential impacts of energy conservation standards. In addition to posing the standard MIA interview questions, DOE solicited data from other manufacturers on differential impacts this company and other small companies might experience from amended energy conservation standards. Because only one manufacturer qualified as a small business, DOE did not analyze a separate subgroup of small business manufacturer for this NOPR or for the final rule.

12.2.3.3.2 Built-in Refrigeration Manufacturer Subgroup

Built-in refrigeration product manufacturers are a second potential subgroup. However, because DOE is establishing separate product classes for built-in products, DOE is already presenting separate results and impacts for this potential manufacturer subgroup. The impacts on the manufacturers of these niche products are therefore already characterized in the broader MIA and do not require an explicit subgroup analysis.

12.2.3.4 Manufacturing Capacity Impact

One significant outcome of amended energy conservation standards could be the obsolescence of existing manufacturing assets, including tooling and investment. The manufacturer interview guides have a series of questions to help identify impacts of amended standards on manufacturing capacity, specifically capacity utilization and plant location decisions in the United States and North America, with and without amended standards; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of any stranded assets; and estimates for any one-time changes to existing plant, property, and equipment (PPE). DOE's estimates of the one-time capital changes and stranded assets affect the cash flow estimates in the GRIM. These estimates can be found in section 12.4.8; DOE's discussion of the capacity impact can be found in section 12.7.2.

12.2.3.5 Employment Impact

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. To assess how domestic direct employment patterns might be affected, the interviews explored current employment trends in the residential refrigeration industry. The interviews also solicited manufacturer views on changes in employment patterns that may result from more stringent standards. The employment impacts section of the interview guide focused on current employment levels associated with manufacturers at each production facility, expected future employment levels with and without amended energy conservation standards, and differences in workforce skills and issues related to the retraining of employees. The employment impacts are reported in section 12.7.1.

12.2.3.6 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers due to amended energy conservation standards and other regulatory actions affecting the same products. DOE analyzed the impact on manufacturers of multiple, product-specific regulatory actions. Based on its own research and discussions with manufacturers, DOE identified regulations relevant to residential refrigeration manufacturers, such as State regulations and other Federal regulations that impact other products made by the same manufacturers. Discussion of the cumulative regulatory burden can be found in section 12.7.3.

12.3 MANUFACTURER IMPACT ANALYSIS KEY ISSUES

Each MIA interview starts by asking: “What are the key issues for your company regarding the energy conservation standard rulemaking?” This question prompts manufacturers to identify the issues they feel DOE should explore and discuss further during the interview. The following sections describe the most significant issues identified by manufacturers. These summaries are provided in aggregate to protect manufacturer confidentiality.

12.3.1 Potential for Significant Changes to Manufacturing Facilities

A number of manufacturers indicated that conversion costs would be exponentially greater if the adopted standards require significant rather than incremental increases in efficiency. While DOE does not analyze design options that would lower consumer utility, manufacturers indicated that for some product classes they would consider wall thickness increases if they resulted in lower per unit costs. However, manufacturers also indicated that wall thickness increases in response to more stringent energy standards would be extremely capital intensive. Changing the wall thickness would require extensive investments to completely replace injection molding equipment, interior fabrication feeder lines and equipment, and foaming fixtures on every production line. Such substantial changes would require many times the investment of incremental efficiency improvements. By comparison, the design and implementation of a new heat exchanger design would only possible require new fabrication tooling for the component and slight adjustments to production line tooling but would leave most of the existing production equipment intact. Smaller manufacturers were generally concerned that conversion costs would disproportionately impact their operations since comparable product and capital conversion costs would be spread over a smaller shipment volume.

Additionally, several manufacturers stated that new standards could increase the total steady state invested capital necessary to maintain current production levels. As an example, many plants leverage economies of scope by utilizing a shared front end of production (cabinet and door bending, for example) to serve multiple product lines. These economies would be forfeited if amended standards disproportionately affected one product class utilizing the shared front end. As such, manufacturing plants could have relatively lower capital intensity following standards.

12.3.2 VIPs

Manufacturers were also concerned about potential issues with a standard that effectively required the widespread adoption of VIPs. In particular, the material costs of VIPs would add significant costs to the products, especially at the retail level. Manufacturers were concerned that using this design option in product classes that historically have been low-cost options could have unintended consequences such as inducing consumers to prolong the life of the products or switch to less profitable products. Manufacturers were also concerned about the additional labor that is required to install VIPs. Additional production steps would be required with VIPs, which require greater care in handling to prevent damaging the components. While less of a concern on lower volume products, the additional production steps on high-speed production lines would add tremendous complexity. The additional production steps and slower line rates would lengthen the production lines and require additional equipment.

Manufacturers were also concerned about the ability of VIP suppliers to ramp up production to meet necessary demand from more stringent standards. Finally, manufacturers indicated that their experience with VIPs has shown a range of efficiency improvements lower than the theoretical benefit of VIPs. They are also concerned about the degradation of the panels over the lifetime of their products. Because of the range of efficiency improvements in practice, some manufacturers indicated they could elect to employ other design pathways that would eliminate these potential problems with the technology.

12.3.3 Impact on U.S. Production and Jobs

Manufacturers generally agreed that standards that required substantial capital conversion costs would lower U.S. production and employment. Depending on the level of these expenditures, some manufacturers stated that new investments would not be made in the U.S., given the lower labor costs overseas. Margins are already thin for certain product classes, and manufacturers believed that higher standards could further reduce profitability. The lower labor costs could offset some of the impact on profitability, especially for their lower margin product lines. Some manufacturers stated they could also choose to source or drop altogether certain product lines they currently manufacture if they did not believe they could recoup the capital investments required to meet amended energy conservation standards on those lines. Any decision to drop or source more product lines would also lead to less domestic production and jobs.

12.3.4 Impacts to Product Utility

Several manufacturers expressed concern that more stringent energy standards could impact the utility of their products. Most residential kitchens have standardized size openings for refrigerators, which would force any wall thickness growth inward and lower internal volume. While this was not analyzed as a design option for all products, manufacturers indicated some in the industry could elect to use thicker walls to meet new standards for full size refrigerator-freezers. Finally, several manufacturers indicated that other product features currently available may have to be removed in order to both meet new standard levels and maintain product prices that would be acceptable to consumers. Examples of these features include ice and water dispensers, glass doors, soda can dispensers, crisper compartments, anti-sweat features, and food preservation capabilities.

Manufacturers are also concerned that the energy savings from more stringent energy conservation standards would not be great enough to justify passing through the added costs to consumers. Currently, manufacturers bundle higher efficiency with other desirable features to justify higher prices for those ENERGY STAR models. According to manufacturers, if amended standards cause prices to rise even higher, the lower operating costs do not justify higher prices, since the savings as a percentage of the purchase price are very low. Therefore, the increased cost of meeting efficiency requirements may cause manufacturers to reduce the amount of other features bundled with these products in order to retain a reasonable price point, causing consumer utility to decline.

The value of future ENERGY STAR levels is also a concern for manufacturers. Many retailers and other distribution channels require ENERGY STAR products. Since the features bundled with ENERGY STAR are the biggest justification of the added costs, manufacturers were concerned that a higher ENERGY STAR level after standards would offer less value to consumers. Consumers would save less energy relative to the added efficiency costs or would have a product with fewer features.

Manufacturers also stated that the financial burden of developing products to meet amended energy conservation standards has an opportunity cost due to limited capital and R&D dollars. Investments incurred to meet amended standards reflect foregone investments in innovation and the development of new features that consumers value and on which manufacturers earn a premium.

12.3.5 Technical Difficulty to Achieve New Standards

Many manufacturers expressed concerns about the technical difficulty to achieve new standards that are significantly more stringent than current levels. Supply of particular components, notably high efficiency compressors and VIPs, were a concern for all product classes, especially at higher efficiency levels that would increase the demand for these components many times over current levels. They also stated that there are fewer low-cost technology improvements available than there were during past rulemakings. Compact units, in general, pose an additional challenge because there are fewer low-capacity compressors with sufficiently high EER ratings. Specifically, compact freezers were cited as a product class in which it will be especially difficult to make significant energy improvements. The standards for compact freezers are already more stringent relative to capacity than are standards for compact refrigerators.

12.3.6 Changes in Consumer Behavior

Several manufacturers noted that higher prices to consumers resulting from amended energy conservation standards could result in product switching between lines of standard-size refrigerator-freezers. Currently, top-mounted refrigerator-freezers are inexpensive commodity products, on which manufacturers said they make little to no profit margin. Instead, manufacturers earn a profit on more expensive and more feature-loaded side-mounted and bottom-mounted refrigerator-freezers. Manufacturers are concerned that if amended energy conservation standards cause retail prices to increase across product classes, many consumers will no longer be willing to pay the premium for side-mounted and bottom-mounted refrigerator-freezers and will switch to buying the less expensive and less profitable top-mounted refrigerator-freezers.

Similarly, a number of manufacturers expressed concern that higher retail prices could alter consumers' decisions to repair or replace their standard-size refrigerator-freezers. Many consumers who in the base case would buy a new refrigerator when their current unit fails would instead opt to repair their existing units in the standards case due to the higher cost of purchasing a new unit. This decision would result in lower shipments for manufacturers and would leave less efficient units in the existing stock.

12.3.7 Separate Product Classes for Built-In Products

Most manufacturers expressed their support for separate product classes for built-in refrigerators and freezers. Manufacturers stated that built-in units are inherently less efficient than their free-standing counterparts for several reasons, including more limited air flow. Because of the limitations, the incremental costs of improving efficiency are higher at every efficiency level. Built-in manufacturers also believed that their components costs per unit were higher than for conventional products due to less bulk purchasing power. Built-in manufacturers also argued that their products offer distinct utility, justifying the need for separate product classes for built-ins. Without separate product classes for built-ins, depending on the stringency of new standards, some or all built-in models could be obsolesced. Built-in manufacturers also suggested that an average correction off of conventional products could be an appropriate means of accounting for the inherently lower efficiency of built-in products.

12.4 GRIM INPUTS AND ASSUMPTIONS

The GRIM serves as the main tool for assessing the impacts on industry due to amended energy conservation standards. DOE relies on several sources to obtain inputs for the GRIM. Data and assumptions from these sources are then fed into an accounting model that calculates the industry cash flow both with and without amended energy conservation standards.

12.4.1 Overview of the GRIM

The basic structure of the GRIM, illustrated in Figure 12.4.1 , is an annual cash flow analysis that uses manufacturer prices, manufacturing costs, shipments, and industry financial information as inputs, and accepts a set of regulatory conditions such as changes in costs, investments, and associated margins. The GRIM spreadsheet uses a number of inputs to arrive at a series of annual cash flows, beginning with the base year of the analysis, 2010, and continuing to 2043. The model calculates the INPV by summing the stream of annual discounted cash flows during this period and adding a discounted terminal value.[8]

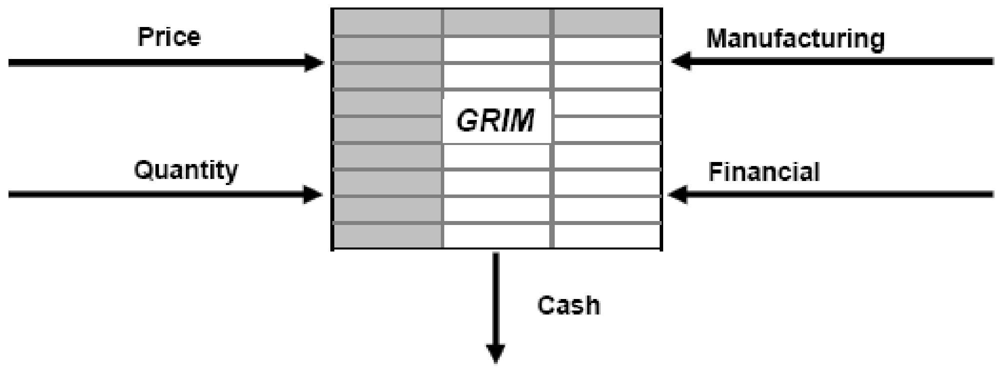

Figure 12.4.1 Using the GRIM to Calculate Cash Flow

The GRIM projects cash flows using standard accounting principles and compares changes in INPV between the base case and the standard-case scenario induced by amended energy conservation standards. The difference in INPV between the base case and the standard case(s) represents the estimated financial impact of the amended energy conservation standard on manufacturers. Appendix 12-B provides more technical details and user information for the GRIM.

12.4.2 Sources for GRIM Inputs

The GRIM uses several different sources for data inputs in determining industry cash flow. These sources include corporate annual reports, company profiles, Census data, credit ratings, the shipments model, the engineering analysis, and the manufacturer interviews.

12.4.2.1 Corporate Annual Reports

Corporate annual reports to the SEC (SEC 10-Ks) provided many of the initial financial inputs to the GRIM. These reports exist for publicly held companies and are freely available to the general public. DOE developed initial financial inputs to the GRIM by examining the annual SEC 10-K reports filed by publicly-traded manufacturers that manufacture residential refrigeration products and whose combined product range includes standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products. Since these companies do not provide detailed information about their individual product lines, DOE used the financial information for the entire companies as its initial estimates of the financial parameters in the GRIM analysis. These primary figures were derived using the same information used to develop the financial parameters for commercial clothes washers and cooking products, since no other publicly available SEC 10-K reports for refrigeration product manufacturers were available. These figures were later revised using feedback from interviews to be representative of manufacturing for each product grouping. DOE used corporate annual reports to derive the following initial inputs to the GRIM:

- Tax rate
- Working capital
- SG&A
- R&D
- Depreciation
- Capital expenditures
- Net PPE

12.4.2.2 Standard and Poor Credit Ratings

S&P provides independent credit ratings, research, and financial information. DOE relied on S&P reports to determine the industry's average cost of debt when calculating the cost of capital.

12.4.2.3 Shipment Model

The GRIM used shipment projections derived from DOE's shipments model in the national impact analysis (NIA). The model relied on historical shipments data for standard-size refrigerator-freezers, standard-size freezers, and compact refrigeration products. Chapter 9 of the TSD describes the methodology and analytical model DOE used to forecast shipments.

12.4.2.4 Engineering Analysis

The engineering analysis establishes the relationship between manufacturer production cost and energy consumption for the products covered in this rulemaking. DOE has adopted a combined efficiency level/design option/reverse engineering approach to developing cost-efficiency curves. DOE established efficiency levels defined as percentage energy use lower than that of baseline efficiency products. To develop the analytically-derived cost-efficiency curves, DOE collected information from various sources on the manufacturing cost and energy use reduction characteristics of each of the design options. Energy use reduction was modeled with a modified version of the established EPA Refrigerator Analysis (ERA) program which was used in the previous refrigerator rulemaking. DOE used the reverse engineering information in combination with the incremental costs for each design option to derive the labor, materials, overhead, and total production costs for products at each efficiency level. The engineering analysis also estimated a manufacturer markup to provide the manufacturer selling price (MSP) for each product at every efficiency level. See chapter 5 for a complete discussion of the engineering analysis.

12.4.2.5 Manufacturer Interviews

During the course of the MIA, DOE conducted interviews with a representative cross-section of manufacturers. DOE also interviewed manufacturers representing a significant portion of sales in every product class. During these discussions, DOE obtained information to determine and verify GRIM input assumptions in each industry. Key topics discussed during the interviews and reflected in the GRIM include:

- capital conversion costs (one-time investments in PPE);
- product conversion costs (one-time investments in research, product development, testing, and marketing);
- product cost structure, or the portion of the MPCs related to materials, labor, overhead, and depreciation costs;
- possible profitability impacts; and
- cost-efficiency curves calculated in the engineering analysis.

12.4.3 Financial Parameters

In the manufacturer interviews, DOE used the financial parameters from the April 2009 cooking products final rule and the January 2010 commercial clothes washers final rule[b] as a starting point for determining the residential refrigeration industry financial parameters. These initial estimates were used because the same white goods manufacturers produce both clothes washers, cooking products, and refrigeration products and no other publicly available SEC 10-K reports for refrigeration product manufacturers were available. These financial parameters were determined by averaging the values in the annual reports of three publicly traded companies engaged in manufacturing and selling clothes washers over an 8-year period (1999-2006). Table 12.4.1 below shows the data used to determine the initial financial parameter estimates.

Table 12.4.1 GRIM Financial Parameters Based on 1999–2006 Weighted Company Financial Data

Parameter	Industry-Weighted Average	Manufacturer		
		A	B	C
Tax Rate ***(% of Taxable Income)***	33.9	6.6	34.1	34.5
Working Capital ***(% of Revenue)***	2.9	9.6	5.6	2.0
SG&A ***(% of Revenue)***	12.5	12.7	12.3	13.2
R&D ***(% of Revenues)***	2.2	2.3	2.0	2.4
Depreciation ***(% of Revenues)***	3.4	3.9	3.4	3.3
Capital Expenditures ***(% of Revenues)***	3.5	1.9	3.4	3.6
Net Property, Plant, and Equipment ***(% of Revenues)***	19.9	17.3	21.6	19.4

During interviews, residential refrigeration manufacturers were asked to provide their own figures for the parameters listed in Table 12.4.1. Where applicable, DOE adjusted the parameters in the GRIM using this feedback and data from publicly traded companies to reflect manufacturing residential refrigeration products. Table 12.4.2

[b] The final rule for commercial clothes washers was published in the *Federal Register* on January 8, 2010 (75 FR1122). The final rule for cooking products was published in the *Federal Register* on April 8, 2009 (74 FR 16040). More information on these rulemakings can be found at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/clothes_washers.html and http://www1.eere.energy.gov/buildings/appliance_standards/residential/cooking_products.html.

presents the revised residential refrigeration parameters for freestanding refrigeration product manufacturers. Many freestanding residential refrigeration product manufacturers sell standard-size refrigerator-freezers, standard-size freezers, and compact refrigeration products. DOE used one set of financial parameters to characterize all three of these product groupings.

Table 12.4.2 GRIM Freestanding Residential Refrigeration Industry Financial Parameters

Parameter	**Revised Estimate (excluding Built-In Product Classes)**
Tax Rate ***% of taxable income***	33.9
Working Capital ***% of revenues***	2.9
SG&A ***% of revenues***	12.5
R&D ***% of revenues***	2.2
Depreciation ***% of revenues***	3.3
Capital Expenditures ***% of revenues***	3.6
Net PPE ***% of revenues***	19.9

For built-in refrigeration product manufacturers, DOE developed separate estimates for financial parameters. The built-in refrigeration product market is served by a different set of manufacturers. Even where manufacturers produce both freestanding and built-in products, the manufacturing process is sufficiently different to warrant a varying cost structure from larger freestanding residential refrigeration product manufacturers. As such, DOE revised its estimates to utilize different financial parameters to analyze the impacts of amended energy conservation standards on built-in refrigeration products in the GRIM. These estimates were revised based on feedback from built-in refrigeration manufacturers during manufacturer interviews and are shown in Table 12.4.3 below.

Table 12.4.3 GRIM Built-In Refrigeration Industry Financial Parameters

Parameter	**Revised Estimate for Built-In Refrigeration Products**
Tax Rate ***% of taxable income***	33.9
Working Capital ***% of revenues***	2.9
SG&A ***% of revenues***	19.0
R&D ***% of revenues***	3.5
Depreciation ***% of revenues***	4.5
Capital Expenditures ***% of revenues***	4.7
Net PPE ***% of revenues***	23.0

12.4.4 Corporate Discount Rate

DOE used the weighted-average cost of capital (WACC) as the discount rate to calculate the INPV. A company's assets are financed by a combination of debt and equity. The WACC is the total cost of debt and equity weighted by their respective proportions in the capital structure of the industry. DOE estimated the WACC for the residential refrigeration industry based on several representative companies, using the following formula:

WACC = After-Tax Cost of Debt x (Debt Ratio) + Cost of Equity x (Equity Ratio) Eq. 1

The cost of equity is the rate of return that equity investors (including, potentially, the company) expect to earn on a company's stock. These expectations are reflected in the market price of the company's stock. The capital asset pricing model (CAPM) provides one widely used means to estimate the cost of equity. According to the CAPM, the cost of equity (expected return) is:

Cost of Equity = Riskless Rate of Return + β x Risk Premium Eq. 2

where:

Riskless rate of return is the rate of return on a "safe" benchmark investment, typically considered the short-term Treasury Bill (T-Bill) yield.

Risk premium is the difference between the expected return on stocks and the riskless rate.

Beta (β) is the correlation between the movement in the price of the stock and that of the broader market. In this case, Beta equals one if the stock is perfectly correlated with the S&P 500 market index. A Beta lower than one means the stock is less volatile than the market index.

DOE determined that the industry average cost of equity for the residential refrigeration industry is 17.9 percent (Table 12.4.4). The representative data was taken from the commercial clothes washers final rule since several of the representative manufacturers are the same as in the residential refrigeration industry.

Table 12.4.4 Cost of Equity Calculation

Parameter	**Industry-Weighted Average %**	**Manufacturer**		
		A	B	C
(1) Average Beta (2002-2006 year)	1.31	1.0*	1.77	1.17
(2) Yield on 10-Year T-Bill (1990-2006)	5.9	-	-	-
(3) Market Risk Premium (1926-1999)	9.2	-	-	-
Cost of Equity (2)+[(1)*(3)]	17.9	-	-	-
Equity/Total Capital	37.2	23.7	-49.8	64.6

* Estimated Beta

Bond ratings are a tool to measure default risk and arrive at a cost of debt. Each bond rating is associated with a particular spread. One way of estimating a company's cost of debt is to treat it as a spread (usually expressed in basis points) over the risk-free rate. DOE used this method to calculate the cost of debt for all three manufacturers by using S&P ratings and adding the relevant spread to the risk-free rate.

In practice, investors use a variety of different maturity Treasury bonds to estimate the risk-free rate. DOE used the 10-year Treasury bond return because it captures long-term inflation expectations and is less volatile than short-term rates. The risk free rate is estimated to be approximately 6 percent, which is the average 10-year Treasury bond return between 1990 and 2006 (the analysis period used in the initial estimate for commercial clothes washers).

For the cost of debt, S&P's Credit Services provided the average spread of corporate bonds for the three public manufacturers between 2002 and 2006. As stated above, the representative data was taken from the commercial clothes washers final rule since several of the representative manufacturers are the same as in the residential refrigeration industry. DOE added the industry-weighted average spread to the average T-Bill yield over the same period. Since proceeds from debt issuance are tax deductible, DOE adjusted the gross cost of debt by the industry average tax rate to determine the net cost of debt for the industry. Table 12.4.5 presents the derivation of the cost of debt and the capital structure of the industry (*i.e.* the debt ratio (debt/total capital)).

Table 12.4.5 Cost of Debt Calculation

Parameter	Industry-Weighted Average %	Manufacturer		
		A	B	C
S&P Bond Rating	--	B-	BBB	BBB
(1) Yield on 10-Year T-Bill (1990-2006)	5.9	-	-	-
(2) Gross Cost of Debt	8.2	13.9	8.1	8.1
(3) Tax Rate	34	6.6	34.1	34.5
Net Cost of Debt (2) x ((1)-(3))	5.4	-	-	-
Debt/Total Capital	62.8	76.3	149.8	35.4

Using public information for these three companies from the commercial clothes washers final rule, the initial estimate for the residential refrigeration industry's WACC was approximately 10.1 percent. Subtracting an inflation rate of 2.9 percent over the analysis period used in the initial estimate, the inflation-adjusted WACC and the initial estimate of the discount rate used in the straw-man GRIM is 7.2 percent. DOE also asked for feedback on the 7.2 percent discount during manufacturer interviews and used this feedback to determine that 7.2 percent was an appropriate discount rate for use in the GRIM.

12.4.5 Trial Standard Levels

DOE developed TSLs for standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products. Consistent with the engineering analysis, DOE analyzed representative product classes for each product grouping. For freestanding products, DOE analyzed seven product classes that comprise approximately 90 percent of all shipments in the market today. DOE also analyzed four built-in product classes. However, DOE would also like to note that the product class structure, including identification numbers and descriptions, have been changed during this rulemaking. The final rule introduces a new structure that takes effect with the standards in 2014. Table 12.4.6 though Table 12.4.9 show the TSLs for all of the product classes that will go into effect in 2014.

Table 12.4.6 through Table 12.4.9 show the TSLs for the product groupings analyzed by DOE. For each representative product class, DOE considered percentage decreases from the baseline energy usage according to the updated test procedure, up to max-tech efficiency levels. DOE extrapolates the amended energy standards to the remaining product classes as described in section 2.15 of chapter 2 of the TSD. Chapter 2 also contains decriptions of the product classes both as they exist today and the new product class structure that takes affect at the the compliance date of this rulemaking in 2014. Table 12.4.6 through Table 12.4.9 also show which unanalyzed product classes are grouped with each analyzed product. Chapter 2 explains this process in greater detail.

Table 12.4.6 through Table 12.4.9 present the efficiency level at each TSL used in the GRIM. Table 12.4.6 presents the TSLs and the corresponding product class efficiencies for standard-size refrigerator-freezers. TSL 1 consists of those efficiency levels that meet current ENERGY STAR criteria. TSL 2 consists of the highest efficiency levels for which the consumer NPV is positive, using a 7-percent discount rate. TSL 3 consists of the highest efficiency levels for which the consumer NPV is positive, using a 3-percent discount rate, as well as the levels recommended in the Joint Comments[c]. TSL 4 consists of those efficiency levels that yield energy use 30 percent below the baseline products. TSL 5 consists of the max-tech efficiency levels.

[c] The Joint Comments were submitted by a group of interested parties representing a number of different interests and throughout DOE’s standards rulemaking process. The Joint Comments included recommended levels for the product classes covered by this rulemaking. The Joint Comments is Comment 49 submitted to DOE Docket No. EERE-2008-BT-STD-0012. DOE considered the Joint Comments to supersede earlier comments by the listed parties regarding issues subsequently discussed in the Joint Comments.

Table 12.4.6 Trial Standard Levels for Standard-Size Refrigerator-Freezers

Trial Standard Level	Representative Product Class		
	3 (Standard-Size Top-Mount Refrigerator-Freezers)	5 (Standard-Size Bottom-Mount Refrigerator-Freezers)	7 (Standard-Size Side-By-Side Refrigerator-Freezers)
	Scaled Product Classes		
	1, 1A, 2, 3I, 3A, and 6	5I and 5A	4 and 4I
	Efficiency Level (% less than baseline energy use)		
1	3 (20)	3 (20)	3 (20)
2	3(20)	3 (20)	4 (25)
3	4 (25)*	3 (20)	4 (25)
4	5 (30)	5 (30)	5 (30)
5	6 (36)	6 (36)	6 (33)

* Efficiency level for product classes 1, 1A, and 2 is 20%.

Table 12.4.7 presents the TSLs and the corresponding efficiencies for standard-size freezers. TSL 1 consists of those efficiency levels that yield energy use 20 percent below the baseline products. TSL 2 consists of the levels recommended in the Joint Comments. TSL 3 consists of incrementally higher efficiency levels than the preceding TSL. TSL 4 consists of the efficiency levels for which the consumer NPV is positive, using a 7-percent discount rate. TSL 5 consists of the max-tech efficiency levels, which are also the efficiency levels for which the consumer NPV is positive, using a 3-percent discount rate.

Table 12.4.7 Trial Standard Levels for Standard-Size Freezers

Trial Standard Level	Representative Product Class	
	9 (Standard-Size Upright Freezers)	10 (Standard-Size Chest Freezers)
	Scaled Product Classes	
	9I	8, 10A
	Efficiency Level (% less than baseline energy use)	
1	3 (20)	3 (20)
2	5 (30)	4 (25)*
3	6 (35)	5 (30)
4	7 (40)	6 (35)
5	8 (44)	7 (41)

* Efficiency level for product class 10A is 30%.

Table 12.4.8 presents the TSLs and the corresponding product class efficiencies for compact refrigeration products. TSL 1 consists of efficiency levels that meet current

ENERGY STAR criteria for compact refrigerators, and efficiency levels that are 10 percent below the baseline energy use for compact freezers. TSL 2 consists of the levels recommended in the Joint Comments. TSL 3 consists of the highest efficiency levels for which the consumer NPV is positive, using both a 3-percent and a 7-percent discount rate. TSL 4 consists of incrementally higher efficiency levels than TSL 3. TSL 5 consists of the max-tech efficiency levels.

Table 12.4.8 Trial Standard Levels for Compact Refrigeration Products

Trial Standard Level	Representative Product Class	
	11 (Compact Refrigerators and Refrigerator-Freezers)	18 (Compact Freezers)
	Scaled Product Classes	
	11A, 12	13, 13I, 13A, 14, 14I, 15, 15I, 16, 17
	Efficiency Level (% less than baseline energy use)	
1	3 (20)	1 (10)
2	4 (25)	1 (10)*
3	5 (30)	2 (15)
4	7 (40)	4 (25)
5	10 (59)	7 (42)

* Efficiency level for product class 13, 13I, 15, and 15I is 15%, efficiency level for product class 14 and 14I is 20%, and efficiency level for product class 13A is 25%.

Table 12.4.9 presents the TSLs and the corresponding product class efficiencies for built-in refrigeration products. TSL 1 consists of the efficiency levels that are 10 percent better than the current standard. TSL 2 consists of the highest efficiency levels for which the consumer NPV is positive, using both a 3-percent and a 7-percent discount rate. TSL 3 consists of the levels recommended in the Joint Comments. TSL 4 consists of incrementally higher efficiency levels than TSL 3. TSL 5 consists of the max-tech efficiency levels.

Table 12.4.9 Trial Standard Levels for Built-in Refrigeration Products

Trial Standard Level	Representative Product Class			
	3A-BI (Built-in All-Refrigerators)	**5-BI (Built-in Bottom-Mount Refrigerator-Freezers)**	**7-BI (Built-in Side-by-Side Refrigerator-Freezers)**	**9-BI (Built-in Upright Freezers)**
	Scaled Product Classes			
	3-BI and 3I-BI	**5A-BI and 5I-BI**	**4-BI and 4I-BI**	**9I-BI**
	Efficiency Level (% less than baseline energy use)			
1	1 (10)	1 (10)	1 (10)	1 (10)
2	2 (15)	2 (15)	1 (10)	3 (20)
3	3 (20)	2 (15)	3 (20)	4 (25)
4	4 (25)	4 (25)	3 (20)	4 (25)
5	5 (29)	5 (27)	4 (22)	5 (27)

12.4.6 NIA Shipment Forecast

The GRIM estimates manufacturer revenues based on total-unit-shipment forecasts and the distribution of these values by efficiency level. Changes in the efficiency mix at each standard level are a key driver of manufacturer finances. For this analysis, the GRIM used the NIA shipments forecasts. However, only the shipments in 2010 and beyond have an impact on INPV because 2010 is the base year to which future cash flows are summed. Chapter 9 of the TSD explains DOE's calculations of total shipments in detail. Table 12.4.10 shows total shipments forecasted in the shipment analysis for standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products in 2014. In order to aggregate shipments in the GRIM, DOE assigned each of the product classes to one of the 11 representative product classes shown in Table 12.4.6 to Table 12.4.9. DOE aggregated the shipments for all the scaled product classes under the corresponding representative product class and used the cost curve for the representative product class with which it is associated.

Table 12.4.10 Total Base Case NIA Shipments Forecast in 2014[d] in the Main NIA Shipment Scenario for Analyzed and Scaled Product Classes

Analyzed Product Class	Product Class Description	Total Industry Shipments (thousands)
3	Standard-Size Top-Mount Refrigerator-Freezers	7,081
5	Standard-Size Bottom-Mount Refrigerator-Freezers	1,950
7	Standard-Size Side-By-Side Refrigerator-Freezers	2.966
9	Standard-Size Upright Freezers	1,171
10	Standard-Size Chest Freezers	1,228
11	Compact Refrigerators and Refrigerator-Freezers	2,547
18	Compact Freezers	879
3A-BI	Built-in All-Refrigerators	28
5-BI	Built-in Bottom-Mount Refrigerator-Freezers	102
7-BI	Built-in Side-by-Side Refrigerator-Freezers	169
9-BI	Built-in Upright Freezers	26

12.4.6.1 Shipments Forecast

As part of the shipments analysis, DOE estimated the base-case shipment distribution by efficiency level for standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products. In the standards case, DOE determined efficiency distributions for cases in which a potential standard applies for 2014 and beyond. DOE assumed that product efficiencies in the base case that did not meet the standard under consideration would roll up to meet the new standard in 2014. DOE further assumed that the ENERGY STAR program will continue to promote high-efficiency appliances after revised standards are introduced in 2014, and that product market shares above a given standard level may shift. DOE describes how it calculated the ENERGY STAR and standards-case distribution in chapter 10. The efficiency distributions used in the base and standards case are shown in Table 12.4.11 through Table 12.4.20 below.

[d] The compliance date for the residential refrigeration energy conservation standard is estimated to be January 2014.

Table 12.4.11 Standard-Size Refrigerator-Freezers: Base-Case Efficiency Distributions

Efficiency Level (*% less than baseline energy use)*	Product Class 3: Standard-Size Top-Mount Refrigerator-Freezers			Product Class 5: Standard-Size Bottom-Mount Refrigerator-Freezers			Product Class 7: Standard-Size Side-By-Side Refrigerator-Freezers		
	Market Share *%*			Market Share *%*			Market Share *%*		
	2007	2014	2021	2007	2014	2021	2007	2014	2021
Baseline	80.6	78.2	80.6	11.8	13.0	11.8	25.0	21.7	21.7
1 (10)	5.9	4.2	5.9	0.1	0.1	0.1	43.0	26.4	26.4
2 (15)	13.2	9.4	0.1	69.8	19.3	0.0	30.3	15.0	15.0
3 (20)	0.2†	8.3†	13.4†	18.3†	67.7†	88.1†	1.7†	37.0†	37.0†
4 (25)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 (30)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 (Max-Tech)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

† Meets current (2008) ENERGY STAR criteria.

Table 12.4.12 Standard-Size Top-Mount Refrigerator-Freezers: Efficiency Distributions in 2014 by Efficiency Level

Efficiency Level (% less than baseline energy use)	Market Share %						
		Standard at Efficiency Level:					
	Base Case	1	2	3	4	5	6
Baseline	78.2	-	-	-	-	-	-
1 (10)	4.2	82.3	-	-	-	-	-
2 (15)	9.4	9.4	91.7	-	-	-	-
3 (20)	8.3	8.3	8.3	100.0	-	-	-
4 (25)	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (36)	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Table 12.4.13 Standard-Size Bottom-Mount Refrigerator-Freezers: Efficiency Distributions in 2014 by Efficiency Level

Efficiency Level (% less than baseline energy use)	Market Share %						
	Base Case	Standard at Efficiency Level: 1	2	3	4	5	6
Baseline	13.0	-	-	-	-	-	-
1 (10)	0.1	13.1	-	-	-	-	-
2 (15)	19.3	19.3	32.4	-	-	-	-
3 (20)	67.7	67.7	67.7	100.0	-	-	-
4 (25)	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (36)	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Table 12.4.14 Standard-Size Side-by Side Refrigerator-Freezers: Efficiency Distributions in 2014 by Efficiency Level

Efficiency Level (% less than baseline energy use)	Market Share %						
	Base Case	Standard at Efficiency Level: 1	2	3	4	5	6
Baseline	21.7	-	-	-	-	-	-
1 (10)	26.4	48.1	-	-	-	-	-
2 (15)	15.0	15.0	63.1	-	-	-	-
3 (20)	37.0	37.0	37.0	100.0	-	-	-
4 (25)	0.0	0.0	0.0	0.0	100.0	-	-
5 (30)	0.0	0.0	0.0	0.0	0.0	100.0	-
6 (33)	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Table 12.4.15 Standard-Size Freezers: Base-Case Efficiency Distributions

Efficiency Level (*% less than baseline energy use)*	Product Class 9: Standard-Size Upright Freezers			Product Class 10: Standard-Size Chest Freezers		
	Market Share %			Market Share %		
	2007	**2014**	**2021**	**2007**	**2014**	**2021**
Baseline	81.5	81.5	81.5	84.6	84.6	84.6
1 (10)	17.0*	17.0	8.5	14.3*	14.3	7.2
2 (15)	1.0	1.0	0.5	0.8	0.8	0.4
3 (20)	0.1	0.1†	9.1†	0.0	0.0†	7.6†
4 (25)	0.2	0.2	0.2	0.0	0.0	0.0
5 (30)	0.2	0.2	0.2	0.0	0.0	0.0
6 (35)	0.0	0.0	0.0	0.4	0.4	0.4
7 (40;41)	0.0	0.0	0.0	0.0	0.0	0.0
8 (44)	0.0	0.0	0.0	-	-	-

* Meets current ENERGY STAR criteria.
† Meets projected new ENERGY STAR criteria.

Table 12.4.16 Standard-Size Upright Freezers: Efficiency Distributions in 2014 by Efficiency Level

Efficiency Level (% less than baseline energy use)	Market Share %								
		Standard at Efficiency Level:							
	Base Case	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Baseline	81.5	-	-	-	-	-	-	-	-
1 (10)	17.0	98.5	-	-	-	-	-	-	-
2 (15)	1.0	1.0	99.5	-	-	-	-	-	-
3 (20)	0.1	0.1	0.1	99.6	-	-	-	-	-
4 (25)	0.2	0.2	0.2	0.2	99.8	-	-	-	-
5 (30)	0.2	0.2	0.2	0.2	0.2	100.0	-	-	-
6 (35)	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (44)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Table 12.4.17 Standard-Size Chest Freezers: Efficiency Distributions in 2014 by Efficiency Level

Efficiency Level (% less than baseline energy use)	Market Share %							
	Base Case	Standard at Efficiency Level:						
		1	2	3	4	5	6	7
Baseline	84.6							
1 (10)	14.3	98.9						
2 (15)	0.8	0.8	99.7					
3 (20)	0.0	0.0	0.0	99.7				
4 (25)	0.0	0.0	0.0	0.0	99.7			
5 (30)	0.0	0.0	0.0	0.0	0.0	99.7		
6 (35)	0.4	0.4	0.4	0.4	0.4	0.4	100.0	
7 (41)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Table 12.4.18 Compact Refrigeration Products: Base-Case Efficiency Distributions

Efficiency Level *(% less than baseline energy use)*	**Product Class 11: Compact Refrigerators and Refrigerator-Freezers**			**Product Class 18: Compact Freezers**		
	Market Share %			**Market Share %**		
	2007	**2014**	**2021**	**2007**	**2014**	**2021**
Baseline	97.1	98.5	98.5	95.4	95.4	95.4
1 (10)	0.3	0.3	0.3	4.6	4.6	4.6
2 (15)	0.0	0.0	0.0	0.0	0.0	0.0
3 (20)	0.9*	0.5	0.2	0.0*	0.0*	0.0*
4 (25)	0.2	0.1	0.1	0.0	0.0	0.0
5 (30)	1.5	0.8†	1.0†	0.0	0.0	0.0
6 (35)	0.0	0.0	0.0	0.0	0.0	0.0
7 (40;42)	0.0	0.0	0.0	0.0	0.0	0.0
8 (45)	0.0	0.0	0.0	-	-	-
9 (50)	0.0	0.0	0.0	-	-	-
10 (59)	0.0	0.0	0.0	-	-	-

* Meets current ENERGY STAR criteria.
† Meets projected new ENERGY STAR criteria.

Table 12.4.19 Compact Refrigerators and Refrigerator-Freezers: Efficiency Distributions in 2014 by Efficiency Level

Efficiency Level (% less than baseline energy use)	Market Share (%)										
			Standard at Efficiency Level:								
	Base Case	1	2	3	4	5	6	7	8	9	10
Baseline	98.5	-	-	-	-	-	-	-	-	-	-
1 (10)	0.3	98.7	-	-	-	-	-	-	-	-	-
2 (15)	0.0	0.0	98.7	-	-	-	-	-	-	-	-
3 (20)	0.5	0.5	0.5	99.2	-	-	-	-	-	-	-
4 (25)	0.1	0.1	0.1	0.1	99.3	-	-	-	-	-	-
5 (30)	0.8	0.8	0.8	0.8	0.8	100.0	-	-	-	-	-
6 (35)	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-	-
7 (40)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-
8 (45)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0		
9 (50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
10 (59)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Table 12.4.20 Compact Freezers: Efficiency Distributions in 2014 by Efficiency Level

Efficiency Level (% less than baseline energy use)	Market Share (%)							
		Standard at Efficiency Level:						
	Base Case	1	2	3	4	5	6	7
Baseline	95.4	-	-	-	-	-	-	-
1 (10)	4.6	100.0	-	-	-	-	-	-
2 (15)	0.0	0.0	100.0	-	-	-	-	-
3 (20)	0.0	0.0	0.0	100.0	-	-	-	-
4 (25)	0.0	0.0	0.0	0.0	100.0	-	-	-
5 (30)	0.0	0.0	0.0	0.0	0.0	100.0	-	-
6 (35)	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
7 (42)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

12.4.6.2 Default Standards-Case NIA Scenario

DOE used the default NIA scenario to calculate the INPV results presented in this chapter. The default NIA scenario used selected inputs from the Reference case in EIA's *Annual Energy Outlook 2010*.[9] The default NIA scenario also accounts for a relative price elasticity of -0.34. For example, a relative price increase of 10 percent results in a 3.4 percent decrease in shipments. In the GRIM, the user can also calculate INPV impacts without incorporating the elasticity effect. See chapter 9 for a description of the relative price elasticity.

12.4.7 Production Costs

Manufacturing a higher-efficiency product is typically more costly than manufacturing a baseline product due to the use of more complex components and higher-cost raw materials. The changes in the MPCs of the analyzed products can affect revenues, gross margins, and cash flow of the industry, making these data a key GRIM input for DOE's analysis.

For the MIA, DOE used the cost efficiency curves derived in the engineering analysis (detailed in chapter 5 and appendix 5-A of the TSD) using appropriate production volume estimates. For instance, more efficient products sold under existing energy conservation standards are manufactured at lower production volumes than baseline efficiency products. Enacting more stringent energy conservation standards will increase production volumes for more efficient units. Because DOE developed two cost efficiency curves for most product classes based on a smaller-sized unit and a larger-sized unit, the cost estimates in these two curves were averaged for each product class to obtain a representative MPC in the year 2009.

To calculate baseline MPCs in 2009, DOE followed a three step process. First, DOE derived each of the baseline products' retail prices from NPD market data (described in chapter 8 of the TSD). Next, DOE discounted these baseline retail prices by the sales tax and retail markup to arrive at the baseline MSPs. Next, DOE discounted the baseline MSPs by the manufacturer markup to arrive at the average baseline MPCs. For all non-built-in product classes, DOE used a 1.26 manufacturer markup to calculate baseline MPCs and MSPs. Because built-in product classes are high-end products that are made in much lower production volumes, DOE used a different cost structure for these products than for the other product classes. DOE used information submitted during manufacturer interviews to estimate that a typical baseline manufacturer markup for built-in products is 1.40. To calculate baseline MPCs for the built-in product classes, DOE discounted the NPD baseline retail prices by the 1.40 manufacturer markup and also a distributor markup to account for products sold through that distribution chain.

DOE also used the information from its tear-down analysis to verify the accuracy of the markup information and cost data for the units it tore down. In addition, DOE used the tear-down cost data to disaggregate the 2009 MPCs into material, labor, and overhead costs. DOE developed different depreciation values for freestanding products and built-in refrigeration products by using a depreciation value that is consistent with historical information in SEC 10-Ks. The remainder of total overhead was allocated to factory overhead. To calculate the incremental MPCs for products above the baseline, DOE added the incremental material, labor, and overhead costs from the engineering cost efficiency curves to the baseline MPCs. Because DOE did not tear down built-in refrigeration products, DOE based its material, labor, and overhead estimates on the most similar freestanding product classes. DOE also assumed that the labor content was twice as great for built-in refrigeration products compared to the most similar freestanding product classes.

As stated in section 12.4.6, DOE allocated shipments for the unanalyzed product classes to the product class for which the amended energy conservation standard is scaled. That way, the total revenue and INPV impacts for each representative product class is also representative of the INPV impacts on the unanalyzed product classes used to promulgate the amended energy conversation standards.

Table 12.4.21 through Table 12.4.31 show the production cost estimates used in the GRIM for each analyzed product class.

Table 12.4.21 MPC Breakdown for Refrigerator-Freezers for Analyzed Product Class 3 in 2009 (Standard-Size Top-Mount Refrigerator-Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	47.92	181.04	32.06	11.32	272.34	1.26	343.15
TSL 1	EL 3 (20)	47.92	239.08	29.64	13.74	330.38	1.26	416.28
TSL 2	EL 3 (20)	47.92	239.08	29.64	13.74	330.38	1.26	416.28
TSL 3	EL 4 (25)*	50.00	261.09	31.11	14.85	357.05	1.26	449.88
TSL 4	EL 5 (30)	53.24	310.65	34.39	17.28	415.56	1.26	523.61
TSL 5	EL 6 (36)	55.28	387.29	36.14	20.77	499.48	1.26	629.34

*Efficiency level for product classes 1, 1A, and 2 is 20%.

Table 12.4.22 MPC Breakdown for Refrigerator-Freezers for Analyzed Product Class 5 in 2009 (Standard-Size Bottom-Mount Refrigerator-Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	70.79	335.96	39.87	19.38	465.99	1.26	587.15
TSL 1	EL 3 (20)	70.79	365.76	38.63	20.62	495.79	1.26	624.70
TSL 2	EL 3 (20)	70.79	365.76	38.63	20.62	495.79	1.26	624.70
TSL 3	EL 3 (20)	70.79	365.76	38.63	20.62	495.79	1.26	624.70
TSL 4	EL 5 (30)	73.29	467.28	39.21	25.15	604.92	1.26	762.20
TSL 5	EL 6 (36)	79.95	544.76	45.14	29.06	698.91	1.26	880.63

Table 12.4.23 MPC Breakdown for Refrigerator-Freezers for Analyzed Product Class 7 in 2009 (Standard-Size Side-By-Side Refrigerator-Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	97.48	415.42	37.36	23.87	574.13	1.26	723.40
TSL 1	EL 3 (20)	97.69	447.90	36.96	25.27	607.82	1.26	765.85
TSL 2	EL 4 (25)	98.29	487.55	36.08	26.98	648.90	1.26	817.61
TSL 3	EL 4 (25)	98.29	487.55	36.08	26.98	648.90	1.26	817.61
TSL 4	EL 5 (30)	101.94	566.95	38.72	30.70	738.30	1.26	930.26
TSL 5	EL 6 (33)	106.65	625.01	43.15	33.61	808.43	1.26	1,018.62

Table 12.4.24 MPC Breakdown for Analyzed Product Class 9 in 2009 (Standard-Size Upright Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	45.72	198.99	27.22	11.80	283.73	1.26	357.50
TSL 1	EL 3 (20)	45.72	230.23	29.28	13.24	318.47	1.26	401.27
TSL 2	EL 5 (30)	45.72	239.00	54.31	14.71	353.75	1.26	445.72
TSL 3	EL 6 (35)	45.72	276.69	52.74	16.28	391.43	1.26	493.20
TSL 4	EL 7 (40)	45.84	327.80	51.88	18.46	443.98	1.26	559.42
TSL 5	EL 8 (44)	48.22	427.36	61.52	23.30	560.40	1.26	706.11

Table 12.4.25 MPC Breakdown for Analyzed Product Class 10 in 2009 (Standard-Size Chest Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	29.43	149.40	19.71	8.61	207.16	1.26	261.02
TSL 1	EL 3 (20)	29.43	161.60	25.91	9.41	226.36	1.26	285.22
TSL 2	EL 4 (25)*	29.43	165.87	50.66	10.67	256.63*	1.26	323.36
TSL 3	EL 5 (30)	29.74	177.84	51.20	11.23	270.00	1.26	340.20
TSL 4	EL 6 (35)	29.43	217.25	48.52	12.81	308.01	1.26	388.10
TSL 5	EL 7 (41)	31.24	282.66	54.69	15.99	384.58	1.26	484.57

*Efficiency level for product class 10A is 30%.

Table 12.4.26 MPC Breakdown for Analyzed Product Class 11 in 2009 (Compact Refrigerators and Refrigerator-Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	2.33	61.15	5.61	3.00	72.10	1.26	90.84
TSL 1	EL 3 (20)	2.33	68.62	8.18	3.43	82.57	1.26	104.04
TSL 2	EL 4 (25)	2.33	71.08	13.35	3.76	90.53	1.26	114.06
TSL 3	EL 5 (30)	2.33	72.42	18.08	4.03	96.86	1.26	122.05
TSL 4	EL 7 (40)	2.33	101.38	11.13	4.98	119.83	1.26	150.99
TSL 5	EL 10 (59)	6.92	159.57	21.25	8.14	195.88	1.26	246.80

Table 12.4.27 MPC Breakdown for Analyzed Product Class 18 in 2009 (Compact Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	2.74	82.38	13.51	4.28	102.90	1.26	129.66
TSL 1	EL 1 (10)	2.74	87.13	13.31	4.48	107.65	1.26	135.64
TSL 2	EL 1 (10)*	2.74	87.13	13.31	4.48	107.65*	1.26	135.64
TSL 3	EL 2 (15)	2.74	89.63	18.96	4.83	116.16	1.26	146.36
TSL 4	EL 4 (25)	3.43	97.72	44.29	6.31	151.75	1.26	191.20
TSL 5	EL 7 (42)	4.54	168.19	45.39	9.46	227.58	1.26	286.75

* Efficiency level for product class 13, 13I, 15, and 15I is 15%, efficiency level for product class 14 and 14I is 20%, and efficiency level for product class 13A is 25%.

Table 12.4.28 MPC Breakdown for Analyzed Product Class 3A-BI in 2009 (Built-in All-Refrigerators

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	95.84	1,615.36	208.81	115.41	2,035.42	1.40	2,849.59
TSL 1	EL 1 (10)	95.84	1,620.46	208.52	115.70	2,040.52	1.40	2,856.73
TSL 2	EL 2 (15)	95.84	1,628.86	208.05	116.17	2,048.92	1.40	2,868.49
TSL 3	EL 3 (20)	98.73	1,695.16	211.76	120.56	2,126.21	1.40	2,976.69
TSL 4	EL 4 (25)	104.59	1,787.89	210.87	126.43	2,229.77	1.40	3,121.68
TSL 5	EL 5 (29)	105.00	1,863.42	208.77	130.87	2,308.06	1.40	3,231.28

Table 12.4.29 MPC Breakdown for Analyzed Product Class 5-BI in 2009 (Built-in Bottom-Mount Refrigerator-Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	141.57	1,847.90	160.55	129.23	2,279.26	1.40	3,190.97
TSL 1	EL 1 (10)	141.64	1,862.79	160.06	130.10	2,294.60	1.40	3,212.44
TSL 2	EL 2 (15)	141.57	1,909.20	157.08	132.71	2,340.56	1.40	3,276.79
TSL 3	EL 2 (15)	141.57	1,909.20	157.08	132.71	2,340.56	1.40	3,276.79
TSL 4	EL 4 (25)	146.16	2,044.43	158.40	141.19	2,490.18	1.40	3,486.25
TSL 5	EL 5 (27)	150.74	2,087.76	160.97	144.23	2,543.70	1.40	3,561.18

Table 12.4.30 MPC Breakdown for Analyzed Product Class 7-BI in 2009 (Built-in Side-by-Side Refrigerator-Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	194.97	2,812.72	168.15	190.89	3,366.73	1.40	4,713.43
TSL 1	EL 1 (10)	195.22	2,847.34	167.95	192.98	3,403.48	1.40	4,764.88
TSL 2	EL 1 (10)	195.22	2,847.34	167.95	192.98	3,403.48	1.40	4,764.88
TSL 3	EL 3 (20)	199.55	2,997.40	168.57	202.30	3,567.83	1.40	4,994.96
TSL 4	EL 3 (20)	199.55	2,997.40	168.57	202.30	3,567.83	1.40	4,994.96
TSL 5	EL 4 (22)	204.13	3,050.21	171.65	205.93	3,631.93	1.40	5,084.70

Table 12.4.31 MPC Breakdown for Analyzed Product Class 9-BI in 2009 (Built-in Upright Freezers)

TSL (Efficiency Level)	Efficiency Level (% less than baseline energy use)	Labor $	Material $	Overhead $	Depreciation $	MPC $	Manufacturer Markup	MSP $
Baseline	Baseline	91.45	1,558.58	154.61	108.47	1,913.11	1.40	2,678.35
TSL 1	EL 1 (10)	91.45	1,569.78	153.97	109.11	1,924.31	1.40	2,694.03
TSL 2	EL 3 (20)	91.51	1,628.82	151.16	112.49	1,983.99	1.40	2,777.58
TSL 3	EL 4 (25)	94.84	1,697.43	155.02	117.05	2,064.35	1.40	2,890.09
TSL 4	EL 4 (25)	94.84	1,697.43	155.02	117.05	2,064.35	1.40	2,890.09
TSL 5	EL 5 (25)	100.62	1,746.54	157.97	120.52	2,125.65	1.40	2,975.91

DOE also incorporated learning over time into the analysis, which affects the MPC and MSPs over time. These prices trends impact the MIA results by changing industry revenue and cash flow in each year. For the MIA, DOE used the same learning rates as used in the NIA from the base year of the analysis, 2011, through the end of the analysis period. DOE also assumed that MPCs and MSPs were similarly impacted by the learning rates in both the base case and standards cases. See chapter 8 for a description of how DOE incorporated learning rates into the analysis.

12.4.8 Conversion Costs

Amended energy conservation standards typically cause manufacturers to incur one-time conversion costs to bring their production facilities and product designs into compliance with new regulations. For the MIA, DOE classified these one-time conversion costs into two major groups: capital conversion costs and product conversion costs. Capital conversion costs are one-time investments in PPE to adapt or change existing production facilities so that new product designs can be fabricated and assembled under the new regulation. Product conversion costs are one-time investments in research, development, testing, marketing and other costs to make product designs comply with amended energy conservation standards. The following sections describe the inputs DOE used in the GRIM in greater detail.

12.4.8.1 Capital Conversion Costs

To calculate industry cash flow impacts DOE evaluated the level of capital conversion costs manufacturers would incur to comply with amended energy conservation standards. This evaluation drew from multiple data sources and methodologies. Table 12.4.32 through Table 12.4.42 show DOE's estimates of the capital conversion costs necessary for each product class at each TSL. The methodology DOE used to calculate the capital conversion costs is described below.

During the MIA interviews, DOE asked manufacturers to estimate the capital conversion costs required to expand the production of higher-efficiency products that may be required by standards. In turn, many manufacturers provided estimates and descriptions of the required tooling and plant changes that would be necessary to upgrade product lines to meet various potential efficiency levels. DOE based its capital conversion cost estimates on the information gathered in these interviews as well as assumptions from the engineering analysis.

Using the interviews and the engineering analysis's design options at each efficiency level for each product class, DOE determined what changes would be required at existing production facilities if manufacturers implemented those design options. DOE used information from manufacturer interviews to determine the level of capital conversion costs that these changes would require. For all freestanding product classes, DOE segmented its capital conversion costs equally between the two product sizes analyzed in the engineering analysis to get a representative total capital conversion cost for each efficiency level for each analyzed product class. Because DOE analyzed one product for the built-in product classes, DOE calculated the capital conversion costs for each built-in product class using the design options for the one analyzed product.

For each product at each efficiency level, DOE assumed that most component swaps, while requiring moderate product conversion costs, would not require changes to existing production lines and equipment, and therefore not require additional capital expenditures. However, for larger condensers and evaporators DOE calculated the tooling investment required for both the fabrication equipment and the tooling changes because these options would cause slight changes to the interiors of existing products. These tooling changes would likely include purchasing new dies or molds for a small change in internal dimensions or shelving.

DOE assumed the major capital conversion costs would occur when manufacturers would have to redesign their existing product lines. For standard-size freezers and compact refrigeration products, DOE analyzed design options that would require changes to insulation thickness, an instance explicitly requiring the redesign of existing lines. For these product classes, DOE used information from manufacturer interviews to determine the cost of the production equipment necessary to implement complete redesigns. DOE allocated these costs to both product sizes analyzed in the engineering analysis for each product class and assumed that one quarter of the total redesign cost would be required for changes to door insulation thickness while the remaining three-quarters of the redesign cost would be required for changes to wall insulation thickness. For standard-size refrigerator-freezers and built-in refrigeration products, DOE understands that a limited number of existing products currently use VIPs. For freestanding standard-size refrigerator-freezers, DOE notes that these current products benefited from a tax credit that allowed a more labor-intensive solution and slower production speed. However, if the standard were set at levels that necessitated VIPs, it would be extremely disruptive to current operations, even those facilities that make a limited number of products with VIPs, due to the high production volumes required. Incorporating VIPs in high volume production would require major changes to the manufacturing processes and equipment currently used for the low-volume products that use VIPs. Therefore, DOE assumed that if the energy conservation standard were set at levels that were analyzed with VIPs as design options, the changes to production facilities would be substantial despite some limited current use of the technology. Because of the changes required to implement these design options would greatly change existing products, DOE expects that the capital conversion costs would approximate the purchase of new production equipment. DOE used the implementation of the first VIP as a proxy for the level that would require new production lines.

For all product classes, DOE used the assumptions from the engineering analysis about the incremental depreciation costs associated with additional VIPs to calculate the additional production equipment that would be required to add additional steps in the manufacturing process. DOE used the incremental per unit depreciation cost assumptions in the engineering analysis for additional VIPs and multiplied that figure by each manufacturer's estimated shipments over an average equipment lifetime of 15 years. DOE calculated each manufacturer's estimated shipments using market share data for each product class that was also requested during manufacturer interviews.

DOE followed this methodology for each product class that interviewed manufacturers produced. DOE then scaled its estimates to account for the rest of the market. DOE interviewed an average of 90 percent of the market across the seven freestanding and four built-in product classes analyzed.

Finally, DOE assumed that the design options that would require capital conversion costs would strand PPE that was not fully depreciated and would have had a longer life if the amended energy conservation standards were not implemented. DOE did not receive quantitative information on the magnitude of stranded assets. However, because net PPE is approximately half of gross PPE in a mature industry and because not all existing assets would need to be replaced if products were completely redesigned, DOE assumed that stranded assets would be 50 percent of the capital conversion costs at each efficiency level.

DOE's estimates of the capital conversion costs for all of the residential refrigeration products can be found in Table 12.4.32 through Table 12.4.42 below.

Table 12.4.32 Capital Conversion Costs for Analyzed Product Class 3 (Standard-Size Top-Mount Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 16 Cubic Foot PC 3 Unit	Capital Conversion Costs for the 16 Cubic Foot PC 3 Unit *2009$ millions*	Design Options Considered for the 21 Cubic Foot PC 3 Unit	Capital Conversion Costs for the 21 Cubic Foot PC 3 Unit *2009$ millions*
TSL 1, TSL 2	EL 3 (20)	Increase Condenser Size by 100% Increase Compressor EER from 5.55 to 6.26 Brushless DC Condenser Fan Motor Increase Evaporator Size by 14% Adaptive Defrost Variable Speed Compressor	$26.0	Increase Compressor EER from 5.94 to 6.08 Increase Evaporator Size by 25% Brushless DC Condenser Fan Motor	$11.6
TSL 3	EL 4 (25)*	TSL 1, TSL 2 Design Options + 12.2 sqft VIP in FZR Cabinet	$252.3	TSL 1, TSL 2 Design Options + Brushless DC Evaporator Fan Motor	$11.6
TSL 4	EL 5 (30)	TSL 3 Design Options + 2.9 sqft VIP in FZR Door 7.1 sqft VIP in FF Door 6.7 sqft VIP in FF Cabinet	$395.4	TSL 3 Design Options + Adaptive Defrost 3.6 sqft VIP in FZR Door 7.6 sqft VIP in FZR Cabinet	$298.3
TSL 5	EL 6 (36)	TSL 4 Design Options + 1.9 sqft more VIP in FF	$412.2	TSL 4 Design Options + Variable Speed Compressor 8.5 sqft VIP in FF Door 10.9 sqft VIP in FF Cabinet	$488.9

*Efficiency level for product classes 1, 1A and 2 is 20%.

Table 12.4.33 Capital Conversion Costs for Analyzed Product Class 5 (Standard-Size Bottom-Mount Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 18.5 Cubic Foot PC 5 Unit	Capital Conversion Costs for the 18.5 Cubic Foot PC 5 Unit *2009$ millions*	Design Options Considered for the 25 Cubic Foot PC 5 Unit	Capital Conversion Costs for the 25 Cubic Foot PC 5 Unit *2009$ millions*
TSL 1, TSL 2, TSL 3	EL 3 (20)	Increase Compressor EER from 5.61 to 6.26 Brushless DC Evaporator Fan Motor Adaptive Defrost Brushless DC Condenser Fan Motor Variable Antisweat Heat Control Increase Evaporator Size by 25%	$11.9	Increase Compressor EER from 5.00 to 6.26	-
TSL 4	EL 5 (30)	TSL 1, 2, 3 Design Options + Variable Speed Compressor 4.8 sqft VIP in FZR Door 6.8 sqft VIP in FF Door 13.7 sqft VIP in FZR Cabinet	$262.1	TSL 1, 2, 3 Design Options + Brushless DC Evaporator Fan Motor Variable Anti-Sweat Heater Control Brushless DC Condenser Fan Motor Variable Speed Compressor	-
TSL 5	EL 6 (36)	TSL 4 Design Options + 7.2 sqft VIP in FF Cabinet	$280.4	TSL 4 Design Options + 9.2 sqft VIP in FF Door 5.9 sqft VIP in FZR Door 14.8 sqft VIP in FZR Cabinet 10.3 sqft VIP in FF Cabinet	$265.2

Table 12.4.34 Capital Conversion Costs for Analyzed Product Class 7 (Standard-Size Side-By-Side Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 22 Cubic Foot PC 7 Unit	Capital Conversion Costs for the 22 Cubic Foot PC 7 Unit *2009$ millions*	Design Options Considered for the 26 Cubic Foot PC 7 Unit	Capital Conversion Costs for the 26 Cubic Foot PC 7 Unit *2009$ millions*
TSL 1	EL 3 (20)	Increase Compressor EER from 5.51 to 6.26 Brushless DC Condenser Fan Motor Increase Evaporator Area 19% Increase Condenser Size by 27% Variable Anti-Sweat Heater Control for Ice Dispenser 5.1 sqft VIP in FZR Door	$179.3	Increase Compressor EER from 5.21 to 6.11 Brushless DC Evaporator Fan Motor Brushless DC Condenser Fan Motor	-
TSL 2, TSL 3	EL 4 (25)	TSL 1 Design Options + Remove 5.1 sqft VIP FZR Door Variable Speed Compressor 3.0 sqft VIP in FZR Cabinet	$179.3	TSL 1 Design Options + Increase Compressor EER from 6.11 to 6.26 Variable Anti-Sweat Heater Control for Ice Dispenser Increase Condenser Size by 10% 6.2 sqft VIP in FZR Door	$164.4
TSL 4	EL 5 (30)	TSL 2 and 3 Design Options + 7.4 sqft more VIP in FZR Cabinet 5.1 sqft VIP in FZR Door 8 sqft VIP in FF Door 7.8 sqft VIP in FF Cabinet	$275.8	TSL 2 and 3 Design Options + Variable Speed Compressor 2.6 sqft VIP in FZR Cabinet	$173.1
TSL 5	EL 6 (33)	TSL 4 Design Options + 4.9 sqft more VIP in FF Cabinet	$293.0	TSL 4 Design Options + 9.1 sqft more VIP in FZR Cabinet 8.2 sqft VIP in FF	$273.2

				Door 13.4 sqft VIP in FF Cabinet	

Table 12.4.35 Capital Conversion Costs for Analyzed Product Class 9 (Standard-Size Upright Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 14 Cubic Foot PC 9 Unit	Capital Conversion Costs for the 14 Cubic Foot PC 9 Unit *2009$ millions*	Design Options Considered for the 20 Cubic Foot PC 9 Unit	Capital Conversion Costs for the 20 Cubic Foot PC 9 Unit *2009$ millions*
TSL 1	EL 3 (20)	Brushless DC Evaporator Fan Motor Increase Compressor EER from 5.04 to 6.08 Add 1 inch Insulation to Door Adaptive Defrost	$9.6	Brushless DC Evaporator Fan Motor Increase Compressor EER from 5.73 to 6.24 Adaptive Defrost Increase Evaporator Size by 22% Forced Convection Condenser with Brushless DC Condenser Fan	$11.2
TSL 2	EL 5 (30)	TSL 1 Design Options + Add 0.56 inch Insulation to Cabinet	$38.4	TSL 1 Design Options + Add 0.7 inch Insulation to Door Add 0.5 inch Insulation to Cabinet	$48.8
TSL 3	EL 6 (35)	TSL 2 Design Options + Remove 0.06 inch Cabinet Insulation Variable Speed Compressor	$38.4	TSL 2 Design Options + Add 0.5 inch Insulation to Cabinet	$48.8
TSL 4	EL 7 (40)	TSL 3 Design Options + Add 0.5 Inch Insulation to Cabinet 5.7 sqft VIP in Door	$46.6	TSL 3 Design Options + Variable Speed Compressor	$48.8
TSL 5	EL 8 (44)	TSL 4 Design Options + 4.6 sqft more VIP in Door 18.9 sqft VIP in Cabinet	$81.3	TSL 4 Design Options + 14.4 sqft VIP in Door 23.1 sqft VIP in Cabinet	$103.8

Table 12.4.36 Capital Conversion Costs for Analyzed Product Class 10 (Standard-Size Chest Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 15 Cubic Foot PC 10 Unit	Capital Conversion Costs for the 15 Cubic Foot PC 10 Unit *2009$ millions*	Design Options Considered for the 20 Cubic Foot PC 10 Unit	Capital Conversion Costs for the 20 Cubic Foot PC 10 Unit *2009$ millions*
TSL 1	EL 3 (20)	Increase Compressor EER from 4.92 to 6.08 Add 0.24 inch Insulation to Door	$9.8	Increase Condenser Size by 24% Increase Compressor EER from 5.71 to 6.25 Convert Door Insulation to PU Foam Add 1 inch Insulation to Door	$19.6
TSL 2	EL 4 (25)*	TSL 1 Design Options + Add 0.76 inch Insulation to Door Add 0.15 inch Insulation to Cabinet	$39.0	TSL 1 Design Options + Add 0.35 inch Insulation to Cabinet	$48.8
TSL 3	EL 5 (30)	TSL 2 Design Options + Add 0.35 inch Insulation to Cabinet	$39.0	TSL 2 Design Options + Add 0.4 inch Insulation to Cabinet 4.5 sqft VIP in Bottom Wall	$55.9
TSL 4	EL 6 (35)	TSL 3 Design Options + Variable Speed Compressor	$39.0	TSL 3 Design Options + Remove 4.5 sqft VIP Bottom Wall Variable Speed Compressor	$48.8
TSL 5	EL 7 (41)	TSL 4 Design Options + Add 0.25 inch Insulation to Cabinet 8.2 sqft VIP on bottom 8.8 sqft VIP on door	$51.7	TSL 4 Design Options + 10.2 sqft VIP in Bottom Wall 12 sqft VIP in Door	$83.0

*Efficiency level for product class 10A is 30%.

Table 12.4.37 Capital Conversion Costs for Analyzed Product Class 11 (Compact Refrigerators and Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 1.7 Cubic Foot PC 11 Unit	Capital Conversion Costs for the 1.7 Cubic Foot PC 11 Unit *2009$ millions*	Design Options Considered for the 4 Cubic Foot PC 11 Unit	Capital Conversion Costs for the 4 Cubic Foot PC 11 Unit *2009$ millions*
TSL 1	EL 3 (20)	Increase Evaporator Size by 20% Increase Compressor EER from 3.02 to 3.47 Increase Condenser Size by 19% Add 3/4 inch Insulation in Door	$12.4	Increase Compressor EER from 4.57 to 5.3 Increase Condenser Size by 22% Add 3/4 inch Insulation to Door	$11.2
TSL 2	EL 4 (25)	TSL 1 Design Options + Add 0.18 inch Insulation in Cabinet	$34.6	TSL 1 Design Options + Convert to Isobutane Refrigerant Add 1/4 inch Insulation to Door	$11.2
TSL 3	EL 5 (30)	TSL 2 Design Options + Add 0.57 inch Insulation in Cabinet	$34.6	TSL 2 Design Options + Add 0.22 inch Insulation to Cabinet Remove 1/4 inch Insulation from Door	$33.4
TSL 4	EL 7 (40)	Eliminate all previous Design Options Variable Speed Compressor Convert to Isobutane Refrigerant	-	TSL 3 Design Options + Add 0.53 inch Insulation to Cabinet	$33.4
TSL 5	EL 10 (59)	TSL 4 Design Options + Increase Evaporator Size by 20% Increase Condenser Size by 19% Add 3/4 inch Insulation in Door Add 3/4 inch Insulation in Cabinet Add 4.7 sqft VIP in Cabinet Add 2.2 sqft VIP in Door	$71.8	TSL 4 Design Options + Variable Speed Compressor Remove 0.2 inch Cabinet Insulation 7.2 sqft VIP Cabinet 4.2 sqft VIP Door	$90.9

Table 12.4.38 Capital Conversion Costs for Analyzed Product Class 18 (Compact Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 3.4 Cubic Foot PC 18 Unit	Capital Conversion Costs for the 3.4 Cubic Foot PC 18 Unit *2009$ millions*	Design Options Considered for the 7 Cubic Foot PC 18 Unit	Capital Conversion Costs for the 7 Cubic Foot PC 18 Unit *2009$ millions*
TSL 1, TSL 2	EL 1 (10)*	Increase Compressor EER from 3.74 to 4.17	-	Increase Compressor EER from 4.50 to 5.02	-
TSL 3	EL 2 (15)	TSL 1 and 2 Design Options + Increase Compressor EER from 4.17 to 4.29 Add 1 inch Insulation to Door	$4.2	TSL 1 and 2 Design Options + Increase Compressor EER from 5.02 to 5.27 Add 0.12 inch Insulation to Door	$4.2
TSL 4	EL 4 (25)	TSL 3 Design Options + Remove 1/4 inch Insulation from Door Add 0.75 inch Insulation to Cabinet Add 2.1 sqft VIP in Bottom Wall	$20.5	TSL 3 Design Options + Add 0.63 inch Insulation to Door Add 0.62 inch Insulation to Cabinet	$16.9
TSL 5	EL 7 (42)	Remove all previous Design Options Variable Speed Compressor Add 0.75 inch Insulation to Door Add 0.75 inch Insulation to Cabinet Add 2.1 sqft VIP in Bottom Wall Add 3.3 sqft VIP in Door	$22.8	Remove all previous Design Options Variable Speed Compressor Add 0.76 inch Insulation to Cabinet Add 3/4 inch Insulation to Door Add 4.1 sqft VIP to Cabinet Bottom Add 5.1 sqft VIP to Door	$34.9

* Efficiency level for product class 13, 13I, 15, and 15I is 15%, efficiency level for product class 14 and 14I is 20%, and efficiency level for product class 13A is 25%.

Table 12.4.39 Capital Conversion Costs for Analyzed Product Class 3A-BI (Built-in All-Refrigerators) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the PC 3A-BI Unit	Capital Conversion Costs for the PC 3A-BI Unit *2009$ millions*
TSL 1	EL 1 (10)	Decrease Both Compressor Capacity (same EER) 10% Increase to Condenser Area Brushless DC Evaporator Fan Upper Evaporator	$0.5
TSL 2	EL 2 (15)	TSL 1 Design Options + Brushless DC Evaporator Fan Lower Evaporator Brushless DC Condenser Fan	$0.5
TSL 3	EL 3 (20)	TSL 2 Design Options + Full VIP--Upper Door Partial VIP--Lower Cabinet	$14.9
TSL 4	EL 4 (25)	TSL 3 Design Options + Full VIP--Lower Cabinet Full VIP--Upper Cabinet Upper System Variable Speed Compressor	$15.5
TSL 5	EL 5 (29)	TSL 4 Design Options + Full VIP--Lower Door Lower System Variable Speed Compressor	$15.8

Table 12.4.40 Capital Conversion Costs for Analyzed Product Class 5-BI (Built-in Bottom-Mount Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the PC 5-BI Unit	Capital Conversion Costs for the PC 5-BI Unit *2009$ millions*
TSL 1	EL 1 (10)	Decrease FF Compressor Capacity (same EER) 10% Increase to Condenser Area Increase FRZ Compressor EER to 6.26 1.0 sqft VIP--FRZ Door	$16.9
TSL 2, TSL 3	EL 2 (15)	TSL 1 Design Options + Remove 1.0 sqft VIP -- FZR Door FRZ Variable Speed Compressor with Brushless DC Condenser Fan	$0.6
TSL 4	EL 4 (25)	TSL 2 and 3 Design Options + 14.6 sqft VIP--FRZ Cabinet (Partial Coverage) Add 3.6 sqft VIP -- FZR Cabinet (Full Coverage) 6.0 sqft VIP--FRZ Door (Full Coverage) FF Variable Speed Compressor with Brushless DC Condenser Fan	$19.1
TSL 5	EL 5 (27)	TSL 4 Design Options + 9.4 sqft VIP -- FF Door (Full Coverage) 3.8 sqft VIP -- FF Cabinet (Full Coverage)	$22.5

Table 12.4.41 Capital Conversion Costs for Analyzed Product Class 7-BI (Built-in Side-by-Side Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for PC 7-BI Unit	Capital Conversion Costs for the PC 7-BI Unit *2009$ millions*
TSL 1, TSL 2	EL 1 (10)	High Efficiency Compressor Heat Exchanger Improvement Variable Anti-Sweat Heater Control Partial VIP to Freezer Door	$22.4
TSL 3, TSL 4	EL 3 (20)	TSL 1 and 2 Design Options + Eliminate VIP to Freezer Door Variable Speed Compressor VIP to Freezer Door VIP to Freezer Cabinet	$23.8
TSL 5	EL 4 (22)	TSL 3 and 4 Design Options + VIP to Fresh Food Cabinet VIP to Fresh Food Door	$29.3

Table 12.4.42 Capital Conversion Costs for Analyzed Product Class 9-BI (Built-in Upright Freezers)

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for PC 9-BI Unit	Capital Conversion Costs for the PC 9-BI Unit *2009$ millions*
TSL 1	EL 1 (10)	Increase Compressor EER to 6.29	-
TSL 2	EL 3 (20)	TSL 1 Design Options + Brushless DC Fan for Evaporator Brushless DC Fan for Condenser 10% Increase to Condenser Area Variable Speed Compressor with Brushless DC Fans 1.5 sqft VIP Upper Door	$14.3
TSL 3, TSL 4	EL 4 (25)	TSL 2 Design Options + VIP Upper Door (Full Coverage) 13.1 sqft VIP Lower Cabinet	$15.3
TSL 5	EL 5 (27)	TSL 3 and 4 Design Options + VIP Lower Cabinet (Full Coverage) VIP--Lower Door VIP--Upper Cabinet	$16.1

12.4.8.2 Product Conversion Costs

DOE based its estimates of the product conversion costs that would be required to meet each TSL on information obtained from manufacturer interviews, the design pathways analyzed in the engineering analysis, and market information about the number of platform and product families for each manufacturer. Similar to how it calculated capital conversion costs, for all freestanding product classes DOE segmented product conversion costs equally between the two product sizes analyzed in the engineering analysis for each efficiency level for each analyzed product class. Because DOE analyzed one product for the built-in product classes, DOE calculated the product conversion costs for each built-in product class using the design options for the one analyzed product.

DOE assigned estimates for the total product development required for each design option based on the necessary engineering resources required to implement each design option across a product platform. DOE assumed that each estimate of the product development effort included engineering resources for R&D, testing, trade costs, and marketing costs to recast product literature. DOE multiplied the estimate by the number of platforms and product families for each manufacturer. DOE assumed that more efficient compressors, larger condensers, more efficient fan motors, adaptive defrost, and variable anti-sweat would be the least costly design options to implement across a product platform because they constitute direct component swapouts. However, DOE assumed that forced convection and larger evaporators would take a slightly greater effort. DOE assumed that variable speed compressors would be a more difficult component to implement because of the interaction with other systems. DOE assigned a greater weight to this design option and also added engineering time if the baseline unit analyzed in the engineering analysis did not have electronic controls. DOE also added a significant cost for manufacturers to train servicers if isobutane were used as a design option. DOE also assumed that VIP use and/or wall thickness increases would require more significant changes to existing platforms than the above-mentioned design options that amount to component swaps. For wall thickness increases, DOE used product development efforts that were analogous to designing a new platform. Because VIPs are not currently common at large scale to most products in the industry, DOE assumed more substantial product development costs for that than other component swaps. However, DOE also assumed that manufacturers' recent experience with the technology would require less effort than designing completely new products, and implementing additional VIPs would require a less substantial effort than the first VIP panel.

Finally, DOE estimated industry product conversion costs by extrapolating the interviewed manufacturers' product conversion costs for each product class to account for the market share of companies that were not interviewed. DOE's estimates of the product conversion costs for all of the refrigeration products addressed in this rulemaking can be found in Table 12.4.43 through Table 12.4.53 below.

Table 12.4.43 Product Conversion Costs for Analyzed Product Class 3 (Standard-Size Top-Mount Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 16 Cubic Foot PC 3 Unit	Product Conversion Costs for the 16 Cubic Foot PC 3 Unit *2009$ millions*	Design Options Considered for the 21 Cubic Foot PC 3 Unit	Product Conversion Costs for the 21 Cubic Foot PC 3 Unit *2009$ millions*
TSL 1, TSL 2	EL 3 (20)	Increase Condenser Size by 100% Increase Compressor EER from 5.55 to 6.26 Brushless DC Condenser Fan Motor Increase Evaporator Size by 14% Adaptive Defrost Variable Speed Compressor	$45.2	Increase Compressor EER from 5.94 to 6.08 Increase Evaporator Size by 25% Brushless DC Condenser Fan Motor	$21.7
TSL 3	EL 4 (25)*	TSL 1, TSL 2 Design Options + 12.2 sqft VIP in FZR Cabinet	$72.2	TSL 1, TSL 2 Design Options + Brushless DC Evaporator Fan Motor	$26.7
TSL 4	EL 5 (30)	TSL 3 Design Options + 2.9 sqft VIP in FZR Door 7.1 sqft VIP in FF Door 6.7 sqft VIP in FF Cabinet	$88.5	TSL 3 Design Options + Adaptive Defrost 3.6 sqft VIP in FZR Door 7.6 sqft VIP in FZR Cabinet	$61.6
TSL 5	EL 6 (36)	TSL 4 Design Options + 1.9 sqft more VIP in FF	$88.5	TSL 4 Design Options + Variable Speed Compressor 8.5 sqft VIP in FF Door 10.9 sqft VIP in FF Cabinet	$85.1

*Efficiency level for product classes 1, 1A, and 2 is 20%.

Table 12.4.44 Product Conversion Costs for Analyzed Product Class 5 (Standard-Size Bottom-Mount Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 18.5 Cubic Foot PC 5 Unit	Product Conversion Costs for the 18.5 Cubic Foot PC 5 Unit *2009$ millions*	Design Options Considered for the 25 Cubic Foot PC 5 Unit	Product Conversion Costs for the 25 Cubic Foot PC 5 Unit *2009$ millions*
TSL 1, TSL 2, TSL 3	EL 3 (20)	Increase Compressor EER from 5.61 to 6.26 Brushless DC Evaporator Fan Motor Adaptive Defrost Brushless DC Condenser Fan Motor Variable Antisweat Heat Control Increase Evaporator Size by 25%	$20.8	Increase Compressor EER from 5.00 to 6.26	$4.9
TSL 4	EL 5 (30)	TSL 1, 2, 3 Design Options + Variable Speed Compressor 4.8 sqft VIP in FZR Door 6.8 sqft VIP in FF Door 13.7 sqft VIP in FZR Cabinet	$45.0	TSL 1, 2, 3 Design Options + Brushless DC Evaporator Fan Motor Variable Anti-Sweat Heater Control Brushless DC Condenser Fan Motor Variable Speed Compressor	$18.9
TSL 5	EL 6 (36)	TSL 4 Design Options + 7.2 sqft VIP in FF Cabinet	$47.6	TSL 4 Design Options + 9.2 sqft VIP in FF Door 5.9 sqft VIP in FZR Door 14.8 sqft VIP in FZR Cabinet 10.3 sqft VIP in FF Cabinet	$41.4

Table 12.4.45 Product Conversion Costs for Analyzed Product Class 7 (Standard-Size Side-By-Side Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 22 Cubic Foot PC 7 Unit	Product Conversion Costs for the 22 Cubic Foot PC 7 Unit *2009$ millions*	Design Options Considered for the 26 Cubic Foot PC 7 Unit	Product Conversion Costs for the 26 Cubic Foot PC 7 Unit *2009$ millions*
TSL 1	EL 3 (20)	Increase Compressor EER from 5.51 to 6.26 Brushless DC Condenser Fan Motor Increase Evaporator Area 19% Increase Condenser Size by 27% Variable Anti-Sweat Heater Control for Ice Dispenser 5.1 sqft VIP in FZR Door	$45.6	Increase Compressor EER from 5.21 to 6.11 Brushless DC Evaporator Fan Motor Brushless DC Condenser Fan Motor	$15.4
TSL 2, TSL 3	EL 4 (25)	TSL 1 Design Options + Remove 5.1 sqft VIP FZR Door Variable Speed Compressor 3.0 sqft VIP in FZR Cabinet	$57.7	TSL 1 Design Options + Increase Compressor EER from 6.11 to 6.26 Variable Anti-Sweat Heater Control for Ice Dispenser Increase Condenser Size by 10% 6.2 sqft VIP in FZR Door	$46.4
TSL 4	EL 5 (30)	TSL 2 and 3 Design Options + 7.4 sqft more VIP in FZR Cabinet 5.1 sqft VIP in FZR Door 8 sqft VIP in FF Door 7.8 sqft VIP in FF Cabinet	$72.3	TSL 2 and 3 Design Options + Variable Speed Compressor 2.6 sqft VIP in FZR Cabinet	$62.0
TSL 5	EL 6 (33)	TSL 4 Design Options + 4.9 sqft more VIP in FF Cabinet	$72.3	TSL 4 Design Options + 9.1 sqft more VIP in FZR Cabinet 8.2 sqft VIP in FF	$70.9

				Door 13.4 sqft VIP in FF Cabinet	

Table 12.4.46 Product Conversion Costs for Analyzed Product Class 9 (Standard-Size Upright Freezers) by TSL

TSL	**Efficiency Level (% reduction from baseline energy use)**	**Design Options Considered for the 14 Cubic Foot PC 9 Unit**	**Product Conversion Costs for the 14 Cubic Foot PC 9 Unit** ***2009$ millions***	**Design Options Considered for the 20 Cubic Foot PC 9 Unit**	**Product Conversion Costs for the 20 Cubic Foot PC 9 Unit** ***2009$ millions***
TSL 1	EL 3 (20)	Brushless DC Evaporator Fan Motor Increase Compressor EER from 5.04 to 6.08 Add 1 inch Insulation to Door Adaptive Defrost	$6.1	Brushless DC Evaporator Fan Motor Increase Compressor EER from 5.73 to 6.24 Adaptive Defrost Increase Evaporator Size by 22% Forced Convection Condenser with Brushless DC Condenser Fan	$7.6
TSL 2	EL 5 (30)	TSL 1 Design Options + Add 0.56 inch Insulation to Cabinet	$12.8	TSL 1 Design Options + Add 0.7 inch Insulation to Door Add 0.5 inch Insulation to Cabinet	$16.5
TSL 3	EL 6 (35)	TSL 2 Design Options + Remove 0.06 inch Cabinet Insulation Variable Speed Compressor	$15.6	TSL 2 Design Options + Add 0.5 inch Insulation to Cabinet	$16.5
TSL 4	EL 7 (40)	TSL 3 Design Options + Add 0.5 Inch Insulation to Cabinet 5.7 sqft VIP in Door	$16.5	TSL 3 Design Options + Variable Speed Compressor	$19.3
TSL 5	EL 8 (44)	TSL 4 Design Options + 4.6 sqft more VIP in Door 18.9 sqft VIP in Cabinet	$17.5	TSL 4 Design Options + 14.4 sqft VIP in Door 23.1 sqft VIP in Cabinet	$21.2

Table 12.4.47 Product Conversion Costs for Analyzed Product Class 10 (Standard-Size Chest Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 15 Cubic Foot PC 10 Unit	Product Conversion Costs for the 15 Cubic Foot PC 10 Unit *2009$ millions*	Design Options Considered for the 20 Cubic Foot PC 10 Unit	Product Conversion Costs for the 20 Cubic Foot PC 10 Unit *2009$ millions*
TSL 1	EL 3 (20)	Increase Compressor EER from 4.92 to 6.08 Add 0.24 inch Insulation to Door	$3.9	Increase Condenser Size by 24% Increase Compressor EER from 5.71 to 6.25 Convert Door Insulation to PU Foam Add 1 inch Insulation to Door	$4.9
TSL 2	EL 4 (25)*	TSL 1 Design Options + Add 0.76 inch Insulation to Door Add 0.15 inch Insulation to Cabinet	$10.4	TSL 1 Design Options + Add 0.35 inch Insulation to Cabinet	$11.5
TSL 3	EL 5 (30)	TSL 2 Design Options + Add 0.35 inch Insulation to Cabinet	$10.4	TSL 2 Design Options + Add 0.4 inch Insulation to Cabinet 4.5 sqft VIP in Bottom Wall	$12.4
TSL 4	EL 6 (35)	TSL 3 Design Options + Variable Speed Compressor	$13.2	TSL 3 Design Options + Remove 4.5 sqft VIP Bottom Wall Variable Speed Compressor	$14.3
TSL 5	EL 7 (41)	TSL 4 Design Options + Add 0.25 inch Insulation to Cabinet 8.2 sqft VIP on bottom 8.8 sqft VIP on door	$14.8	TSL 4 Design Options + 10.2 sqft VIP in Bottom Wall 12 sqft VIP in Door	$16.2

*Efficiency level for product class 10A is 30%.

Table 12.4.48 Product Conversion Costs for Analyzed Product Class 11 (Compact Refrigerators and Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 1.7 Cubic Foot PC 11 Unit	Product Conversion Costs for the 1.7 Cubic Foot PC 11 Unit *2009$ millions*	Design Options Considered for the 4 Cubic Foot PC 11 Unit	Product Conversion Costs for the 4 Cubic Foot PC 11 Unit *2009$ millions*
TSL 1	EL 3 (20)	Increase Evaporator Size by 20% Increase Compressor EER from 3.02 to 3.47 Increase Condenser Size by 19% Add 3/4 inch Insulation in Door	$7.1	Increase Compressor EER from 4.57 to 5.3 Increase Condenser Size by 22% Add 3/4 inch Insulation to Door	$4.7
TSL 2	EL 4 (25)	TSL 1 Design Options + Add 0.18 inch Insulation in Cabinet	$10.3	TSL 1 Design Options + Convert to Isobutane Refrigerant Add 1/4 inch Insulation to Door	$20.8
TSL 3	EL 5 (30)	TSL 2 Design Options + Add 0.57 inch Insulation in Cabinet	$10.3	TSL 2 Design Options + Add 0.22 inch Insulation to Cabinet Remove 1/4 inch Insulation from Door	$24.6
TSL 4	EL 7 (40)	Eliminate all previous Design Options Variable Speed Compressor Convert to Isobutane Refrigerant	$8.2	TSL 3 Design Options + Add 0.53 inch Insulation to Cabinet	$24.6
TSL 5	EL 10 (59)	TSL 4 Design Options + Increase Evaporator Size by 20% Increase Condenser Size by 19% Add 3/4 inch Insulation in Door Add 3/4 inch Insulation in Cabinet Add 4.7 sqft VIP in Cabinet Add 2.2 sqft VIP in Door	$17.3	TSL 4 Design Options + Variable Speed Compressor Remove 0.2 inch Cabinet Insulation 7.2 sqft VIP Cabinet 4.2 sqft VIP Door	$30.5

Table 12.4.49 Product Conversion Costs for Analyzed Product Class 18 (Compact Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the 3.4 Cubic Foot PC 18 Unit	Product Conversion Costs for the 3.4 Cubic Foot PC 18 Unit *2009$ millions*	Design Options Considered for the 7 Cubic Foot PC 18 Unit	Product Conversion Costs for the 7 Cubic Foot PC 18 Unit *2009$ millions*
TSL 1, TSL 2	EL 1 (10)*	Increase Compressor EER from 3.74 to 4.17	$1.3	Increase Compressor EER from 4.50 to 5.02	$2.3
TSL 3	EL 2 (15)	TSL 1 and 2 Design Options + Increase Compressor EER from 4.17 to 4.29 Add 1 inch Insulation to Door	$2.8	TSL 1 and 2 Design Options + Increase Compressor EER from 5.02 to 5.27 Add 0.12 inch Insulation to Door	$3.6
TSL 4	EL 4 (25)	TSL 3 Design Options + Remove 1/4 inch Insulation from Door Add 0.75 inch Insulation to Cabinet Add 2.1 sqft VIP in Bottom Wall	$8.0	TSL 3 Design Options + Add 0.63 inch Insulation to Door Add 0.62 inch Insulation to Cabinet	$7.4
TSL 5	EL 7 (42)	Remove all previous Design Options Variable Speed Compressor Add 0.75 inch Insulation to Door Add 0.75 inch Insulation to Cabinet Add 2.1 sqft VIP in Bottom Wall Add 3.3 sqft VIP in Door	$8.5	Remove all previous Design Options Variable Speed Compressor Add 0.76 inch Insulation to Cabinet Add 3/4 inch Insulation to Door Add 4.1 sqft VIP to Cabinet Bottom Add 5.1 sqft VIP to Door	$10.4

* Efficiency level for product class 13, 13I, 15, and 15I is 15%, efficiency level for product class 14 and 14I is 20%, and efficiency level for product class 13A is 25%.

Table 12.4.50 Product Conversion Costs for Analyzed Product Class 3A-BI (Built-in All-Refrigerators) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the PC 3A-BI Unit	Product Conversion Costs for the PC 3A-BI Unit *2009$ millions*
TSL 1	EL 1 (10)	Decrease Both Compressor Capacity (same EER) 10% Increase to Condenser Area Brushless DC Evaporator Fan Upper Evaporator	$4.2
TSL 2	EL 2 (15)	TSL 1 Design Options + Brushless DC Evaporator Fan Lower Evaporator Brushless DC Condenser Fan	$6.2
TSL 3	EL 3 (20)	TSL 2 Design Options + Full VIP--Upper Door Partial VIP--Lower Cabinet	$12.2
TSL 4	EL 4 (25)	TSL 3 Design Options + Full VIP--Lower Cabinet Full VIP--Upper Cabinet Upper System Variable Speed Compressor	$14.2
TSL 5	EL 5 (29)	TSL 4 Design Options + Full VIP--Lower Door Lower System Variable Speed Compressor	$16.2

Table 12.4.51 Product Conversion Costs for Analyzed Product Class 5-BI (Built-in Bottom-Mount Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for the PC 5-BI Unit	Product Conversion Costs for the PC 5-BI Unit *2009$ millions*
TSL 1	EL 1 (10)	Decrease FF Compressor Capacity (same EER) 10% Increase to Condenser Area Increase FRZ Compressor EER to 6.26 1.0 sqft VIP--FRZ Door	$12.6
TSL 2, TSL 3	EL 2 (15)	TSL 1 Design Options + Remove 1.0 sqft VIP -- FZR Door FRZ Variable Speed Compressor with Brushless DC Condenser Fan	$7.7
TSL 4	EL 4 (25)	TSL 2 and 3 Design Options + 14.6 sqft VIP--FRZ Cabinet (Partial Coverage) Add 3.6 sqft VIP -- FZR Cabinet (Full Coverage) 6.0 sqft VIP--FRZ Door (Full Coverage) FF Variable Speed Compressor with Brushless DC Condenser Fan	$15.8
TSL 5	EL 5 (27)	TSL 4 Design Options + 9.4 sqft VIP -- FF Door (Full Coverage) 3.8 sqft VIP -- FF Cabinet (Full Coverage)	$19.1

Table 12.4.52 Product Conversion Costs for Analyzed Product Class 7-BI (Built-in Side-by-Side Refrigerator-Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for PC 7-BI Unit	Product Conversion Costs for the PC 7-BI Unit *2009$ millions*
TSL 1, TSL 2	EL 1 (10)	High Efficiency Compressor Heat Exchanger Improvement Variable Anti-Sweat Heater Control Partial VIP to Freezer Door	$22.3
TSL 3, TSL 4	EL 3 (20)	TSL 1 and 2 Design Options + Eliminate VIP to Freezer Door Variable Speed Compressor VIP to Freezer Door VIP to Freezer Cabinet	$29.0
TSL 5	EL 4 (22)	TSL 3 and 4 Design Options + VIP to Fresh Food Cabinet VIP to Fresh Food Door	$33.5

Table 12.4.53 Product Conversion Costs for Analyzed Product Class 9-BI (Built-in Upright Freezers) by TSL

TSL	Efficiency Level (% reduction from baseline energy use)	Design Options Considered for PC 9-BI Unit	Product Conversion Costs for the PC 9-BI Unit *2009$ millions*
TSL 1	EL 1 (10)	Increase Compressor EER to 6.29	$2.2
TSL 2	EL 3 (20)	TSL 1 Design Options + Brushless DC Fan for Evaporator Brushless DC Fan for Condenser 10% Increase to Condenser Area Variable Speed Compressor with Brushless DC Fans 1.5 sqft VIP Upper Door	$14.7
TSL 3, TSL 4	EL 4 (25)	TSL 2 Design Options + VIP Upper Door (Full Coverage) 13.1 sqft VIP Lower Cabinet	$15.9
TSL 5	EL 5 (27)	TSL 3 and 4 Design Options + VIP Lower Cabinet (Full Coverage) VIP--Lower Door VIP--Upper Cabinet	$18.4

12.4.9 Markup Scenarios

DOE used several standards case markup scenarios to represent the uncertainty about the impacts of amended energy conservation standards on prices and profitability. In the base case, DOE used the same baseline markups calculated in the engineering analysis for all product classes. In the standards case, DOE modeled two markup scenarios to represent the uncertainty about the potential impacts on prices and profitability following the implementation of amended energy conservation standards: (1) a flat markup scenario, and (2) a preservation of operation profit scenario. These scenarios lead to different markups values, which, when applied to the inputted MPCs, result in varying revenue and cash flow impacts.

12.4.9.1 Flat Markup Scenario

The flat markup scenario assumes that the cost of goods sold for each product is marked up by a flat percentage to cover standard SG&A expenses, R&D expenses, and profit. The flat markup scenario uses the baseline manufacturer markup (discussed in chapter 6) for all products in both the base case and the standards case. To derive this percentage, DOE evaluated publicly available financial information for manufacturers of white goods. DOE also requested feedback on this value during manufacturer interviews. DOE used a markup of 1.26 for freestanding refrigeration products (standard-size refrigerator-freezers, standard-size freezers, and compact refrigeration products) and 1.40 for built-in refrigeration products. This scenario represents the upper bound of industry profitability in the standards case because manufacturers are able to fully pass through additional costs due to standards to their customers.

12.4.9.2 Preservation of Operating Profit Scenario

DOE also modeled a lower bound profitability scenario. During interviews, multiple manufacturers stated that the higher production costs could severely harm profitability. Because of the highly competitive market, several manufacturers suggested that the additional costs required at higher efficiencies could not be fully passed through to customers. In particular, several manufacturers noted their customer base is composed of a limited number of retailers that have substantial buying power and are resistant to price increases. They also noted that the average costs of refrigeration products have been fairly constant or fallen within product classes even as new products and additional features have been added. Finally, manufacturers noted that retail customers price products at fixed price points with jumps in feature bundles accounting for the different price points.

Because of the market dynamics among manufacturers and retailers and because of the pressure to keep the current price points fixed for a given bundle, DOE also modeled the preservation of operating profit markup scenario. In this scenario, the manufacturer markups are lowered so that, in the standards case, manufacturers are only able to maintain the base-case total operating profit in absolute dollars, despite higher product costs and investment. DOE implemented this scenario in the GRIM by lowering the manufacturer markups at each TSL to yield approximately the same earnings before interest and taxes in the standards case in the year after the compliance date of the amended standards, as in the base case. This scenario represents the lower bound of industry profitability following amended energy conservation standards because higher production costs and the investments required to comply with the amended energy conservation standard do not yield additional operating profit.

DOE implemented this scenario by calculating a markup that yielded the same EBIT in the base case and the standards case for each product class. For most TSLs, DOE only calibrated a lower markup for the efficiency level that was minimally compliant to the amended energy conservation standards (since products that exceed the standard would not be impacted by the standards). However, for TSLs that analyzed the levels recommended in the Joint Comments, shipments for some of the unanalyzed product classes corresponded to different percentage reductions in baseline energy use. For these TSLs, DOE calculated a markup for each efficiency level impacted by an efficiency level that was different than the analyzed product class. Each of these markups maintained the base case EBIT for the analyzed product class at the efficiency level recommended by the Joint Comments. In this way, amended energy conservation standards would also impact the profitability of these products in the preservation of operating profit scenario. However, for all TSLs the base case operating profit is maintained as production costs rise, leading to profitability impacts in the standard case under the preservation of operating profit markup scenario. Table 12.4.54 through Table 12.4.64 lists the products DOE analyzed with the corresponding markups at each TSL.

Table 12.4.54 Preservation of Operating Profit Markups for Analyzed Product Class 3 (Standard-Size Top-Mount Refrigerator-Freezers)

Efficiency Level (% reduction from baseline energy use)	Baseline	TSL 1	TSL 2	TSL 3*	TSL 4	TSL 5
Baseline (0)	1.2600	-	-	-	-	-
EL 1 (10)	1.2600	-	-	-	-	-
EL 2 (15)	1.2600	-	-	-	-	-
EL 3 (20)	1.2600	1.2494	1.2494	1.2446	-	-
EL 4 (25)	1.2600	1.2600	1.2600	1.2453	-	-
EL 5 (30)	1.2600	1.2600	1.2600	1.2600	1.2381	-
EL 6 (36)	1.2600	1.2600	1.2600	1.2600	1.2600	1.2313

*Efficiency level for product classes 1, 1A, and 2 is 20%.

Table 12.4.55 Preservation of Operating Profit Markups for Analyzed Product Class 5 (Standard-Size Bottom-Mount Refrigerator-Freezers)

Efficiency Level (% reduction from baseline energy use)	Baseline	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Baseline (0)	1.2600	-	-	-	-	-
EL 1 (10)	1.2600	-	-	-	-	-
EL 2 (15)	1.2600	-	-	-	-	-
EL 3 (20)	1.2600	1.2592	1.2592	1.2592	-	-
EL 4 (25)	1.2600	1.2600	1.2600	1.2600	-	-
EL 5 (30)	1.2600	1.2600	1.2600	1.2600	1.2471	-
EL 6 (36)	1.2600	1.2600	1.2600	1.2600	1.2600	1.2400

Table 12.4.56 Preservation of Operating Profit Markups for Analyzed Product Class 7 (Standard-Size Side-By-Side Refrigerator-Freezers)

Efficiency Level (% reduction from baseline energy use)	Baseline	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Baseline (0)	1.2600	-	-	-	-	-
EL 1 (10)	1.2600	-	-	-	-	-
EL 2 (15)	1.2600	-	-	-	-	-
EL 3 (20)	1.2600	1.2581	-	-	-	-
EL 4 (25)	1.2600	1.2600	1.2539	1.2539	-	-
EL 5 (30)	1.2600	1.2600	1.2600	1.2600	1.2464	-
EL 6 (33)	1.2600	1.2600	1.2600	1.2600	1.2600	1.2419

Table 12.4.57 Preservation of Operating Profit Markups for Analyzed Product Class 9 (Standard-Size Upright Freezers)

Efficiency Level (% reduction from baseline energy use)	Baseline	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Baseline (0)	1.2600	-	-	-	-	-
EL 1 (10)	1.2600	-	-	-	-	-
EL 2 (15)	1.2600	-	-	-	-	-
EL 3 (20)	1.2600	1.2530	-	-	-	-
EL 4 (25)	1.2600	1.2600	-	-	-	-
EL 5 (30)	1.2600	1.2600	1.2470	-	-	-
EL 6 (35)	1.2600	1.2600	1.2600	1.2418	-	-
EL 7 (40)	1.2600	1.2600	1.2600	1.2600	1.2363	-
EL 8 (44)	1.2600	1.2600	1.2600	1.2600	1.2600	1.2285

Table 12.4.58 Preservation of Operating Profit Markups for Analyzed Product Class 10 (Standard-Size Chest Freezers)

Efficiency Level (% reduction from baseline energy use)	Baseline	TSL 1	TSL 2*	TSL 3	TSL 4	TSL 5
Baseline (0)	1.2600	-	-	-	-	-
EL 1 (10)	1.2600	-	-	-	-	-
EL 2 (15)	1.2600	-	-	-	-	-
EL 3 (20)	1.2600	1.2545	-	-	-	-
EL 4 (25)	1.2600	1.2600	1.2471	-	-	-
EL 5 (30)	1.2600	1.2600	1.2396	1.2444	-	-
EL 6 (35)	1.2600	1.2600	1.2600	1.2600	1.2384	-
EL 7 (41)	1.2600	1.2600	1.2600	1.2600	1.2600	1.2303

*Efficiency level for product class 10A is 30%.

Table 12.4.59 Preservation of Operating Profit Markups for Analyzed Product Class 11 (Compact Refrigerators and Refrigerator-Freezers)

Efficiency Level (% reduction from baseline energy use)	**Baseline**	**TSL 1**	**TSL 2**	**TSL 3**	**TSL 4**	**TSL 5**
Baseline (0)	1.2600	-	-	-	-	-
EL 1 (10)	1.2600	-	-	-	-	-
EL 2 (15)	1.2600	-	-	-	-	-
EL 3 (20)	1.2600	1.2514	-	-	-	-
EL 4 (25)	1.2600	1.2600	1.2463	-	-	-
EL 5 (30)	1.2600	1.2600	1.2600	1.2430	-	-
EL 6 (35)	1.2600	1.2600	1.2600	1.2600	-	-
EL 7 (40)	1.2600	1.2600	1.2600	1.2600	1.2340	-
EL 8 (45)	1.2600	1.2600	1.2600	1.2600	1.2600	-
EL 9 (50)	1.2600	1.2600	1.2600	1.2600	1.2600	-
EL 10 (58)	1.2600	1.2600	1.2600	1.2600	1.2600	1.2233

Table 12.4.60 Preservation of Operating Profit Markups for Analyzed Product Class 18 (Compact Freezers)

Efficiency Level (% reduction from baseline energy use)	Baseline	TSL 1	TSL 2*	TSL 3	TSL 4	TSL 5
Baseline (0)	1.2600	-	-	-	-	-
EL 1 (10)	1.2600	1.2571	1.2609	-	-	-
EL 2 (15)	1.2600	1.2600	1.2500	1.2524	-	-
EL 3 (20)	1.2600	1.2600	1.2347	1.2600	-	-
EL 4 (25)	1.2600	1.2600	1.2318	1.2600	1.2387	-
EL 5 (30)	1.2600	1.2600	1.2600	1.2600	1.2600	-
EL 6 (35)	1.2600	1.2600	1.2600	1.2600	1.2600	-
EL 7 (42)	1.2600	1.2600	1.2600	1.2600	1.2600	1.2261

* Efficiency level for product class 13, 13I, 15, and 15I is 15%, efficiency level for product class 14 and 14I is 20%, and efficiency level for product class 13A is 25%.

Table 12.4.61 Preservation of Operating Profit Markups for Analyzed Product Class 3A-BI (Built-in All-Refrigerators)

Efficiency Level (% reduction from baseline energy use)	Baseline	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Baseline (0)	1.4000	-	-	-	-	-
EL 1 (10)	1.4000	1.3998	-	-	-	-
EL 2 (15)	1.4000	1.4000	1.3995	-	-	-
EL 3 (20)	1.4000	1.4000	1.4000	1.3967	-	-
EL 4 (25)	1.4000	1.4000	1.4000	1.4000	1.3928	-
EL 5 (29)	1.4000	1.4000	1.4000	1.4000	1.4000	1.3902

Table 12.4.62 Preservation of Operating Profit Markups for Analyzed Product Class 5-BI (Built-in Bottom-Mount Refrigerator-Freezers)

Efficiency Level (% reduction from baseline energy use)	**Baseline**	**TSL 1**	**TSL 2**	**TSL 3**	**TSL 4**	**TSL 5**
Baseline (0)	1.4000	-	-	-	-	-
EL 1 (10)	1.4000	1.3994	-	-	-	-
EL 2 (15)	1.4000	1.4000	1.3990	1.3990	-	-
EL 3 (20)	1.4000	1.4000	1.4000	1.4000	-	-
EL 4 (25)	1.4000	1.4000	1.4000	1.4000	1.3959	-
EL 5 (27)	1.4000	1.4000	1.4000	1.4000	1.4000	1.3942

Table 12.4.63 Preservation of Operating Profit Markups for Analyzed Product Class 7-BI (Built-in Side-by-Side Refrigerator-Freezers)

Efficiency Level (% reduction from baseline energy use)	**Baseline**	**TSL 1**	**TSL 2**	**TSL 3**	**TSL 4**	**TSL 5**
Baseline (0)	1.4000	-	-	-	-	-
EL 1 (10)	1.4000	1.3996	1.3996	-	-	-
EL 2 (15)	1.4000	1.4000	1.4000	-	-	-
EL 3 (20)	1.4000	1.4000	1.4000	1.3975	1.3975	-
EL 4 (22)	1.4000	1.4000	1.4000	1.4000	1.4000	1.3960

Table 12.4.64 Preservation of Operating Profit Markups for Analyzed Product Class 9-BI (Built-in Upright Freezers)

Efficiency Level (% reduction from baseline energy use)	Baseline	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Baseline (0)	1.4000	-	-	-	-	-
EL 1 (10)	1.4000	1.3996	-	-	-	-
EL 2 (15)	1.4000	1.4000	-	-	-	-
EL 3 (20)	1.4000	1.4000	1.3971	-	-	-
EL 4 (25)	1.4000	1.4000	1.4000	1.3939	1.3939	-
EL 5 (27)	1.4000	1.4000	1.4000	1.4000	1.4000	1.3916

12.4.10 Federal Production Tax Credits

In the GRIM, DOE allows the user to include the estimates of the benefit of the Federal production tax credits found in title I section 1334 (c)(1)(B) of the Energy Policy Act of 2005 and updated by the Energy Improvement and Extension Act of 2008 (Pub. L. No. 110-343). For the results presented in this chapter, DOE included these benefits as a direct cash benefit to the industry in 2010. See appendix 12-C for a description of how DOE estimated the Federal production tax credits and its impacts on INPV results.

12.5 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in the previous sections, the GRIM estimated indicators of financial impacts on the residential refrigeration industry. The following sections detail additional inputs and assumptions for standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products. The main results of the MIA are also reported in this section. The MIA consists of two key financial metrics: INPV and annual cash flows.

12.5.1 Introduction

The INPV measures the industry value and is used in the MIA to compare the economic impacts of different TSLs in the standards case. The INPV is different from DOE's net present value, which is applied to the U.S. economy. The INPV is the sum of all net cash flows discounted at the industry's cost of capital, or discount rate. The residential refrigeration products GRIM estimates cash flows from 2010 to 2043. This timeframe models both the short-term impacts on the industry from the announcement of the standard until the compliance date (2010 until an estimated compliance date of

January 2014) and a long-term assessment over the 30 year analysis period used in the NIA (2014 – 2043).

In the MIA, DOE compares the INPV of the base case (no amended energy conservation standards) to that of each TSL in the standards case. The difference between the base case and a standards case INPV is an estimate of the economic impacts that implementing that particular TSL would have on the industry. For the residential refrigeration industry, DOE examined the two markup scenarios described above: the flat markup and the preservation of operating profit.While INPV is useful for evaluating the long-term effects of amended energy conservation standards, short-term changes in cash flow are also important indicators of the industry's financial situation. For example, a large investment over one or two years could strain the industry's access to capital. Consequently, the sharp drop in financial performance could cause investors to flee, even though recovery may be possible. Thus, a short-term disturbance can have long-term effects that the INPV cannot capture. To get an idea of the behavior of annual net cash flows, Figure 12.5.1 through Figure 12.5.8 below present the annual net or free cash flows from 2010 through 2024 for the base case and different TSLs in the standards case.

Because the same markup scenarios are used for each group of refrigeration products, each of the figures below has a similar shape. Annual cash flows are discounted to the base year, 2010. Between 2010 and the 2014 compliance date of the amended energy conservation standard, cash flows are driven by the level of conversion costs and the proportion of these investments spent every year. After the standard announcement date (*i.e.*, the publication date of the final rule), industry cash flows begin to decline as companies use their financial resources to prepare for the amended energy conservation standard. The more stringent the amended energy conservation standard, the greater the impact on industry cash flows in the years leading up to the compliance date, as product conversion costs lower cash inflows from operations and capital conversion costs increase cash outflows for capital expenditures.

Free cash flow in the year the amended energy conservation standards take effect is driven by two competing factors. In addition to capital and product conversion costs, amended energy conservation standards could create stranded assets, *i.e.*, tooling and equipment that would have enjoyed longer use if the energy conservation standard had not made them obsolete. In this year, manufacturers write down the remaining book value of existing tooling and equipment whose value is affected by the amended energy conservation standard. This one time write down acts as a tax shield that alleviates decreases in cash flow from operations in the year of the write-down. In this year, there is also an increase in working capital that reduces cash flow from operations. A large increase in working capital is needed due to more costly production components and materials, higher inventory carrying to sell more expensive products, and higher accounts receivable for more expensive products. Depending on these two competing factors, cash flow can either be positively or negatively affected in the year the standard takes effect.

In the years following the compliance date of the standard, the impact on cash flow depends on the operating revenue. More stringent TSLs typically have a positive impact on cash flows relative to the base case under the flat markup scenario because manufacturers are able to earner higher operating profit at each TSL in the standards case, which increases cash flow from operations. There is very little impact on cash flow from operations under the preservation of operating profit scenario because this scenario is calibrated to have the same operating income in the standards case at each TSL as the base case as in the year after the standard takes effect. In this scenario, the industry value is impacted because production costs increase, but operating profit remains approximately equal to the base case which decreases profit margins as a percentage of revenue.

12.5.2 Industry Financial Impacts

Table 12.5.1 through Table 12.5.8 provide the INPV estimates for the residential refrigeration industry. Figure 12.5.1 through Figure 12.5.8 present the annual net cash flows for standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products under each markup scenario.

Table 12.5.1 Changes in Industry Net Present Value for Standard-Size Refrigerator-Freezers (Flat Markup Scenario)

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009$ millions)*	2,670.1	2,552.2	2,450.9	2,325.1	1,885.1	1,627.9
Change in INPV	*(2009$ millions)*		(117.8)	(219.2)	(345.0)	(784.9)	(1,042.2)
	(%)		-4.4%	-8.2%	-12.9%	-29.4%	-39.0%

*For tables in section 12.5.2, values in parenthesis indicate negative numbers

Table 12.5.2 Changes in Industry Net Present Value for Standard-Size Refrigerator-Freezers (Preservation of Operating Profit Markup Scenario)

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009$ millions)*	2,670.1	2,417.5	2,274.2	2,089.4	1,360.8	828.6
Change in INPV	*(2009$ millions)*		(252.6)	(395.9)	(580.7)	(1,309.3)	(1,841.5)
	(%)		-9.5%	-14.8%	-21.7%	-49.0%	-69.0%

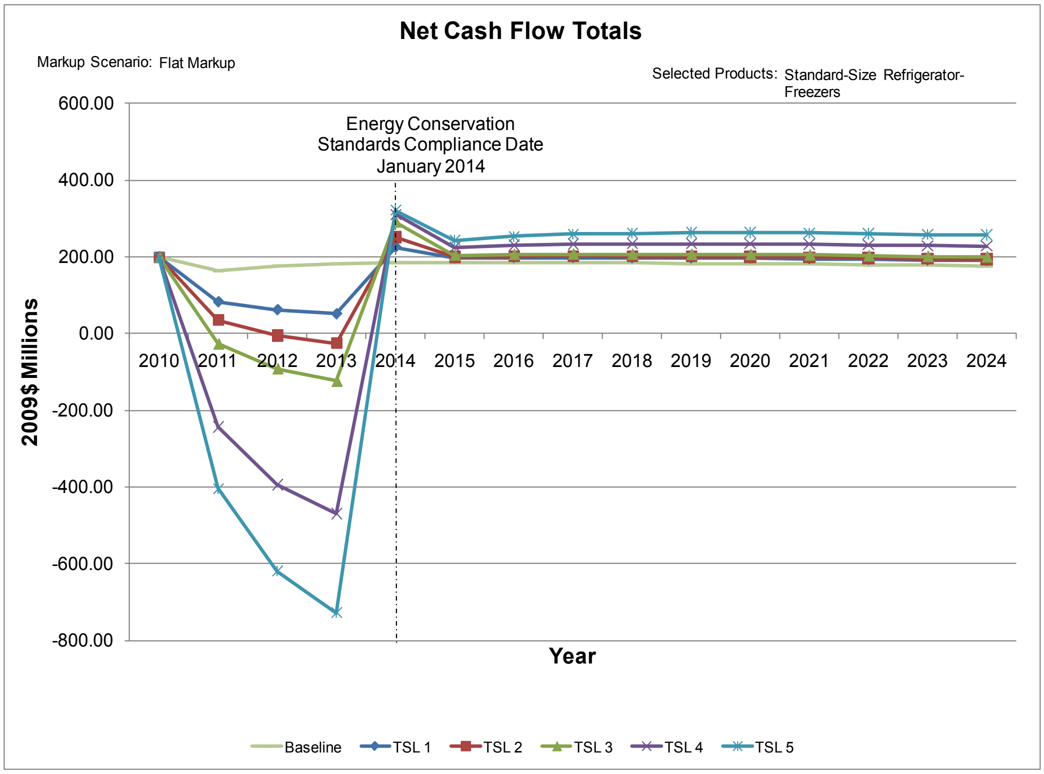

Figure 12.5.1 Annual Industry Net Cash Flows for Standard-Size Refrigerator-Freezers (Flat Markup Scenario)

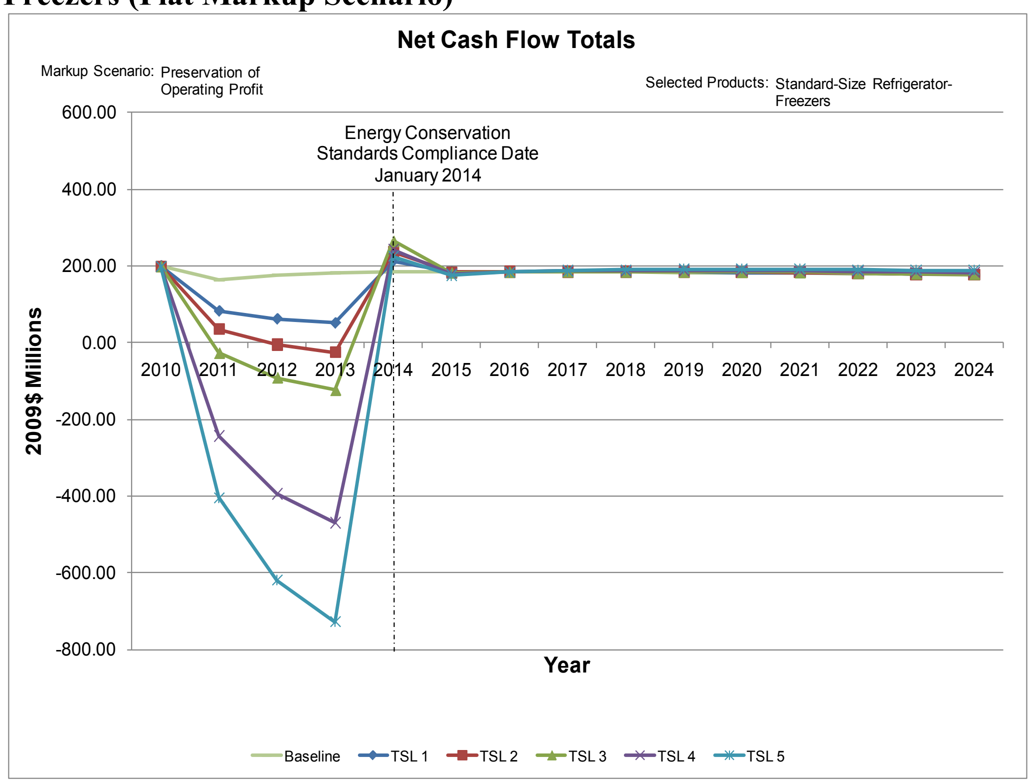

Figure 12.5.2 Annual Industry Net Cash Flows for Standard-Size Refrigerator-Freezers (Preservation of Operating Profit Markup Scenario)

Table 12.5.3 Changes in Industry Net Present Value for Standard-Size Freezers (Flat Markup Scenario)

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009$ millions)*	337.8	308.0	214.1	225.3	252.4	192.7
Change in INPV	*(2009$ millions)*		(29.8)	(123.7)	(112.5)	(85.4)	(145.0)
	(%)		-8.8%	-36.6%	-33.3%	-25.3%	-42.9%

Table 12.5.4 Changes in Industry Net Present Value for Standard-Size Freezers (Preservation of Operating Profit Markup Scenario)

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009$ millions)*	337.8	287.7	167.3	159.6	155.3	39.0
Change in INPV	*(2009$ millions)*		(50.0)	(170.5)	(178.1)	(182.4)	(298.8)
	(%)		-14.8%	-50.5%	-52.7%	-54.0%	-88.5%

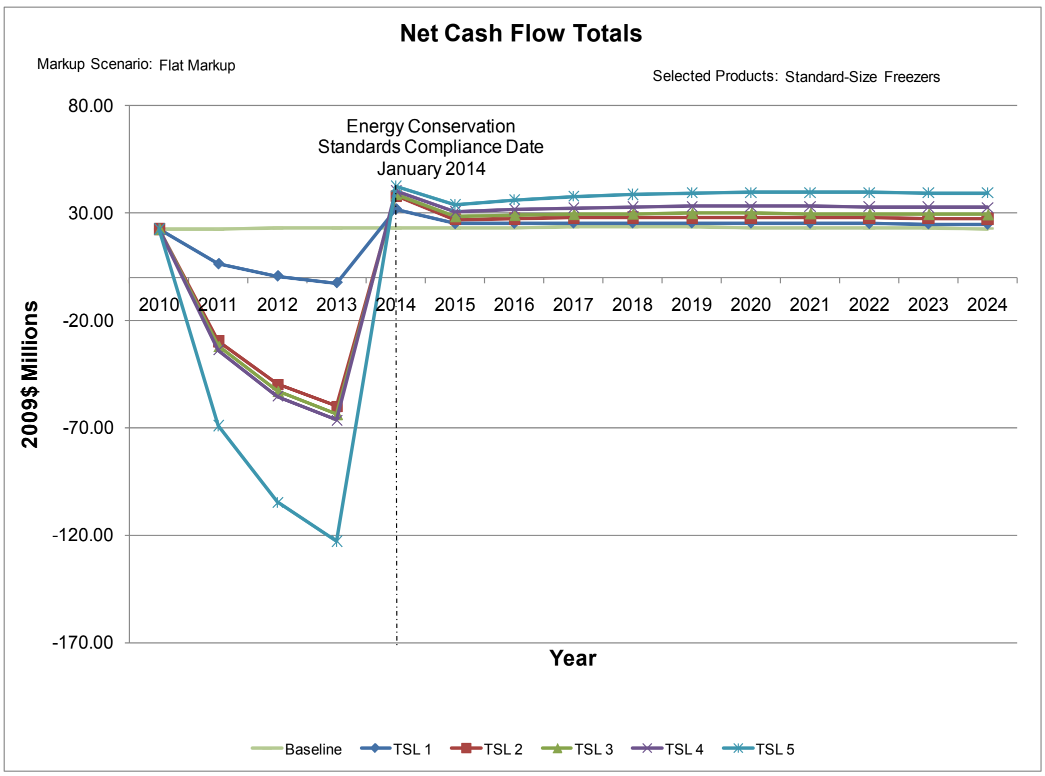

Figure 12.5.3 Annual Industry Net Cash Flows for Standard-Size Freezers (Flat Markup Scenario)

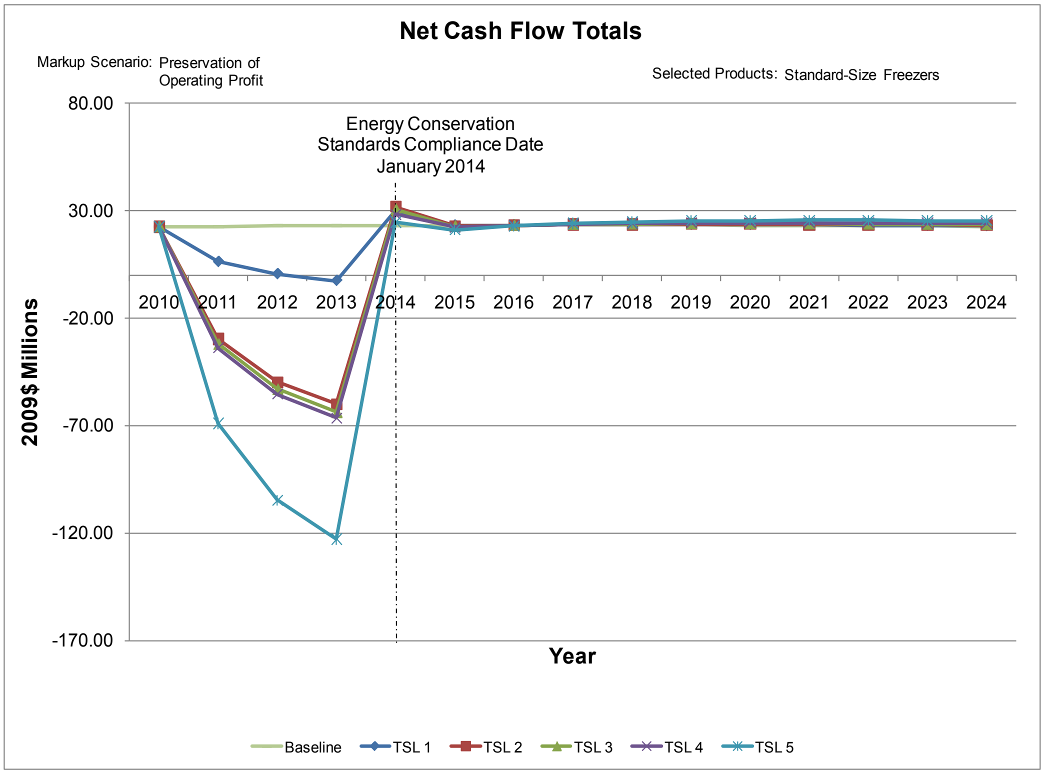

Figure 12.5.4 Annual Industry Net Cash Flows for Standard-Size Freezers (Preservation of Operating Profit Markup Scenario)

Table 12.5.5 Changes in Industry Net Present Value for Compact Refrigeration Products (Flat Markup Scenario)

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009$ millions)*	169.4	152.8	133.3	106.5	127.9	14.5
Change in INPV	*(2009$ millions)*		(16.6)	(36.2)	(62.9)	(41.5)	(154.9)
	(%)		-9.8%	-21.4%	-37.1%	-24.5%	-91.4%

Table 12.5.6 Changes in Industry Net Present Value for Compact Refrigeration Products (Preservation of Operating Profit Markup Scenario)

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009$ millions)*	169.4	141.6	110.8	80.1	76.6	(73.2)
Change in INPV	*(2009$ millions)*		(27.8)	(58.7)	(89.3)	(92.8)	(242.6)
	(%)		-16.4%	-34.6%	-52.7%	-54.8%	-143.2%

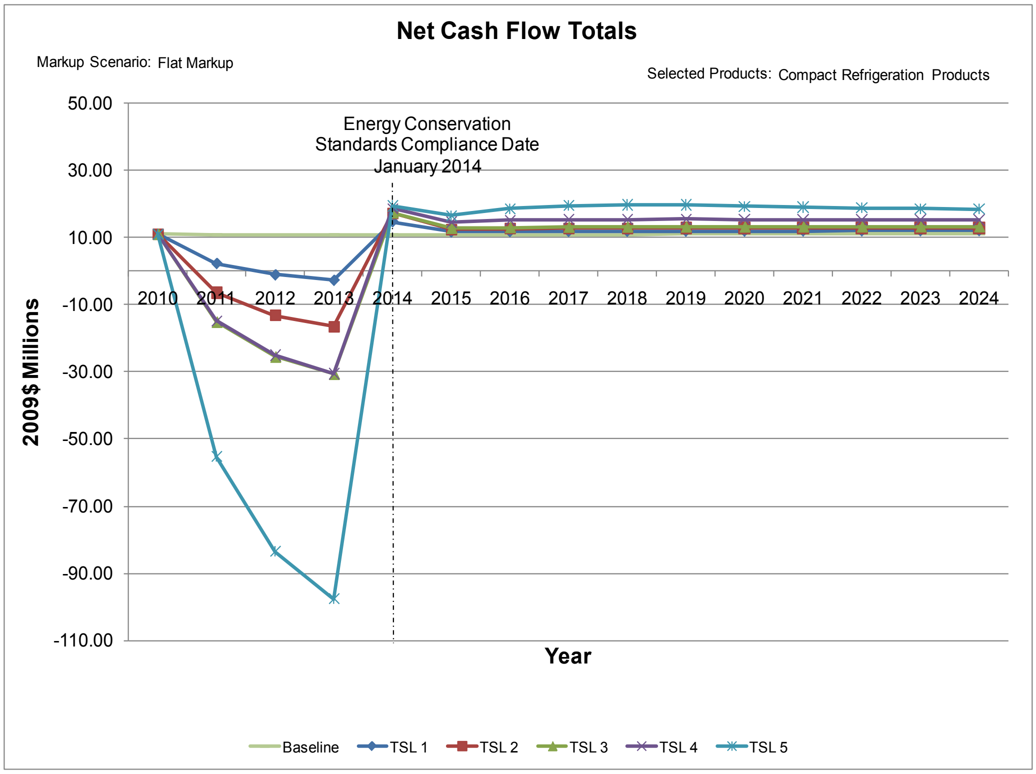

Figure 12.5.5 Annual Industry Net Cash Flows for Compact Refrigeration Products (Flat Markup Scenario)

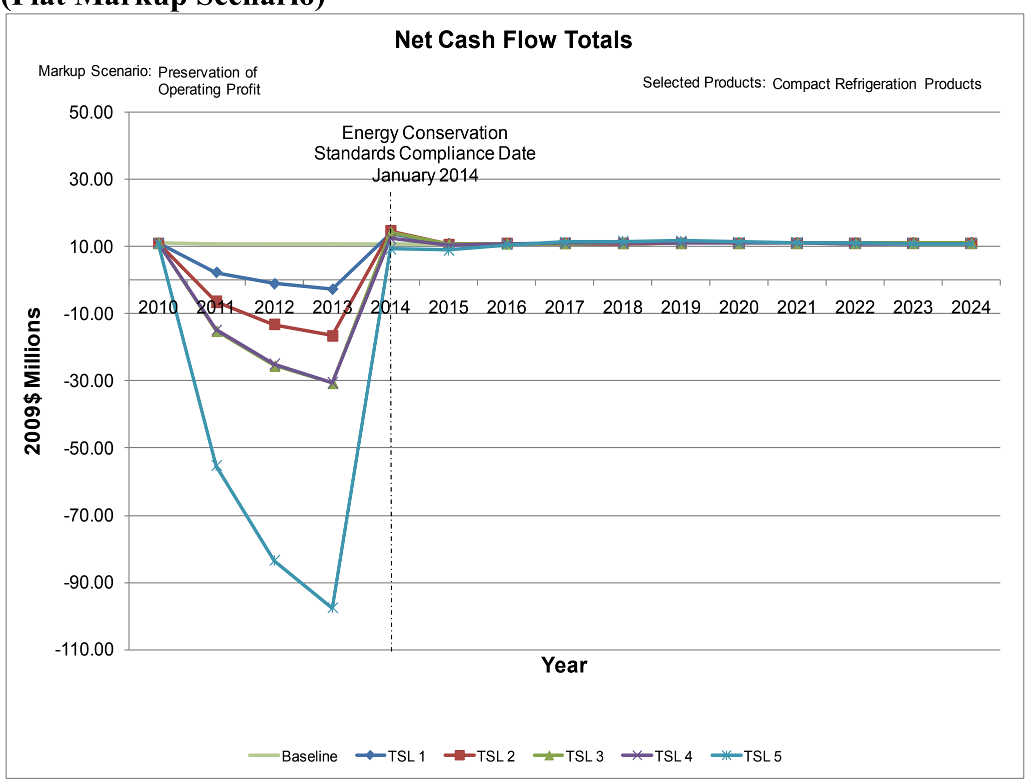

Figure 12.5.6 Annual Industry Net Cash Flows for Compact Refrigeration Products (Preservation of Operating Profit Markup Scenario)

Table 12.5.7 Changes in Industry Net Present Value for Built-In Refrigeration Products (Flat Markup Scenario)

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009$ millions)*	554.1	502.2	499.0	486.1	471.2	464.2
Change in INPV	*(2009$ millions)*		(51.9)	(55.1)	(68.0)	(82.9)	(89.9)
	(%)		-9.4%	-9.9%	-12.3%	-15.0%	-16.2%

Table 12.5.8 Changes in Industry Net Present Value for Built-In Refrigeration Products (Preservation of Operating Profit Markup Scenario)

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009$ millions)*	554.1	501.5	497.6	477.0	456.5	442.0
Change in INPV	*(2009$ millions)*		(52.6)	(56.5)	(77.2)	(97.6)	(112.1)
	(%)		-9.5%	-10.2%	-13.9%	-17.6%	-20.2%

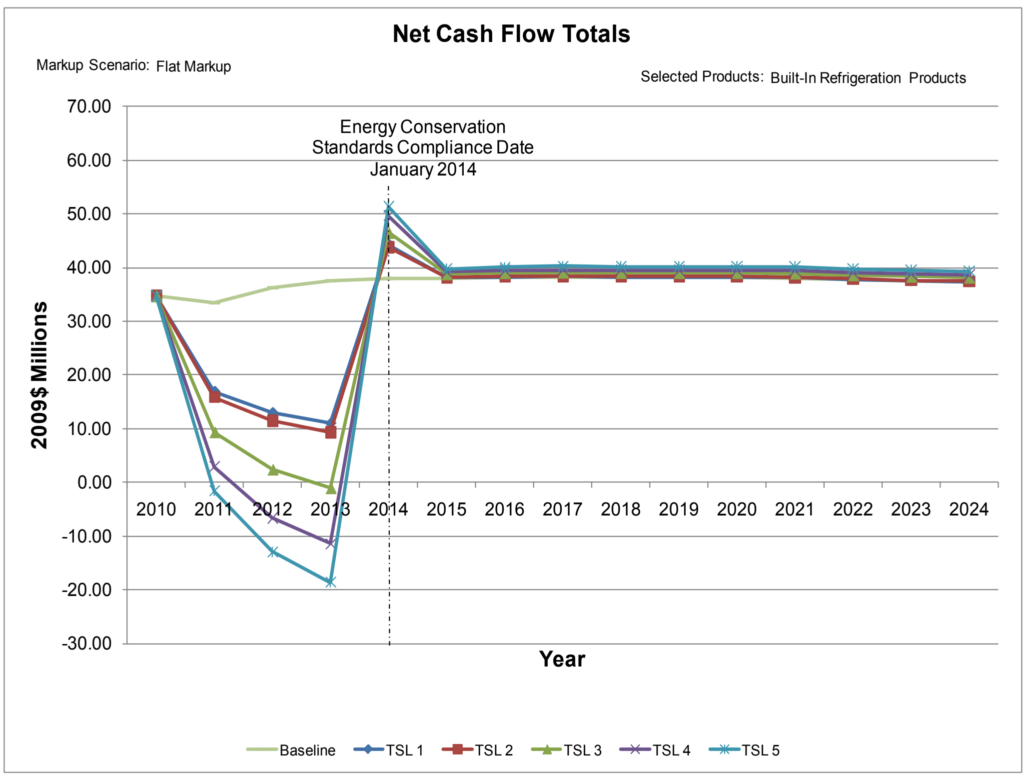

Figure 12.5.7 Annual Industry Net Cash Flows for Built-In Refrigeration Products (Flat Markup Scenario)

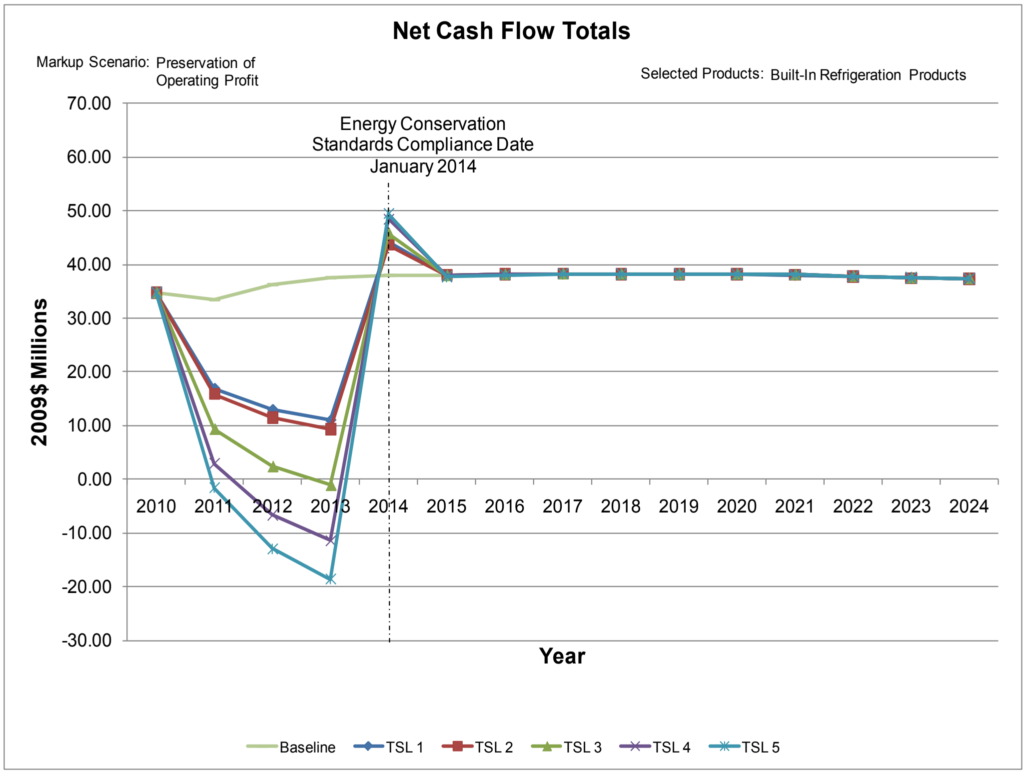

Figure 12.5.8 Annual Industry Net Cash Flows for Built-In Refrigeration Products (Preservation of Operating Profit Markup Scenario)

12.6 IMPACTS ON SMALL RESIDENTIAL REFRIGERATION MANUFACTURERS

DOE conducted a more focused inquiry of the companies that could be small business manufacturers of products covered by this rulemaking. During its market survey, DOE used all available public information to identify potential small manufacturers. DOE's research involved industry trade association membership directories (including AHAM), product databases (e.g., FTC, The Thomas Register, CEC, and ENERGY STAR databases), individual company websites, and marketing research tools like Dun and Bradstreet reports to create a list of every company that manufactures or sells residential refrigeration products covered by this rulemaking. DOE also asked stakeholders and industry representatives if they were aware of any other small manufacturers during manufacturer interviews and at previous DOE public meetings. DOE reviewed all publicly-available data and contacted select companies on its list, as necessary, to determine whether they met the SBA's definition of a small business manufacturer of covered residential refrigeration products. DOE screened out companies that did not offer products covered by this rulemaking, did not meet the definition of a "small business," or are foreign owned and operated.

DOE initially identified at least 65 distinct brands of residential refrigeration products sold in the U.S. by 47 parent companies. Out of these 47 companies, DOE determined that the majority (31 of 47) were distributors or sold branded products (were not the original equipment manufacturer). Of the 16 manufacturers, DOE found 15 to exceed the SBA's size limit or were foreign-owned and operated. Thus, DOE identified one small residential refrigeration product manufacturer that produces covered products and can be considered a small business.

Based on its market research, the one small business manufacturer of residential refrigeration products identified by DOE is a niche manufacturer that produces premium undercounter units. Undercounter refrigerator and freezers are high-end products that are meant to be either freestanding or recessed. The small business manufacturer identified by DOE primarily manufactures products that are covered by this rulemaking, such as undercounter refrigerators and refrigerator-freezers, plus several products outside of the scope of coverage for this rulemaking, such as ice makers and wine coolers. However, most compact refrigeration products are imported with market share split among multiple domestic and foreign manufacturers. Several manufacturers who still produce compact products domestically focus on the premium niche market of undercounter refrigerators and freezers.

DOE did not conduct a more in-depth analysis of the potential impacts on small business manufacturers because only one small business manufacturer would potentially be impacted by the amended energy conservation standards. In addition, that manufacturer would not likely be differentially harmed by the amended energy conservation standards compared to its most direct competitors. The small business manufacturer has the largest market share of undercounter refrigerator and freezers. Since undercounter units are a very small segment of compact refrigerators and freezers, the small business manufacturer is the market leader of a very small segment of compact products. Many of the other undercounter manufacturers, while not technically small businesses by the SBA definition, also have low overall production volumes. Finally, the undercounter market is a niche market that does not compete with overall compact refrigeration sales. Undercounter products are luxury items purchased by consumers that typically are less concerned about first costs compared to purchasers of other residential refrigeration products. While most compact sales are inexpensive products with retail prices in the low hundreds of dollars, undercounter products typically cost many times that. While this niche market is small, the much higher sales price and lower volumes indicate that profit margins could be higher than the industry average.

12.7 OTHER IMPACTS

12.7.1 Employment

12.7.1.1 Methodology

To quantitatively assess the impacts of amended energy conservation standards on residential refrigeration manufacturing employment, DOE used the GRIM to estimate the domestic labor expenditures and number of domestic production workers in the base case and at each TSL from 2010 to 2043. DOE used statistical data from the most recent U.S. Census Bureau's 2007 Economic Census, the results of the engineering analysis, and interviews with manufacturers to determine the inputs necessary to calculate industry-wide labor expenditures and domestic employment levels. Labor expenditures involved with the manufacture of the product are a function of the labor intensity of the product, the sales volume, and an assumption that wages remain fixed in real terms over time.

In the GRIM, DOE used the labor content of each product and the MPCs from the engineering analysis to estimate the annual labor expenditures for each product grouping. In the GRIMs, the labor expenditures in each year are calculated by multiplying the MPCs by the labor percentage of each product from the engineering analysis. DOE used Census data and interviews with manufacturers to estimate the portion of the total labor expenditures that is attributable to U.S. (i.e., domestic) labor.

The estimates of production workers in this section only cover workers up to the line-supervisor level that are directly involved in fabricating and assembling a product within the Original Equipment Manufacturer (OEM) facility. Workers that perform services that are closely associated with production operations, such as material handing with a forklift, are also included as production labor. DOE's estimates only account for production workers who manufacture the specific products covered by this rulemaking. For example, a worker on a wine cooler line would not be included with the estimate of the number of residential refrigeration workers.

DOE multiplied the total annual labor expenditures in the GRIM by the percentage of U.S. production for domestic consumption to calculate domestic labor expenditures for production labor in each industry. The domestic annual labor expenditures in the GRIM were converted to domestic production employment levels by dividing production labor expenditures by the annual payment per production worker (production worker hours times the labor rate found in the 2007 ASM).[e] DOE calculated the number of non-production employees by multiplying the number of production workers by the ratio of non-production workers to production workers calculated using the employment data in the 2007 ASM.

DOE calculated the domestic annual labor expenditures and employment levels for the base case and at each TSL. The impacts on domestic employment due to standards can be assessed by comparing the employment results in the base case to the results at each TSL. In the GRIM analyses, the estimates shown are the maximum potential employment in the industry because they assume manufacturers would continue to produce the same scope of covered products in the same production facilities. Consequently, the upper bound of the employment impacts calculated in the GRIM assumes that domestic production is not shifted to lower-labor-cost countries. Because there is a real risk of manufacturers exiting the market or no longer offering the same scope of covered products in response to amended energy conservation standards, the lower end of the range of employment results in this section include the estimate of the total number of U.S. production workers in the industry that could lose their jobs if all existing production were to no longer be made domestically. Consequently, the lower

[e] The labor rates and production hours per year per employee found in the Census Bureau's 2007 report are similar to figures reported in the engineering analysis. DOE used 2007 ASM figures to ensure a consistent set of publicly available data for the manufacturing employment analysis.

bound of the potential negative employment analysis does not account for some manufacturers' dependence on the total production volume of all products produced in a facility to achieve an adequate scale. For example, should a standard-size refrigerator-freezers manufacturer move part of its production abroad, its domestic production facility may no longer have the manufacturing scale to get volume discounts on its purchases or be able to justify maintaining major capital equipment. Thus, the impact on a manufacturing facility due to a line closure can affect far more employees than just the production workers directly associated with a covered product.

While the results present a range of employment impacts following the compliance date of amended energy conservation standards, the discussion below also includes a qualitative discussion of the likelihood of negative employment impacts at the various TSLs.

12.7.1.2 Standard-Size Refrigerator-Freezers Employment Impacts

The GRIM forecasts the standard-size refrigerator-freezers domestic labor expenditure for production labor in 2014 will be approximately $278 million. Using the $18.60 wage rate and 2,032 production hours per year per employee found in the 2007 ASM, the GRIM estimates there will be approximately 7,351 domestic production employees involved in manufacturing standard-size refrigerator-freezers covered by this rulemaking. In addition, DOE estimates that 961 non-production employees in the United States will support standard-size refrigerator-freezers production.[f] The employment spreadsheet of the GRIM shows the annual domestic employment impacts in further detail. Approximately 42 percent of standard-size refrigerator-freezers sold in the United States are manufactured domestically.

Table 12.7.1 illustrates the range of potential impacts of amended energy conservation standards on domestic production employment levels at each TSL for the standard-size refrigerator-freezers market.

[f] As defined in the 2007 ASM, production workers number include "workers (up through the line-supervisor level) engaged in fabricating, processing, assembling, inspecting, receiving, storing, handling, packing, warehousing, shipping (but not delivering), maintenance, repair, janitorial and guard services, product development, auxiliary production for plant's own use (*e.g.*, power plant), recordkeeping, and other services closely associated with these production operations at the establishment covered by the report. Employees above the working-supervisor level are excluded from this item." Non-production workers are defined as "employees of the manufacturing establishment including those engaged in factory supervision above the line-supervisor level. It includes sales (including driver-salespersons), sales delivery (highway truck drivers and their helpers), advertising, credit, collection, installation and servicing of own products, clerical and routine office functions, executive, purchasing, financing, legal, personnel (including cafeteria, medical, etc.), professional, and technical employees. Also included are employees on the payroll of the manufacturing establishment engaged in the construction of major additions or alterations utilized as a separate work force."

Table 12.7.1 Potential Changes in the Total Number of Domestic Standard-Size Refrigerator-Freezers Production Workers in 2014

	Trial Standard Level					
	Base Case	1	2	3	4	5
Total Number of Domestic Production Workers in 2014 (without changes in production locations)	7,351	7,164	7,127	7,172	7,109	6,981
Potential Changes in Domestic Production Workers in 2014*	-	(187) - (7,351)	(224) - (7,351)	(179) - (7,351)	(242) - (7,351)	(307) - (7,351)

*DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers.

Figure 12.7.1 below shows total annual domestic employment levels for each TSL calculated by the GRIM.

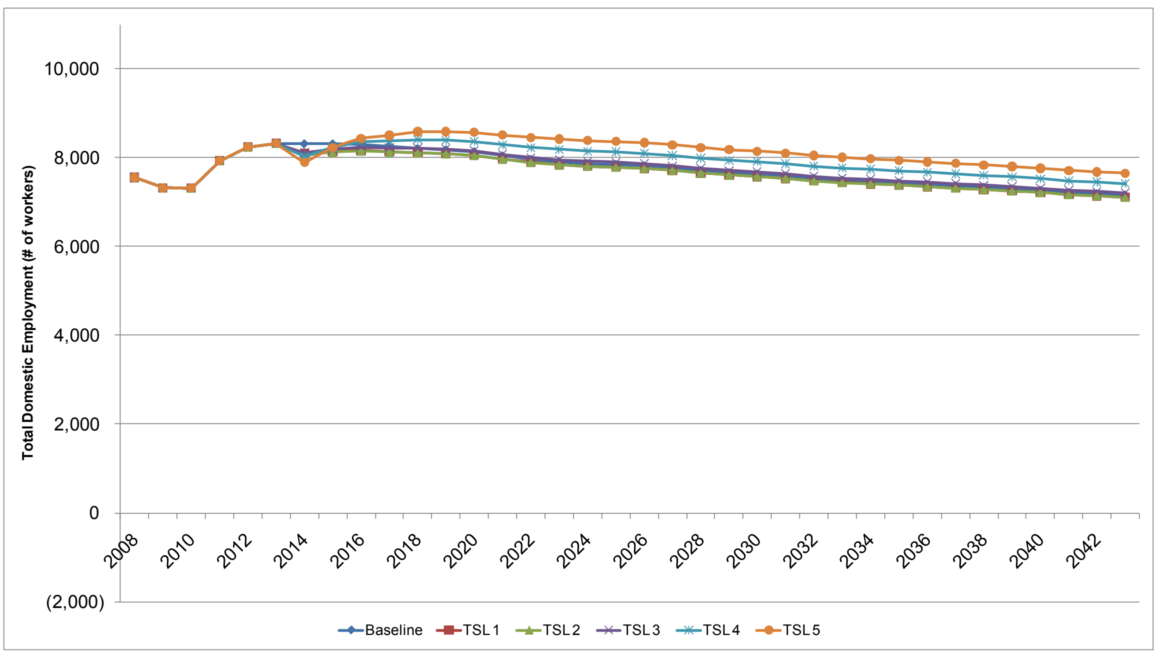

Figure 12.7.1 Total Standard-Size Refrigerator-Freezers Industry Domestic Employment by Year

All examined TSLs show relatively minor impacts on domestic employment levels at the lower end of the range. Most of the design options used in the engineering analysis involve the swapping of components in baseline units with more efficient parts for top-mounted, side-by-side, and bottom-mounted refrigerator-freezers. These component swaps for these design options add primarily material costs and do not greatly impact the labor content of the baseline products. The relatively small decreases in domestic production employment for the lower end of the range of the employment impacts arise from higher product prices lowering shipments the year the standard becomes effective. At these higher TSLs, the effects of lower shipments more than offset the additional product labor that is required to manufacture products that use VIP panels.

During interviews, manufacturers indicated that their domestic employment levels could be impacted under two scenarios: (1) the widespread adoption of VIPs or (2) significant capital conversion costs that would force them to consider non-domestic manufacturing locations once the compliance date for the amended energy conservation standards arrive. The widespread adoption of VIPs would increase the labor content of today's products. The labor content of products with VIPs increases because of the extra handling steps that would be required to ensure that VIPs are not damaged during production. Because of the competitive nature of the industry, manufacturers believed the extra labor costs could force them to move their remaining domestic production to Mexico to take advantage of the cheaper labor.

Manufacturers also indicated that large conversion costs would likely force them to consider investing in lower-labor-cost countries. For most product categories, there is a range of efficiency levels that can be met with relatively low-cost components (as analyzed in the engineering analysis). Beyond these levels, manufacturers would need to decide to follow the MPC design options analyzed in the engineering analysis for each product category. Manufacturers indicated the analyzed design options the use multiple VIPs would involve significant capital conversion costs and add very large material cost to their products and would likely result in relocation. However, manufacturers indicated they would face even larger capital conversion costs at lower efficiencies if they redesigned their products with thicker walls. While not analyzed as a design option for standard-size refrigerator-freezers, increasing wall thickness would likely result in moving domestic production outside of the U.S. at lower efficiency levels.

12.7.1.3 Standard-Size Freezers Employment Impacts

The GRIM calculates that the standard-size freezers domestic labor expenditure for production labor in 2014 will be approximately $62 million. Using the $18.60 wage rate and 2,032 production hours per year per employee found in the 2007 ASM, the GRIM estimates there will be approximately 1,643 U.S. production employees involved in manufacturing standard-size freezers covered by this rulemaking. In addition, DOE estimates that 215 non-production employees in the United States will support standard-size freezers production and manufacturer sales. The employment spreadsheet of the GRIM shows the annual domestic employment impacts in further detail. Approximately 80 percent of standard-size freezers sold in the United States are manufactured domestically.

Table 12.7.2 illustrates the range of potential impacts of amended energy conservation standards on domestic production employment levels at each TSL for the standard-size freezers market.

Table 12.7.2 Potential Changes in the Total Number of Domestic Standard-Size Freezers Production Workers in 2014

	Trial Standard Level					
	Base Case	1	2	3	4	5
Total Number of Domestic Production Workers in 2014 (without changes in production locations)	1,643	1,597	1,537	1,497	1,410	1,303
Potential Changes in Domestic Production Workers in 2014*	-	(46) - (1,643)	(106) - (1,643)	(146) - (1,643)	(233) - (1,643)	(340) - (1,643)

*DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers.

Figure 12.7.2 below shows total annual domestic employment levels for each TSL calculated by the GRIM.

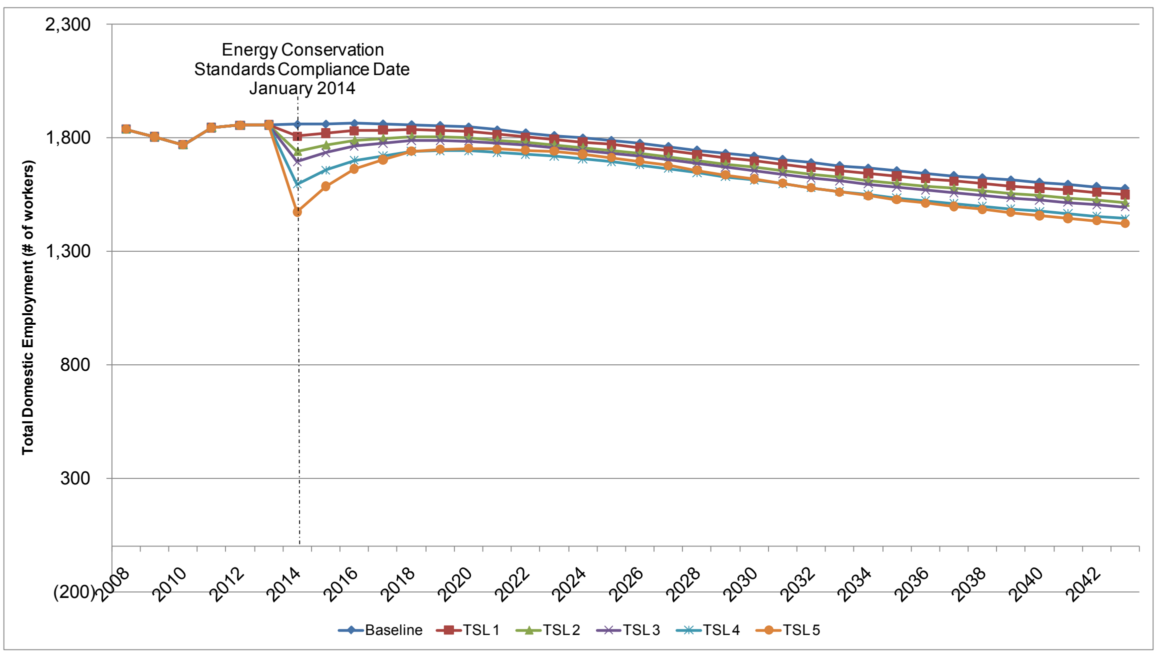

Figure 12.7.2 Total Standard-Size Freezers Industry Domestic Employment by Year

Similar to standard-size refrigerator-freezers, there are relatively small decreases in employment at the lower end of the range of employment impacts. These slight declines are caused by higher prices that drive lower shipments once manufacturers must meet the amended energy conservation standard. Standard-size freezers manufacturers also indicated that domestic production could be shifted abroad any efficiency level that required large capital conversion costs. At TSL 1, DOE does not expect substantial changes to domestic employment in the standard-size freezer market if manufacturers use the design options listed in the engineering analysis to reach the efficiency requirements at this TSL. However, at TSL 2 through TSL 5, manufacturers indicated that there could be domestic employment impacts depending on the design pathway used to reach the required efficiencies. At TSL 2 and above, the engineering analysis assumes that manufacturers would have to use wall thickness changes to reach the required efficiencies. Manufacturers indicated that because these products are typically low-end, they would likely follow the design pathways in the engineering analysis and increase the wall insulation thickness to reach higher efficiencies in order to avoid having to pass large price increases on to consumers. While this would result in extremely large conversion costs and would more likely lead to manufacturers moving production offshore, manufacturers believed this strategy would help to maintain sales volumes.

12.7.1.4 Compact Refrigeration Products Employment Impacts

DOE's research suggests that a limited percentage of compact refrigerators and refrigerator-freezers are made domestically. The overwhelming majority of products are imported. Manufacturers with domestic manufacturing facilities tend to source or import their compact products. The small employment numbers are mostly from remaining domestic production of compact chest freezers. As a result, amended energy conservation standards for compact refrigerators or refrigerator-freezers are unlikely to noticeably alter domestic employment levels.

Table 12.7.3 illustrates the range of potential impacts of amended energy conservation standards on domestic production employment levels at each TSL for the compact refrigeration products market.

Table 12.7.3 Potential Changes in the Total Number of Domestic Compact Refrigeration Products Production Workers in 2014

	Trial Standard Level					
	Base Case	1	2	3	4	5
Total Number of Domestic Production Workers in 2014 (without changes in production locations)	27	26	26	25	24	40
Potential Changes in Domestic Production Workers in 2014*	-	(1) - (27)	(1) - (27)	(2) - (27)	(3) - (27)	(13) - (27)

*DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers.

Figure 12.7.3 below shows total annual domestic employment levels for each TSL calculated by the GRIM.

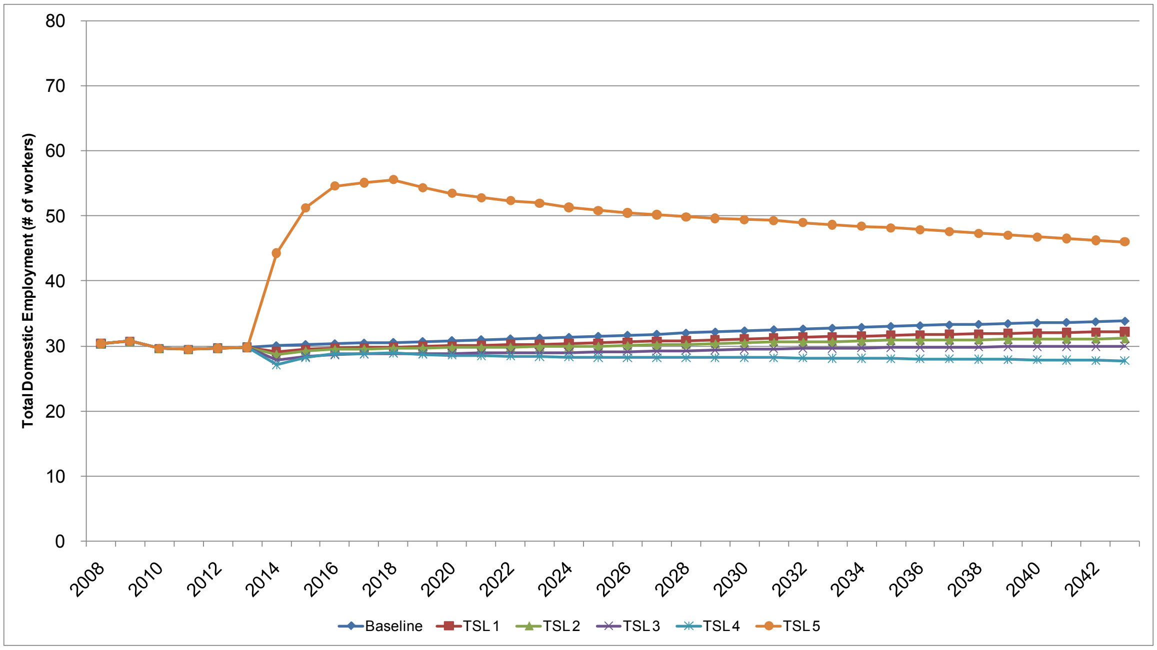

Figure 12.7.3 Total Compact Refrigeration Products Industry Domestic Employment by Year

12.7.1.5 Built-In Refrigeration Products Employment Impacts

The GRIM forecasts the built-in refrigeration products domestic labor expenditure for production labor in 2014 will be approximately $43 million. Using the $18.60 wage rate and 2,032 production hours per year per employee found in the 2007 ASM, the GRIM estimates there will be approximately 1,139 U.S. production employees involved in manufacturing built-in refrigeration products covered by this rulemaking. In addition, DOE estimates that 149 non-production employees in the United States will support built-in refrigeration products production. The employment spreadsheet of the GRIM shows the annual domestic employment impacts in further detail. Approximately 94 percent of built-in refrigeration products sold in the United States are manufactured domestically.

Table 12.7.4 illustrates the range of potential impacts of amended energy conservation standards on domestic production employment levels at each TSL for the built-in refrigeration products market.

Table 12.7.4 Potential Changes in the Total Number of Domestic Built-In Refrigeration Products Production Workers in 2014

	Trial Standard Level					
	Base Case	1	2	3	4	5
Total Number of Domestic Production Workers in 2014 (without changes in production locations)	1,139	1,139	1,338	1,145	1,148	1,171
Potential Changes in Domestic Production Workers in 2014*	-	0 - (1,139)	(1) - (1,139)	6 - (1,139)	9 - (1,139)	32 - (1,139)

*DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers.

Figure 12.7.4 below shows total annual domestic employment levels for each TSL calculated by the GRIM.

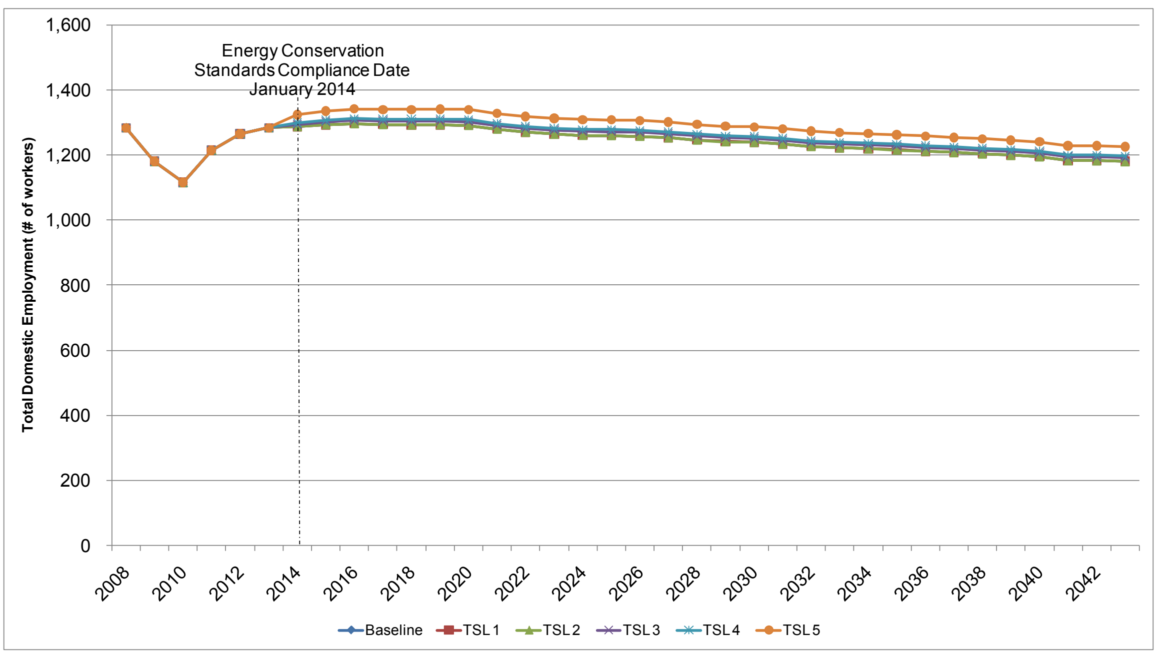

Figure 12.7.4 Total Built-In Refrigeration Products Industry Domestic Employment by Year

Employment in the built-in refrigeration market follows a pattern similar to that seen in the market for standard-size refrigerator-freezers and standard-size freezers at lower TSLs. At TSL 1 and TSL 2, higher prices result in fewer shipments, and a consequent reduction in labor expenditures that more than offsets the additional labor required to manufacturer products with VIPs. However, at TSL 3 and above, the use of additional VIPs in built-in refrigeration products requires enough additional labor to cause a slight increase in the number of domestic production workers. Because built-in products are high-end products with far fewer shipments, it is less likely that manufacturers would chose to move all production facilities in response to amended energy conservation standards. The higher margins and profit earned in this market also make it more likely that manufacturers could earn a return on the investments required to reach the amended energy conservation standards and invest in existing facilities rather than move production.

12.7.2 Production Capacity

Manufacturers indicated that design changes involving thicker walls or multiple VIP panels would require substantial changes to their current manufacturing process. While these technologies would require the purchase of millions of dollars of production equipment, most manufacturers indicated they would likely be able to make even these substantial changes in between the announcement of the final rule and compliance date of an amended energy conservation standard. Manufacturers have had experience with the design options involving VIPs (even if not at the scale that would be required if the higher efficiency levels were adopted) and thickening walls. In addition, the design changes and investments analyzed at the levels required by the amended energy conservation standards for most product classes are more similar in magnitude to the introduction of a new product line – not completely redesigning all products. Therefore, a larger capacity concern of manufacturers is the ability of their suppliers, particularly manufacturers of VIPs and more efficient compressors, to ramp up production in time to meet the amended energy conservation standard. DOE analyzed VIP supply in appendix 4-A.

12.7.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have serious consequences for some manufacturers, groups of manufacturers, or an entire industry. Assessing the impact of a single regulation may overlook this cumulative regulatory burden. For the cumulative regulatory burden analysis, DOE looks at other significant product-specific regulations that could affect residential refrigeration manufacturers that will take effect 3 years before or after the compliance date of amended energy conservation standards for these products.[g] In addition to the amended energy conservation regulations on residential refrigeration products, several other Federal regulations apply to these products and other equipment produced by the same manufacturers. While the cumulative regulatory burden focuses on the impacts on manufacturers of other Federal requirements, DOE also has described a number of other regulations in section 12.7.3.3 because it recognizes that these regulations also impact the products covered by this rulemaking.

Companies that produce a wide range of regulated products may be faced with more capital and product development expenditures than competitors with a narrower

[g] The compliance date for residential refrigeration products is 3 years from the date of publication of the final rule (approximately January 2014).

scope of products. Regulatory burdens can prompt companies to exit the market or reduce their product offerings, potentially reducing competition. Smaller companies in particular can be affected by regulatory costs since these companies have lower sales volumes over which they can amortize the costs of meeting new regulations. An energy conservation standard is not economically justified if it contributes to an unacceptable level of cumulative regulatory burden.

12.7.3.1 DOE Regulations for Other Products Produced by Residential Refrigeration Manufacturers

In addition to the amended energy conservation standards on residential refrigeration products, several other Federal regulations and pending regulations apply to other products produced by the same manufacturers. DOE recognizes that each regulation can significantly affect a manufacturer's financial operations. Multiple regulations affecting the same manufacturer can quickly strain manufacturers' profits and possibly cause an exit from the market. Table 12.7.5 lists the other DOE energy conservation standards that could also affect manufacturers of residential refrigeration products in the 3 years leading up to and after the compliance date of amended energy conservation standards for these products.

Table 12.7.5 Other DOE and Federal Actions Affecting the Residential Refrigeration Industry

Regulation	Approximate Compliance Date*	Number of Impacted Companies from the Market and Technology Assessment (MTA) (See Chapter 3)	Estimated Total Industry Conversion Costs
ASHRAE Products	2012	1	N/A
Packaged Terminal Air Conditioners and Packaged Terminal Heat Pumps	2012	5	$17.3 million (2007$)[h]
Cooking Products	2012	13	$22.6 million (2006$)[i]
Residential Boilers	2012	0	N/A†
General Service Fluorescent Lamps and Incandescent Reflector Lamps	2012	2	$363.1 million (2008$)[j]
Dehumidifiers	2012	5	N/A†††
Beverage Vending Machines	2012	1	$14.5 million (2008$)[k]
Commercial Clothes Washers	2013	4	$20.4 million (2008$)[l]
Direct Heating Equipment	2013	0	$5.39 million (2009$)[m]

[h] Estimated industry conversion expenses were published in the TSD for the October 2008 packaged terminal air conditioners and packaged terminal heat pumps final rule. 73 FR 58772. The TSD for the 2008 packaged terminal air conditioners and packaged terminal heat pumps final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/ptacs_pthps_final_tsd.html.
[i] Estimated industry conversion expenses were published in the TSD for the April 2009 residential cooking products final rule. 74 FR 16040. The TSD for the 2009 residential cooking products final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/residential/cooking_products_final_rule_tsd.html.
[j] Estimated industry conversion expenses were published in the TSD for the July 2009 general service fluorescent lamps and incandescent reflector lamps final rule. 74 FR 34080. The TSD for the 2009 lamps final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/residential/incandescent_lamps_standards_final_rule_tsd.html.
[k] Estimated industry conversion expenses were published in the TSD for the August 2009 beverage vending machines final rule. 74 FR 44914. The TSD for the 2009 beverage vending machines final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/beverage_machines_final_rule_tsd.html.
[l] Estimated industry conversion expenses were published in the TSD for the January 2010 commercial clothes washers final rule. 75 FR 1122. The TSD for the 2010 commercial clothes washers final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/clothes_washers_ecs_final_rule_tsd.html
[m] Estimated industry conversion expenses were published in the TSD for the April 2010 heating products final rule. 75 FR 20112. The TSD for the 2010 heating products final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr_tsd.html.

Residential Pool Heaters	2013	0	$0.3 million (2009$)[n]
Battery Chargers and External Power Supplies	2013*	4	N/A††
Room Air Conditioners	2014*	9	N/A††
Residential Clothes Dryers	2014*	9	N/A††
Fluorescent Lamp Ballasts	2014*	2	N/A††
Walk-In Freezers and Coolers	2015*	0	N/A††
Metal Halide Lamp Fixtures	2015*	0	N/A††
Residential Clothes Washers	2015*	10	N/A††
Small Electric Motors	2015	0	$51.2 million (2009$)[o]
Residential Water Heaters	2015	2	$95.9 million (2009$)[p]
Commercial Electric Motors	2015*	2	N/A††
Residential Furnaces	2015*	2	N/A††
Commercial Distribution Transformers	2016*	2	N/A††
Commercial Refrigeration Equipment	2016*	1	N/A††
Residential Central Air Conditioners	2016*	3	N/A††

*The dates listed are an approximation. The exact dates are pending final DOE action.
† Energy conservation standards and compliance dates for residential boilers can be found at 10 CFR 430.32(e)(2)(ii)-(iv).
†† For energy conservation standards for rulemakings awaiting DOE final action, DOE does not have a finalized estimated total industry conversion cost.
††† For minimum performance requirements prescribed by the Energy Independence and Security Act of 2007 (EISA 2007), DOE did not estimate total industry conversion costs because an MIA was not completed as part of a rulemaking. Pub. L. 110-140. EISA 2007 made numerous amendments to the Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163, (42 U.S.C. 6291–6309), which established an energy conservation program for major household appliances and industrial and commercial equipment.

Some Federal DOE regulations have a more significant impact on manufacturers of residential refrigeration products than others because manufacturers hold a significant market share in those covered products. Table 12.7.6 below shows the DOE energy conservation standards with compliance dates within three years of residential refrigeration products where manufacturers are expected to be most impacted due to their

[n] Estimated industry conversion expenses were published in the TSD for the April 2010 heating products final rule. 75 FR 20112. The TSD for the 2010 heating products final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr_tsd.html.
[o] Estimated industry conversion expenses were published in the TSD for the March 2010 small motors final rule. 75 FR 10874. The TSD for the 2010 small motors final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/sem_finalrule_tsd.html.
[p] Estimated industry conversion expenses were published in the TSD for the April 2010 heating products final rule. 75 FR 20112. The TSD for the 2010 heating products final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr_tsd.html.

market positions. For these rulemakings, residential refrigeration manufacturers would likely be burdened by a significant portion of the estimated industry conversion costs. In some cases, specific market share data was not available, but manufacturers were identified as major or minor manufacturers in the given market when this information was publicly available.

Table 12.7.6 DOE Regulations on Products For Which Residential Refrigeration Manufacturers Hold Significant Market Share

		Manufacturer Market Share in DOE Regulated Product					
Regulation	**Estimated Industry Total Conversion Expenses (millions)**	**GE**	**Whirlpool**	**Electrolux**	**LG**	**Samsung**	**Haier**
Packaged Terminal Air Conditioners and Packaged Terminal Heat Pumps	$17.3 million (2007$)	N/A (major)	N/A (major)		N/A (major)		
Ranges and Ovens	$22.6 million (2006$)	47% (electric); 37% (gas)	29% (electric); 25% (gas)	8% (electric); 23% (gas)	N/A (major)	N/A (minor)	N/A (minor)
General Service Fluorescent Lamps and Incandescent Reflector Lamps	$363.1 million (2008$)	N/A (major)					
Dehumidifiers	N/A		35%	6%	35%	3%	
Commercial Clothes Washers	$20.4 million (2008$)	N/A (major)	N/A (major)	N/A (minor)	N/A (minor)		
Room Air Conditioners	N/A		13%	13%	32%	5%	8%
Residential Clothes Dryers	N/A	16% (electric); 10% (gas)	70% (electric); 74% (gas)	8% (electric); 5% (gas)	N/A (minor)	N/A (minor)	N/A (minor)
Fluorescent Lamp Ballasts	N/A	N/A (major)					
Residential Clothes Washers	N/A	16%	64%	6%	6%		

12.7.3.2 Other Federal Regulations

Unites States Clean Air Act

The Clean Air Act is defines the EPA's responsibilities for protecting and improving the nation's air quality and the stratospheric ozone layer. The most significant of these additional regulations are the EPA mandated phase-out of hydro chlorofluorocarbons (HCFCs). The Act demands on a quarterly basis that any person who produced, imported, or exported certain substances, including HCFC refrigerants, must report the amount produced, imported and exported. Additionally, effective January 1, 2015, selling, manufacturing, and using any such substance is banned unless such substance has been used, recovered, and recycled; is used and entirely consumed in the production of other chemicals; or is used as a refrigerant in appliances manufactured prior to January 1, 2020. Finally, production phase-outs will continue until January 1, 2030 when such production will be illegal. These bans could trigger design changes to natural or low global warming potential refrigerants and could impact the insulation used in products covered by this rulemaking.

Potential Climate Change and Greenhouse Gas Legislation

Many manufacturers expressed concern about potential climate change legislation. One proposed regulation that would exacerbate the manufacturer burden caused by more stringent energy conservation standards on refrigeration products is H.R. 2454, the American Clean Energy and Security Act of 2009. This legislation would initiate a phase-down of hydrofluorocarbons (HFCs) and would make the amended energy conservation standard levels considered in this rulemaking more difficult to achieve. Converting facilities to use cyclopentane would be disruptive to manufacturing facilities because of the plant changes required to use a flammable foam blowing agent safely.

A further complication of an HFC phase-down for manufacturers is that isobutane, the most likely refrigerant replacement of HFCs, is itself currently restricted by UL safety rules. UL 250 limits the amount of charge in refrigerators and would prevent its use in most residential refrigeration products. While isobutane is more efficient than typical HFC refrigerants, some manufacturers were concerned that its adoption would cause a significant cost to train their servicers to avoid safety problems with the new refrigerant. Several other manufacturers would like to see the current charge limits increased, allowing them consistency with factories overseas that already use these more flammable hydrocarbons.

12.7.3.3 Other Regulations That Could Impact Residential Refrigeration Manufacturers

While the cumulative regulatory burden focuses on the impacts on manufacturers of other Federal requirements, in this section DOE has described a number of other regulations below that could also impact the residential refrigeration products covered by this rulemaking

State Energy Conservation Standards

Manufacturers indicated that California has several programs that are either already in place or are currently in development that affect manufacturers of residential refrigeration products. Various building, electrical, mechanical, and plumbing codes in California affect residential refrigeration products, and products are also subject to California's laws on the Restriction on the use of certain Hazardous Substances (RoHS). California's RoHS law took effect January 1, 2007 and was modeled after the EU's directive (described below), which bans certain hazardous substances from electrical and electronic equipment. California and Washington also have energy conservation standards for wine chillers. Connecticut, Maine, Minnesota, New York, Rhode Island, Vermont, and Washington all prohibit the sale or distribution of products containing intentionally-added mercury without a label. In Oregon, Penta- and Octa-BDE have been restricted since 2006, and Oregon banned Deca-BDE in June 2009. These substances belong to a group of brominated flame retardants (BFRs) commonly known as Polybrominated Diphenyl Ethers (PBDEs). In Maryland, a ban on Deca-BDE will be phased-in beginning October 1, 2010.

International Energy Conservation Standards

Residential refrigeration manufacturers that sell products outside of the United States are subject to several international energy conservation standards. In the European Union, refrigerators and other appliances must carry the EU Energy Label. The energy efficiency of the product is rated in energy levels ranging from A to G on the outside label, with 'A' being the most energy efficient. Recently, A+ and A++ qualifications were also introduced for refrigerated appliances. This labeling system enables consumers to compare the energy efficiency of products, and it incentivizes manufacturers to improve the energy performance of their products. In the EU, products are also subject to RoHS. This regulation bans the sale of new equipment in the EU that contains more than agreed levels of lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB) and PBDE flame retardants. Waste Electrical and Electronic Equipment (WEEE) and the Registration, Evaluation, Authorization, and restriction of Chemicals (REACH) are additional regulations that create compliance costs for manufacturers that compete in Europe. REACH deals with chemicals and their safe use and has provisions that will be phased-in over eleven years, beginning June 1, 2007. The EU also sets limits for the amount of energy consumed by equipment when it is in standby mode and off mode. Additionally, HFCs are banned in refrigerants in several countries, such as Austria, Denmark, and Switzerland.

Canada also has several regulations that affect manufacturers of residential refrigeration products. Ontario's Product Safety Regulation 438/07 ensures the safety of electrical products and equipment sold and used in Ontario. The manufacture of PBDE is banned in Canada, including the controversial Deca-BDE. The import of products containing Octa-BDE and Penta-BDE is also banned.

Several other foreign countries, such as Australia and South Korea, have energy conservation standards in place for residential refrigeration products or are in the process of establishing standards for these products. Other countries, such as India and Saudi Arabia, have labeling requirements for refrigerators.

12.8 CONCLUSION

The following sections summarize the impacts for the scenarios DOE believes are most likely to capture the range of impacts on residential refrigeration product manufacturers as a result of amended energy conservation standards. DOE also notes that while these scenarios bound the range of most plausible impacts on manufacturers, there potentially could be circumstances which cause manufacturers to experience impacts outside of this range.

12.8.1 Standard-Size Refrigerator-Freezers

TSL 1 represents the current ENERGY STAR level for standard-size refrigerator-freezers or a 20-percent reduction in measured energy consumption over the current energy conservation standards for the analyzed standard-size top-mount product class 3, a 20-perecent reduction for the analyzed standard-size bottom-mount product class 5, and a 20-percent reduction for the analyzed standard-size side-by-side product class 7. At TSL 1, DOE estimates impacts on INPV to range -$117.8 million to -$252.6 million, or a change in INPV of -4.4 percent to -9.5 percent. At this TSL, industry free cash flow is estimated to decrease by approximately 71.8 percent to $51.5 million, compared to the base-case value of $182.8 million in the year leading up to the amended energy conservation standards.

The INPV impacts at TSL 1 are relatively minor, in part because the vast majority of manufacturers produce ENERGY STAR units in significant volumes, particularly for product classes 5 and 7. Approximately 42 percent of product class 7 shipments and 47 percent of product class 5 shipments currently meet this TSL. By contrast, the vast majority of product class 3 shipments are baseline units. Additionally, most of the design options DOE analyzed at this TSL are one-for-one component swaps, including more efficient compressors and brushless DC condenser and evaporator fan motors, which require only modest changes to the manufacturing process at TSL 1. As such, DOE estimated total product conversion costs of $153 million and capital conversion costs of $229 million.

While substantial on a nominal basis, the total conversion costs are relatively low compared to the industry value of $2.7 billion. The total conversion costs at TSL 1 are mostly driven by the design options that manufacturers could use to improve the efficiency of the smaller-sized units of the product classes analyzed. For example, the analyzed design options for the 22-cubic foot product class 7 unit included a VIP in the freezer door, while the 26-cubic foot product class 7 unit only analyzed less costly component swaps. VIP implementation would require significant capital and product conversion costs because additional production steps are required to hold and bind each panel in its location before the product is foamed. Each additional step requires more equipment to lengthen production lines and, because of lower throughput, more production lines for each manufacturer to maintain similar shipment volumes. Some manufacturers have experience with VIPs, but DOE expects substantial engineering and testing resources would be required for their use in new platforms and/or at higher production volumes.

Similarly, the 16-cubic foot product class 3 unit uses a variable speed compressor as a design option. While not a capital intensive solution, variable speed compressors would require substantial engineering time to integrate the complex component, especially if electronic control systems would also be required. Because these changes are more complex than the other analyzed design options, more than three-quarters of the conversion costs for TSL 1 are attributable to the use of the VIPs and variable speed compressors in the smaller-volume product class 7 and product class 3 units, respectively.

The flat markup scenario shows slightly negative impacts at TSL 1, indicating that the outlays for conversion costs marginally outweigh any additional profit earned on incrementally higher variable costs. On a shipment-weighted basis, the average MPC for standard-size refrigerator-freezers increases by 10 percent at TSL 1 after standards. These small component cost changes are not significant enough to fully recoup these investments even if manufacturers earn additional profit on these costs, as the flat markup scenario assumes. Hence, there is a slight negative impact, even in the upper-bound scenario, at TSL 1.

The efficiency requirements for product class 3 and product class 5 refrigerator-freezers are the same at TSL 2 as TSL 1. However, the efficiency requirements for product class 7 increase to a 25-percent reduction in measured energy consumption from current energy conservation standards. DOE estimates the INPV impacts at TSL 2 range from -$219.2 million to -$395.9 million, or a change in INPV of -8.2 percent to -14.8 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 113.9 percent to -$25.4 million, compared to the base-case value of $182.8 million in the year leading up to the amended energy conservation standard.

The additional impacts at TSL 2 relative to TSL 1 result from the further improvements manufacturers must make to product class 7 refrigerator-freezers to achieve a 25-percent energy reduction, as very few shipments of product class 7 currently exceed the ENERGY STAR level. Specifically, for the 22-cubic foot product, the design options DOE analyzed include a variable speed compressor and a VIP in the freezer cabinet, instead of the door as in TSL 1. For the 26-cubic foot product class 7 unit, the design options analyzed include a VIP in the freezer door in addition to additional component swaps and the component swaps needed to meet TSL 1. Total conversion costs increase by $208 million compared to TSL 1, which is largely driven by the initial use of VIPs in the 26-cubic foot product class 7 unit. Besides these specific changes to side-by-side units, at TSL 2 most production lines of standard-size refrigerator-freezers do not use of VIPs or other very costly components, mitigating some of the disruption to current facilities. Consequently, the INPV impacts, while greater than at TSL 1, are still relatively moderate compared to the value of the industry as a whole.

At TSL 2, the INPV in the flat markup is lower than at TSL 1, which means the additional conversion costs to add more VIPs leaves manufacturers worse off even if they can earn additional profit on these costly components. In the preservation of operating profit markup scenario, the industry earns no additional profit on this greater investment, lowering cash flow from operations in the standards case and resulting in greater INPV impacts.

The efficiency requirements for product class 5 and product class 7 refrigerator-freezers are the same at TSL 3 as TSL 2. However, the efficiency requirements for product class 3 increase to a 25-percent reduction in measured energy consumption from current energy conservation standards. TSL 3 represents a 25-percent reduction in measured energy consumption over the current energy conservation standards both product class 3 and product class 7. In addition, TSL 3 represents a 20-percent reduction in measured energy consumption for the unanalyzed product classes 1, 1A, and 2. DOE estimates the INPV impacts at TSL 3 to range from -$345.0 million to -$580.7 million, or a change in INPV of -12.9 percent to -21.7 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 168.0 percent to -$124.3 million, compared to the base-case value of $182.8 million in the year leading up to the standards.

The additional negative impacts on industry cash flow result from the changes to product class 3 refrigerator-freezers to reach a 25-percent reduction in energy use (side-by-side products met this efficiency level at TSL 2). Specifically, the design options DOE analyzes at TSL 3 for 16-cubic foot top-mount refrigerator-freezers include the use of VIPs for the first time (in the freezer cabinet), in addition to the component swaps discussed above. In total, DOE estimates product conversion costs of $229 million and capital conversion costs of $620 million at TSL 3. The high cost to purchase new production equipment and the large engineering effort to manufacture new platforms for these smaller-sized product class 3 units drive the vast majority of this additional $258 million in conversion costs that DOE estimates manufacturers would incur at TSL 3. Because the smaller size top-mounted units account for a large percentage of total shipments, the production equipment necessary to implement new platforms for these products is costly.

While production of units meeting TSL 3 is fairly limited, several manufacturers have introduced products that meet these efficiency levels in response to Federal production tax credits. This experience mitigates some of the product conversion costs by giving manufacturers some experience with the newer technologies. However, the more severe impacts at TSL 3, relative to TSL 2, are due to the incremental outlays for conversion costs to make the changes described above. In particular, any experience with VIPs on some products does not lower the substantial capital conversion necessary to purchase production equipment necessary to manufacture products that are substantially different from existing products.

As mentioned above, the preservation of operating profit markup scenario assumes no additional profit is earned on the higher production costs, which lower profit margins as a percentage of revenue and leads to worse impacts on INPV. In the flat markup scenario, the impact of the investments is mitigated by the assumption that manufacturers can earn a similar profit margin as a percentage of revenues on their higher variable costs. At TSL 3 MPCs increase by an average of 16 percent after standards, leading to additional per-unit profit in this scenario. However, the magnitude of the conversion investments still leads to negative INPV impacts even if additional profit is earned on the incremental manufacturing costs. The lower industry shipments driven by the relative price elasticity assumption account for approximately $45 million of the impact in the flat markup scenario.

TSL 4 represents a 30-percent reduction in measured energy consumption over the current energy conservation standards for product class 3, product class 5, and product class 7. DOE estimates the INPV impacts at TSL 4 to range from -$784.9 million to -$1,309.3 million, or a change in INPV of -29.4 percent to -49.0 percent. At this TSL, the industry cash flow is estimated to decrease by approximately a factor of 3.6 to -$469.3 million, compared to the base-case value of $182.8 million in the year leading up to the amended energy conservation standards.

At TSL 4, significant changes to the manufacturing process are necessary for all refrigerator-freezers. A 30-percent reduction in energy consumption is the max available top-mount on the market; the maximum available side-by-side and bottom-mount only slightly exceed a 30-percent reduction. The design options DOE analyzed for all standard-size products—with the exception of the 25-cubic foot product class 5 unit—use multiple VIPs in the fresh food compartment, freezer doors, and cabinets to reach the 30-percent efficiency level. The design options also include the use of variable speed compressors for all units analyzed except the 21-cubic foot product class 3 unit. These product changes substantially increase the variable costs across nearly all platforms at this TSL.

While products that meet the efficiency requirements of TSL 4 are not in widespread production, several manufacturers produce units at these efficiencies due to tax credit incentives. However, at TSL 4 most manufacturers expect to completely redesign existing production lines if the amended energy conservation standards were set at levels that necessitated these changes across most or all of their products. Manufacturers would need to purchase injection molding equipment, cabinet bending equipment, and other equipment for interior tooling as they would need to create new molds for these production lines. These changes drive DOE's estimate of the large product and capital conversion costs at TSL 4 ($348 million and $1,405 million, respectively). The significant incremental investment relative to TSL 3 results, in large part, from the design option of adding VIPs to the 21-cubic foot analyzed product class 3 unit. This top-mounted refrigerator-freezer represents a substantial portion of the market and manufacturers would have to completely redesign these platforms.

As a result of the large investment necessary to meet this TSL, some manufacturers could move production to Mexico or other lower-labor-costs countries to achieve cost savings for labor expenditures. In addition to the large capital conversion costs, the shipment-weighted average MPC increases by approximately 36 percent at TSL 4 after standards compared to the base case. However, the magnitude of the conversion costs at TSL 4 are so large that even if manufacturers can reap additional profit from these higher product costs (as in the flat markup scenario), they would still be substantially impacted, as shown by the negative INPV results in the flat markup scenario. Additionally, the 36-percent increase in MPC drives shipments lower due to the price elasticity. Lower industry volume from the decline in shipments accounts for approximately 16-percent of the change in industry value in the flat markup scenario. The large, negative impact on INPV is even greater under the preservation of operating profit markup scenario due to the inability to pass on the higher costs of expensive design options such as variable speed compressors and VIPs.

TSL 5 represents max tech for all standard-size refrigerator-freezers. The max-tech level corresponds to reductions in measured energy consumption compared to the current energy conservation standards for product class 3 (36 percent), product class 5 (36 percent), and product class 7 (33 percent), respectively. DOE estimates the INPV impacts at TSL 5 to range from -$1,042.2 million to -$1,841.5 million, or a change in INPV of -39.0 percent to -69.0 percent. At this TSL, the industry cash flow is estimated to decrease by a factor of approximately 5.0 to -$727.5 million, compared to the base-case value of $182.8 million in the year leading up to the amended energy conservation standards.

No products that meet TSL 5 are currently offered on the U.S. market. At TSL 5, the changes required to meet this TSL are similar to those at TSL 4, as complete redesigns of all platforms would be required. TSL 5 requires much more extensive use of VIPs, however. The higher conversion costs at TSL 5 are primarily due to the use of VIPs in additional locations in the door, cabinet and freezer, whereas at TSL 4 some of the analyzed design options of the larger-sized units included limited or no VIP use. This level would require manufacturers to further lengthen assembly lines and even modify or move their facilities outside of the United States. These factors drive the projected $2,419 million conversion cost estimate at this TSL. As with TSL 4, at TSL 5 some manufacturers could elect to move production out of the U.S. to offset some of the additional product costs. At TSL 5, DOE estimates MPCs increase by approximately 58 percent after standards compared to the base case. Similar to TSL 4, this substantially reduces shipments due to the price elasticity effect and exacerbates the industry impacts in both markup scenarios.

As with other TSLs, the impact on INPV is mitigated under the flat markup scenario because manufacturers are able to fully pass on the large increase in MPC to consumers, thereby increasing manufacturers' gross profit in absolute terms. However, even assuming manufacturers could earn the same gross margin percentage per unit on those higher costs, the capital and product conversion costs cause negative INPV impacts, as shown by the 39-percent decline in INPV in the flat markup scenario. This large impact even in the lower bound scenario demonstrates that the large conversion costs to redesign all existing platforms results in substantial harm. The result is predicted even if manufacturers earn a historical margin on these additional costs. Due to the extremely large cost increases at the max-tech level, it is less likely at TSL 5 than at other examined levels that manufacturers could fully pass through the increase in production costs. If margins are impacted, TSL 5 would result in a substantial INPV loss under this scenario.

12.8.2 Standard-Size Freezers

TSL 1 represents a 20-percent reduction in measured energy use over the current energy conservation standards for the analyzed standard-size upright freezer product class 9 and a 20-percent reduction for the analyzed standard-size chest freezer product class 10. DOE estimates the INPV impacts at TSL 1 to range from -$29.8 million to -$50.0 million, or a change in INPV of -8.8 percent to -14.8 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 111.2 percent to -$2.6 million, compared to the base-case value of $23.2 million in the year leading up to the amended energy conservation standards.

While products meeting TSL 1 are currently produced only in limited volumes, the changes in the manufacturing process would not require completely new platforms to meet the energy requirements at this TSL. For most standard-size freezer platforms, the design options DOE analyzed include the use of brushless DC evaporator fan motors and compressors with higher EERs. However, the design options to meet this efficiency level also include increasing door insulation thickness for all analyzed products except the 20-cubic foot product class 10 unit. Increasing door insulation thickness drives the majority of the conversion cost outlay DOE estimates manufacturers would incur at TSL 1. To increase door insulation thickness, manufacturers would need to purchase new tooling for their door assemblies. DOE estimates that these changes would result in product conversion costs of $22 million and capital conversion costs of $50 million at TSL 1. However, the conversion costs are somewhat mitigated at TSL 1 because the design options analyzed would not change the production equipment for the cabinet.

At TSL 1, variable costs increase by approximately 10 percent after standards relative to base case MPCs. The flat markup scenario shows less severe impacts because it assumes manufacturers can pass on these substantially higher product costs and maintain gross margin percentages. Additionally, the reduction in shipments due to the price elasticity has only a marginally negative effect at this TSL. The relatively large conversion costs decrease industry value under both markup scenarios and account for a substantial portion of the INPV impacts. This is especially the case if manufacturers are unable to earn any additional profit on the higher production costs (the preservation of operating profit scenario).

TSL 2 represents a reduction in measured energy consumption over the current standards of 30 percent for product class 9 and 25 percent for product class 10. TSL 2 also represents reductions for the other product classes as well -- product class 8 (upright freezers with manual defrost, 25 percent) and product class 10A (chest freezers with automatic defrost, 30 percent). DOE estimates the INPV impacts at TSL 2 to range from -$123.7 million to -$170.5 million, or a change in INPV of -36.6 percent to -50.5 percent. At this TSL, the industry cash flow is estimated to decrease by approximately a factor of 3.6 to -$60.0 million, compared to the base-case value of $23.2 million in the year leading up to the amended energy conservation standards.

The vast majority of the standard-size freezer market does not currently meet the efficiency requirements at TSL 2. DOE's design options assume that, in addition to the component swaps noted above, manufacturers would increase the insulation thickness of both the door and cabinet. As a result, product redesigns are expected across most platforms, which could substantially disrupt current manufacturing processes. These changes account for the majority of DOE's estimates for total product conversion costs of $51 million and capital conversion costs of $175 million, an increase over TSL 1 of $29 million and $125 million, respectively. The magnitude of the investments, relative to the industry value, results in severe INPV impacts. Even if manufacturers are able to pass on the estimated 24-percent increase in product costs onto their customers after standards, the large product and capital conversion costs resulting from increased insulation thickness decrease INPV. If manufacturers are not able to pass on these costs, as shown by the preservation of operating profit scenario, INPV impacts are projected to be severe.

TSL 3 represents a 35-percent reduction in measured energy use over the current energy conservation standards for product class 9 and a 30-percent reduction for product class 10. DOE estimates the INPV impacts at TSL 3 to range from -$112.5 million to -$178.1 million, or a change in INPV of -33.3 percent to -52.7 percent. At this TSL, the industry cash flow is estimated to decrease by a factor of approximately 3.7 to -$63.8 million, compared to the base-case value of $23.2 million in the year leading up to the amended energy conservation standards.

The efficiency requirements at TSL 3 are more stringent than the max available products in the market for product class 9 and product class 10. The impacts at TSL 3 are similar to those at TSL 2 because the design options analyzed by DOE already required platform redesigns at TSL 2. However, the additional design options analyzed at TSL 3 also include a variable speed compressor in the 14-cubic foot product class 9 unit and VIPs in the bottom wall of the 20-cubic foot product class 10 unit. These design options substantially increase the variable costs associated with these products but do not greatly change the product and capital conversion costs. DOE estimates that under TSL 3, the average MPC of a standard-size freezer is roughly 34 percent higher after standards than in the base case, leading to a 9-percent drop in shipments from the price elasticity assumption for 2014 alone.

The impacts at TSL 3 under the flat markup scenario become less severe than at TSL 2 because the scenario assumes manufacturers can fully pass on the added cost to consumers, while investments do not significantly increase from TSL 2 to TSL 3. However, under the preservation of operating profit markup scenario, manufacturers do not receive any extra profit on units of higher cost, resulting in worse INPV impacts at TSL 3 than at TSL 2.

TSL 4 represents a 40-percent reduction in measured energy use over the current energy conservation standards for product class 9 and a 35-percent reduction for product class 10. DOE estimates the INPV impacts at TSL 4 to range from -$85.4 million to -$182.4 million, or a change in INPV of -25.3 percent to -54.0 percent. At this TSL, the industry cash flow is estimated to decrease by a factor of approximately 3.9 to -$66.5 million, compared to the base-case value of $23.2 million in the year leading up to the amended energy conservation standards.

At TSL 4, the design options DOE analyzed include the addition of a variable speed compressor for the 20-cubic foot product class 9 unit, the 15-cubic foot product class 10 unit, and the 20-cubic foot product class 10 unit. For the 14-cubic foot product class 9 unit, the design options analyzed were even thicker wall cabinet insulation and the implementation of VIPs.

The relative impacts at TSL 4 are also caused by the incremental MPCs compared to the conversion costs to implement these design options. Outlays for conversion costs increase only slightly at TSL 4 (by 4 percent, compared to TSL 3) while variable costs increase substantially (by approximately 52 percent after standards compared to the baseline) due to the addition of variable speed compressors and VIPs. Because manufacturers earn incrementally more profit on each unit at TSL 4 compared to TSL 3 in the flat markup scenario—without substantial changes to conversion costs—further declines in industry value, though still substantial, are mitigated in this scenario. However, manufacturers expressed skepticism that such large cost increases could be passed on. This view is reflected by the severely negative results in the preservation of operating profit scenario.

TSL 5 represents max tech for the standard-size freezer product classes. This TSL reflects a 44-percent reduction in measured energy use for product class 9 and a 41-percent reduction for product class 10. DOE estimates the INPV impacts at TSL 5 to range from -$145.0 million to -$298.8 million, or a change in INPV of -42.9 percent to -88.5 percent. At this TSL, the industry cash flow is estimated to decrease by a factor of approximately 6.3 to -$122.8 million, compared to the base-case value of $23.2 million in the year leading up to the amended energy conservation standards.

To achieve the max-tech level at TSL 5, DOE analyzed design options that include the widespread implementation of multiple VIPs on all standard-size freezers, in addition to the use of more efficient components and thicker insulation already necessary to achieve the efficiency requirements at TSL 4. DOE estimated that TSL 5 would require product and capital conversion costs of $70 million and $320 million, respectively. These large conversion costs result from the changes associated with multiple VIP implementation and wall thickness increases. In addition, DOE estimates that product costs would almost double base-case MPCs after standards, driven by the use of variable speed compressors and VIPs in the doors and cabinet of all product lines. As a result, INPV decreases substantially from TSL 4 to TSL 5.

12.8.3 Compact Refrigeration Products

TSL 1 represents a 20-percent reduction in measured energy use over the current energy conservation standards for the analyzed compact refrigerators and refrigerator-freezers product class 11 and a 10-percent reduction for the analyzed compact freezer product class 18. DOE estimates the INPV impacts at TSL 1 to range from -$16.6 million to -$27.8 million, or a change in INPV of -9.8 percent to -16.4 percent. At this TSL, industry cash flow is estimated to decrease by approximately 125.1 percent to -$2.7 million, compared to the base-case value of $10.7 million in the year leading up to the amended energy conservation standards. A small percentage of product class 18 shipments currently meet this TSL, but most product class 11 shipments are baseline units.

The design options analyzed by DOE at TSL 1 assumed that more significant changes in the manufacturing process would be required for product class 11, while product class 18 would only require increased compressor efficiency. For product class 11, DOE analyzed several design options that represent component changes, such as a more efficient compressor and increased heat exchanger area, which do not have a significant impact on consumer prices or conversion costs. However, DOE also analyzed increasing door insulation thickness for product class 11, which drives the bulk of the estimated $15 million and $24 million outlays for product conversion and capital conversion costs, respectively. As described for standard-size refrigerator-freezers and standard-size freezers, increasing insulation thickness requires manufacturers to invest in injection molding equipment and other equipment for interior tooling to manufacturer products with different door dimensions. The overall impacts at TSL 1 are relatively moderate because the conversion costs are still small compared to the industry value of $169.4 million.

The higher production costs at TSL 1 do not have a substantial impact on INPV at TSL 1. The MPC of compact refrigeration products on a shipment-weighted basis increases 11 percent over the base case at TSL 1 after standards. The combined INPV impacts are greater under the preservation of operating profit scenario since manufacturers cannot pass on any of the added cost to consumers under that scenario, resulting in lower cash flows from operations. However, because production costs do not greatly increase at TSL 1, the impacts on INPV are relatively low under this scenario as well.

TSL 2 represents a 25-percent reduction in measured energy use over the current energy conservation standards for product class 11 and a 10-percent reduction for product class 18. TSL 2 also represents a 15-percent reduction in measured energy consumption for the unanalyzed product classes 13, 13I, 15, and 15I, and a 20-percent reduction for the unanalyzed product classes 14 and 14I. DOE estimates the INPV impacts at TSL 2 to range from -$36.2 million to -$58.7 million, or a change in INPV of -21.4 percent to -34.6 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 254.9 percent to -$16.6 million, compared to the base-case value of $10.7 million in the year leading up to the amended energy conservation standards.

At TSL 2, further changes are required for product class 11. In addition to component swaps, the design options analyzed by DOE include thicker cabinet insulation. As discussed for TSL 1, increasing insulation thickness significantly impacts product and capital conversion costs, but much more so when adding insulation to the cabinet (as opposed to the door). To increase the insulation thickness of the cabinet, manufacturers must replace virtually all stamping equipment, which greatly increases the capital conversion costs. Additionally, DOE analyzed the use of isobutane refrigerant as a design option for the 4-cubic foot product class 11 unit. At TSL 2, a substantial portion of the investment to reach TSL 2 would likely be for training service technicians to handle this volatile refrigerant. As a result of thicker cabinet insulation and conversion to isobutane, product conversion and capital conversion costs roughly double at TSL 2 (to $35 million for product conversion costs and $46 million for capital conversion costs). The shipment-weighted MPC increased 22 percent at TSL 2 after standards compared to baseline costs, which also contributed to the more severe impacts projected under the preservation of operation profit scenario if manufacturers do not earn additional profit on these higher costs.

TSL 3 represents a 30-percent reduction in measured energy consumption over the current energy conservation standards for product class 11 and a 15-percent reduction for product class 18. DOE estimates the INPV impacts at TSL 3 to range from -$62.9 million to -$89.3 million, or a change in INPV of -37.1 percent to -52.7 percent. At this TSL, the industry cash flow is estimated to decrease by a factor of approximately 3.9 to -

$30.6 million, compared to the base-case value of $10.7 million in the year leading up to the amended energy conservation standards.

At TSL 3, the design options analyzed for both product class 18 units include thicker door insulation, which further increases the capital conversion costs over TSL 1 and TSL 2, where this was not analyzed as a design option. The additional impacts at TSL 3 are also due to more stringent requirements for product class 11. A 30-percent reduction for product class 11 is greater than the most efficient units on the market today. For both analyzed sizes of product class 11, DOE analyzed the design option of thicker insulation in the cabinet for both units analyzed. The net effect is a large increase in conversion costs due to the much higher cost of the equipment necessary to manufacture the cabinet. At TSL 3, DOE estimated total product conversion costs of $41 million and capital conversion costs of $76 million, a 46 percent total increase in conversion costs over TSL 2. The effect of the design changes at TSL 3 on shipment-weighted unit cost is a 27-percent increase over the average baseline MPC after standards. The magnitude of the investments relative to the industry value leads to significant impacts, although they are moderated somewhat in the flat markup because manufacturers earn additional profit on the investments.

TSL 4 represents a 40-percent reduction in measured energy use over the current energy conservation standards for product class 11 and a 25-percent reduction for product class 18. DOE estimates the INPV impacts at TSL 4 to range from -$41.5 million to -$92.8 million, or a change in INPV of -24.5 percent to -54.8 percent. At this TSL, the industry cash flow is estimated to decrease by a factor of approximately 3.9 to -$30.5 million, compared to the base-case value of $10.7 million in the year leading up to the amended energy conservation standards.

The design options analyzed at TSL 4 would also severely disrupt current manufacturing processes. For the 1.7-cubic foot product class 11 unit, DOE analyzed a variable speed compressor and isobutane refrigerant as design options. For the 4-cubic foot product class 11 unit and the 7-cubic foot product class 18 unit, DOE analyzed thicker insulation in the cabinets. For 3.4-cubic foot product class 18 unit, DOE analyzed both an increase to cabinet insulation thickness and VIPs in the bottom wall as design options. Although increasing insulation thickness, converting to isobutane, and implementing VIPs all would necessitate large conversion costs, capital conversion costs decrease slightly from TSL 3 to TSL 4 because of the removal of all previous design options in the 1.7-cubic foot unit. In other words, the design options analyzed for this unit cause less substantial changes to existing production equipment, but would also require a large investment by manufacturers to train service technicians to deal with the refrigerant. Because this task would require a large outlay for product conversion costs, total conversion costs are roughly the same at TSL 3 and TSL 4. Adding a variable speed compressor in the smaller product class 11 unit analyzed also has a substantial impact on unit price because of its high component cost. At TSL 4, the shipment-weighted MPC is 60-percent higher than the baseline MPC after standards. These cost increases are projected to cause a 16-percent decrease in shipments at TSL 4 in 2014 alone. Over time, this decline significantly contributes to the negative impacts on INPV in both markup scenarios.

The large conversion costs and higher prices leading to lower shipments cause a decrease in INPV from TSL 3 to TSL 4 under the preservation of operating profit markup scenario (since this scenario assumes higher production costs are not passed on to consumers). However, under the flat markup scenario, manufacturers are able to earn additional profit on the new high-cost components such as variable speed compressors, resulting in an increase in INPV from TSL 3 to TSL 4.

TSL 5 represents max tech for both product classes 11 and 18. The max-tech level corresponds to a 59-percent and 42-percent reduction in measured energy use for product class 11 and product class 18, respectively. DOE estimates the INPV impacts at TSL 5 to range from -$154.9 million to -$242.6 million, or a change in INPV of -91.4 percent to -143.2 percent. At this TSL, the industry cash flow is estimated to decrease approximately ten-fold to -$97.6 million, compared to the base-case value of $10.7 million in the year leading up to the amended energy conservation standards.

The design options DOE analyzed include the use of VIPs for all analyzed product class 11 and 18 units to reach max-tech efficiency levels. Additionally, the design options analyzed for some products also included other costly changes. For the 1.7- cubic foot product class 11 unit, the design options analyzed included multiple VIPs, a larger heat exchanger, and thicker insulation. The design options analyzed for the 4-cubic foot product class 11 unit also included a variable speed compressor and thicker insulation. For product class 18, DOE assumed that manufacturers would remove the design options necessary to meet TSLs 1 through 4 and add a variable speed compressor and thicker insulation for both analyzed products. These significant changes greatly increase the investment required to manufacture standards-compliant products. DOE estimated that product conversion costs would be $67 million at TSL 5, an increase of almost 40 percent over TSL 4. DOE also estimated that capital conversion costs would be $220 million, a more than three-fold increase over TSL 4. This drastic increase in conversion costs demonstrates the significant investments required by implementing widespread use of VIPs and increasing wall thickness.

At TSL 5, the shipment-weighted MPC increases by over 150 percent over the baseline after standards due to the high material costs of VIPs and variable speed compressors. These large jumps cause shipments to decrease by 42 percent due to the price elasticity in 2014 alone. As a result of lower industry shipments and extremely high conversion costs, INPV decreases substantially from TSL 4 to TSL 5 and becomes negative under the preservation of operating profit scenario, which indicates the industry loses more than its base-case value in the standards case under this scenario.

12.8.4 Built-In Refrigeration Products

TSL 1 represents a 10-percent reduction in measured energy use over the current energy conservation standards for the analyzed built-in all-refrigerator product class 3A-BI, the analyzed built-in bottom-mount product class 5-BI, the analyzed built-in side-by-side product class 7-BI, and for the analyzed built-in freezer product class 9-BI. DOE estimates the INPV impacts at TSL 1 to range from -$51.9 million to -$52.6 million, or a change in INPV of -9.4 percent to -9.5 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 70.7 percent to $11.0 million, compared to the base-case value of $37.5 million in the year leading up to the amended energy conservation standards.

At TSL 1, the design options that DOE analyzes result in moderate changes in the manufacturing process for built-in refrigeration products. For product classes 3A-BI and 9-BI, the design options that DOE analyzed to reach TSL 1 included the use of more efficient components that do not require significant changes to the manufacturing process. However, for product class 5-BI and product class 7-BI, the design options DOE analyzed also include the use of VIPs in the freezer door. While these components add to the overall costs of production, the added costs represent a small percentage of the total cost of a built-in refrigeration product. These cost deltas are low compared to the overall cost of the products and result in small impacts even if no additional profit is earned on the incremental MPCs. The estimated product conversion costs for all built-in refrigeration products at TSL 1 are $41 million and the estimated capital conversion costs are $40 million. The implementation of VIPs represents a substantial part of the conversion costs, but several built-in refrigeration manufacturers have products that use similar technology, which helps to mitigate some of the product conversion costs that would be required to design products from the ground up.

TSL 2 represents a 15-percent reduction in measured energy use for product class 3A-BI and product class 5-BI. For product classes 7-BI and 9-BI, TSL 2 represents a reduction of 10 percent and 20 percent, respectively. DOE estimates the INPV impacts at TSL 2 to range from -$55.1 million to -$56.5 million, or a change in INPV of -9.9 percent to -10.2 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 75.2 percent to $9.3 million, compared to the base-case value of $37.5 million in the year leading up to the amended energy conservation standards.

The efficiency requirements for product class 7-BI refrigerator-freezers do not change from TSL 1 to TSL 2, but the efficiency requirements for all other analyzed built-in product classes increase. The design options that DOE analyzes at TSL 2 for product classes 3A-BI and 7-BI still only include component swaps to reach a 15-percent efficiency improvement. Product class 5-BI uses a variable speed compressor in the freezer with a brushless DC condenser fan motor, but no longer use the VIPs used to reach TSL 1. The design options analyzed for product class 9-BI include a brushless DC evaporator and condenser fan motor, a larger condenser, a variable speed compressor, and a VIP in the upper door. Because product class 5-BI no longer uses VIPs and fewer changes to existing products are necessary, the overall impact is a slight decrease in capital conversion costs from $40 million at TSL 1 to $38 million at TSL 2. Product conversion costs increase to $51 million at TSL 2 because additional engineering time would be required to implement the additional component changes. However, because the complexity of the changes to the products and production facilities are similar at TSL 1 and TSL 2, there is only a small decrease in INPV from TSL 1 to TSL 2.

TSL 3 represents a 20-percent reduction in measured energy use for product class 3A-BI and product class 7-BI. For product classes 5-BI and 9-BI, TSL 2 represents a reduction of 15 percent and 25 percent, respectively. DOE estimates the INPV impacts at

TSL 3 to range from -$68.0 million to -$77.2 million, or a change in INPV of -12.3 percent to -13.9 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 102.9 percent to -$1.1 million, compared to the base-case value of $37.5 million in the year leading up to the amended energy conservation standards.

The efficiency requirements for product class 5-BI do not change from TSL 2 to TSL 3. However, the design options for all other built-in refrigeration products at TSL 3 include the implementation of VIPs. The widespread implementation of VIPs increases product and capital conversion costs, which are estimated to be $65 million and $55 million at TSL 3, respectively. Substantial changes to existing production facilities would be required to manufacture products that meet the required efficiencies at TSL 3. Most of the capital conversion costs involve purchasing new production equipment and would result in high stranded assets. The extensive changes that manufacturers would be required to make to existing facilities and the projected erosion of profitability if the additional production cost of implementing VIPs does not yield additional profit result in a projected decrease in INPV from TSL 3 to TSL 4. However, the industry value is high relative to the required capital conversion costs and the cost of the additional VIP panels is relatively small compared to the overall cost of the products, which helps to mitigate some of the negative impacts caused by these changes.

TSL 4 represents a 25-percent reduction in measured energy use over the current energy conservation standards for the following product classes: 3A-BI, 5-BI, and 9-BI. For product class 7-BI, TSL 4 represents a 20-percent reduction in measured energy use from current energy conservation standards. DOE estimates the INPV impacts at TSL 4 to range from -$82.9 million to -$97.6 million, or a change in INPV of -15.0 percent to -17.6 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 130.3 percent to -$11.4 million, compared to the base-case value of $37.5 million in the year leading up to the amended energy conservation standards.

The efficiency requirements for product class 7-BI do not change from TSL 3 to TSL 4. The design options for the other built-in refrigeration products all include the addition of more VIPs to reach TSL 4. The design options analyzed for product classes 3A-BI and 5-BI also include using a variable speed compressor. The complexity of implementing multiple component swaps and the additional production equipment necessary to use additional VIPs increases both the product and capital conversion costs. These costs are estimated to be $75 million and $74 million at TSL 4, respectively, and result in a decrease in INPV from TSL 3 to TSL 4.

TSL 5 represents max tech for the four built-in product classes. This TSL represents a reduction in measured energy use of 29 percent, 27 percent, 22 percent, and 27 percent, respectively, for product classes 3A-BI, 5-BI, 7-BI, and 9-BI. DOE estimates the INPV impacts at TSL 5 to range from -$89.9 million to -$112.1 million, or a change in INPV of -16.2 percent to -20.2 percent. At this TSL, the industry cash flow is estimated to decrease by approximately 149.5 percent to -$18.6 million, compared to the base-case value of $37.5 million in the year leading up to the amended energy conservation standards.

The design options analyzed by DOE include the widespread use of VIPs to achieve the max-tech efficiency levels at TSL 5. Additionally, product class 3A-BI uses multiple variable speed compressors. Since the implementation of VIPs is both research and capital intensive, product and capital conversion costs increase to $87 million and $84 million, respectively. The complexity of implementing multiple component swaps and the additional production equipment necessary to use additional VIPs increases both the product and capital costs.

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CHAPTER 13. EMPLOYMENT IMPACT ANALYSIS

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CHAPTER 13. EMPLOYMENT IMPACT ANALYSIS

13.1 INTRODUCTION

DOE conducted an employment impact analysis for the NOPR and final rule. DOE's employment impact analysis is designed to estimate indirect national job creation or elimination resulting from possible standards, due to reallocation of the associated expenditures for purchasing and operating residential refrigeration products.

13.2 ASSUMPTIONS

DOE expects energy conservation standards to decrease energy consumption, and therefore to reduce energy expenditures. The savings in energy expenditures may be spent on new investment or not at all (i.e., they may remain "saved"). The standards may increase the purchase price of appliances, including the retail price plus sales tax, and increase installation costs.

Using an input/output econometric model of the U.S. economy, this analysis estimated the year-to-year effect of these expenditure impacts on net economic output and employment. DOE intends this analysis to quantify the indirect employment impacts of these expenditure changes. It evaluated direct employment impacts at manufacturers' facilities in the manufacturer impact analysis (see Chapter 12).

13.3 METHODOLOGY

The Department based its analysis on an input/output model of the U.S. economy that estimates the effects of standards on major sectors of the economy related to buildings and the net impact of standards on jobs. The Pacific Northwest National Laboratory developed the model, ImSET 3.1.1[1] (Impact of Sector Energy Technologies) as a successor to ImBuild[2], a special-purpose version of the IMPLAN[3] national input/output model. ImSET estimates the employment and income effects of building energy technologies. In comparison with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy-efficiency investments in buildings.

In an input/output model, the level of employment in an economy is determined by the relationship of different sectors of the economy and the spending flows among them. Different sectors have different levels of labor intensity and so changes in the level of spending (e.g., due to the effects of an efficiency standard) in one sector of the economy will affect flows in other sectors, which affects the overall level of employment.

ImSET uses a 187-sector model of the national economy to predict the economic effects of residential and commercial buildings technologies. ImSET collects estimates of initial investments, energy savings, and economic activity associated with spending the savings resulting from standards (e.g., changes in final demand in personal consumption, business investment and spending, and government spending). It provides overall estimates of the change in national output for each input-output sector. The model applies estimates of employment and wage income per dollar of economic output for each sector and calculates impacts on national employment and wage income.

Energy-efficiency technology primarily affects the U.S. economy along three spending pathways. First, general investment funds are diverted to sectors that manufacture, install, and maintain energy-efficient appliances. The increased cost of appliances leads to higher employment in the appliance manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities toward firms that supply production inputs. Third, electric utility sector investment funds are released for use in other sectors of the economy. When consumers use less energy, electric utilities experience relative reductions in demand which leads to reductions in utility sector investment and employment.

13.4 RESULTS

The results in this section refer to impacts of residential refrigeration product standards relative to the base case for each appliance. DOE disaggregated the impact of standards on employment into three component effects: increased capital investment costs, decreased energy and water costs, and changes in operations and maintenance costs. These component effects and a summary impact are presented for residential standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products, and built-in refrigeration products.

Figures 13.4.1-13.4.4 summarize the employment impacts of the increased investment and spending on higher-efficiency equipment. Because refrigeration product manufacturing is relatively capital-intensive compared to other sectors of the economy, the net result is a decrease in employment.

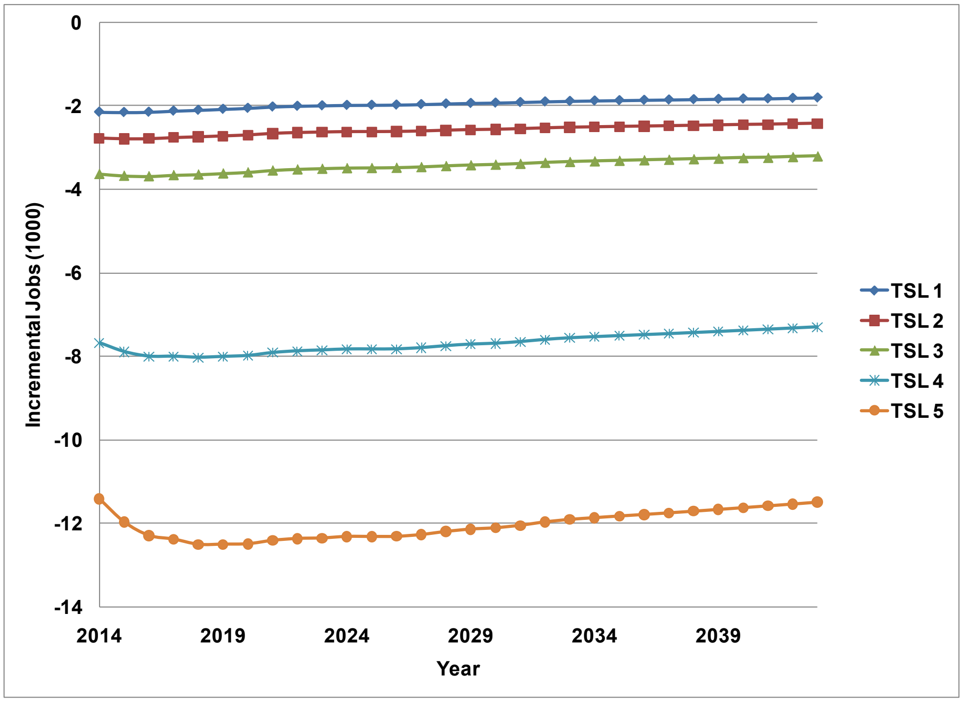

Figure 13.4.1 Refrigerator-Freezer Employment Impact of Increased Equipment Cost

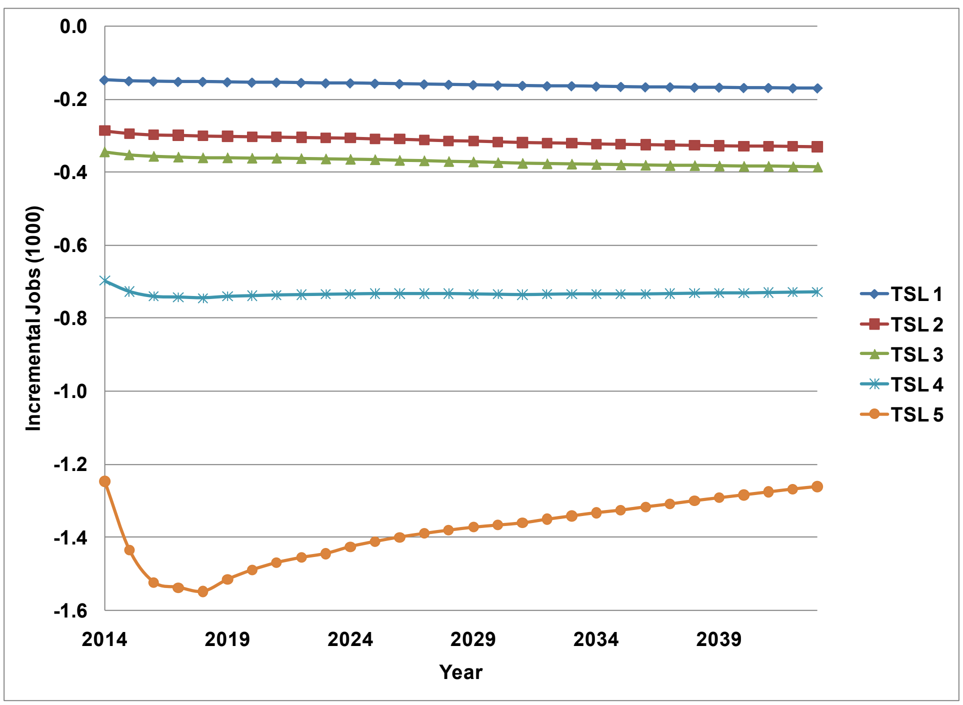

Figure 13.4.2 Compact Refrigeration Products Employment Impact of Increased Equipment Cost

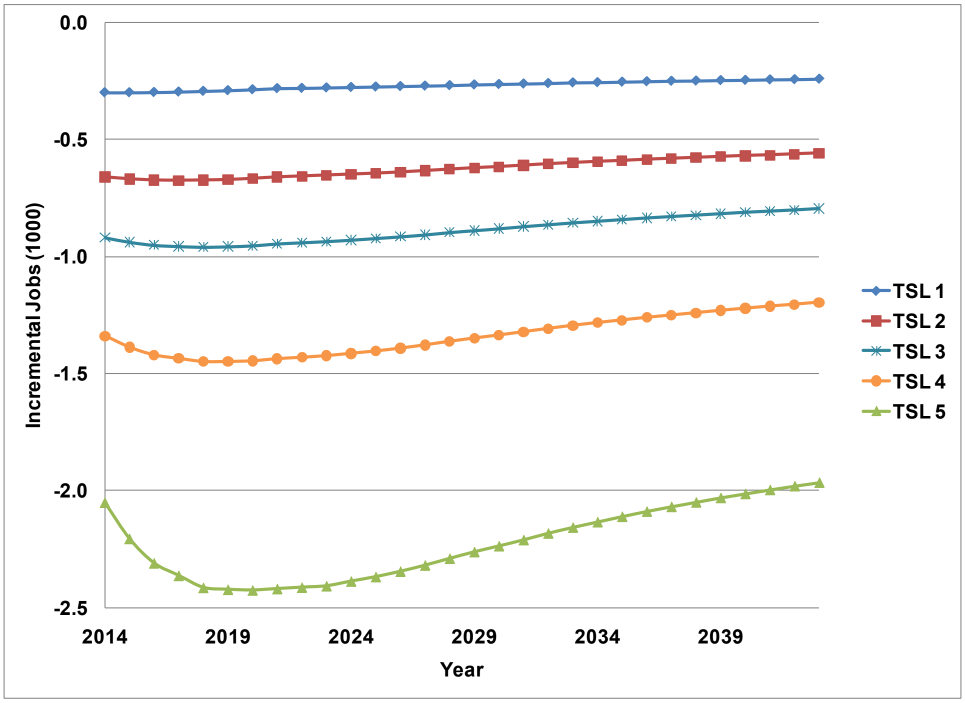

Figure 13.4.3 Freezer Employment Impact of Increased Equipment Cost

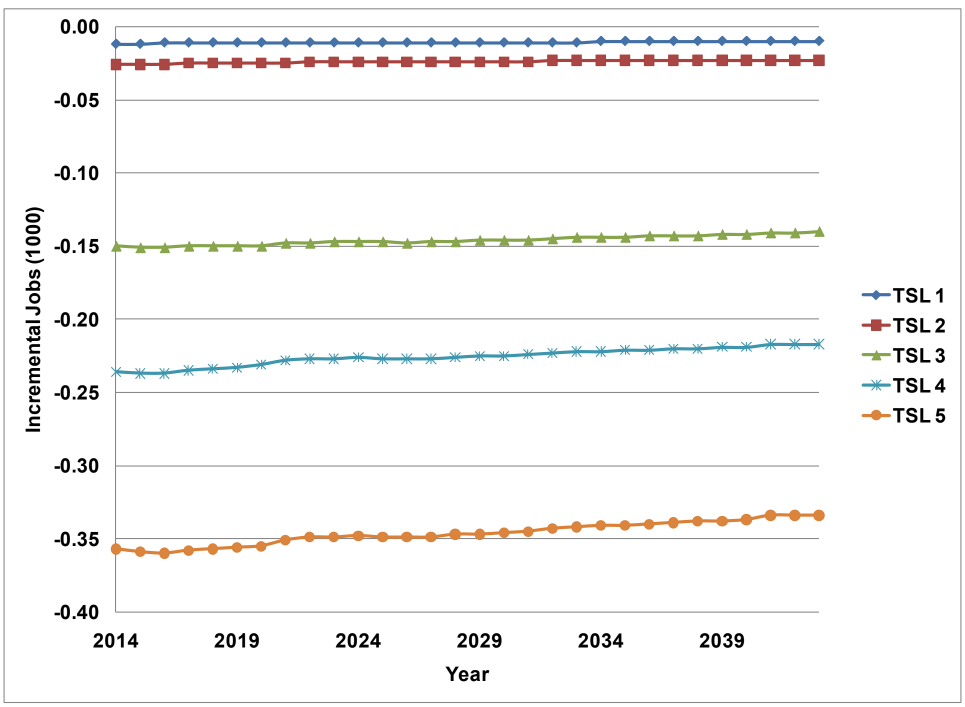

Figure 13.4.4 Built-in Refrigeration Products Employment Impact of Increased Equipment Cost

Figures 13.4.5-13.4.8 show the employment impact of redirected spending made possible by appliance operating cost savings. In this case, the employment impact is strongly positive.

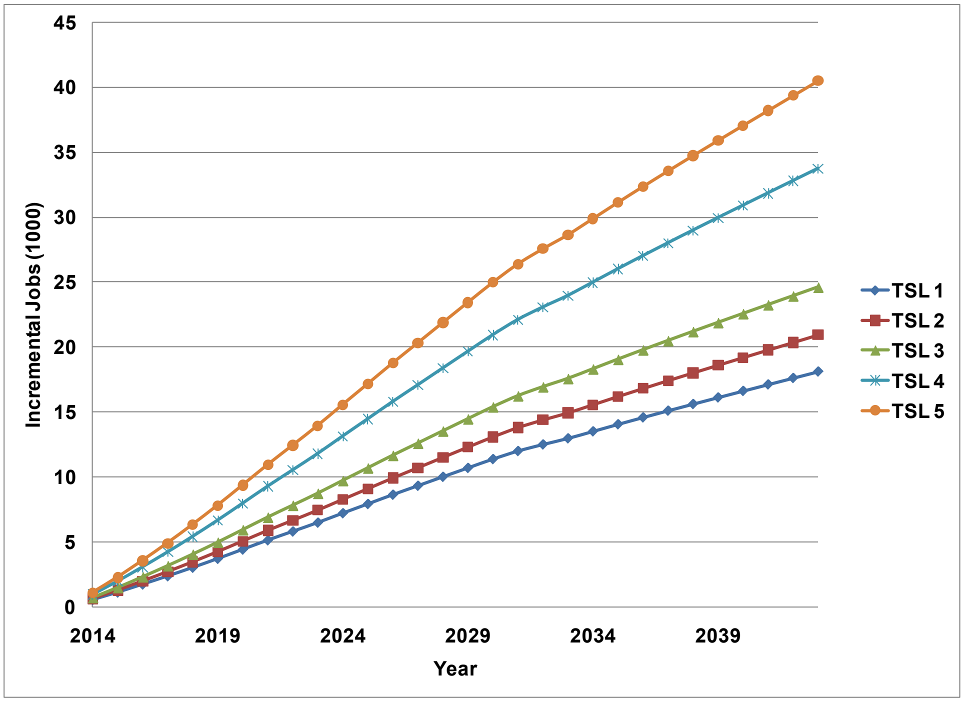

Figure 13.4.5 Refrigerator-Freezer Employment Impact of Operating Cost Savings

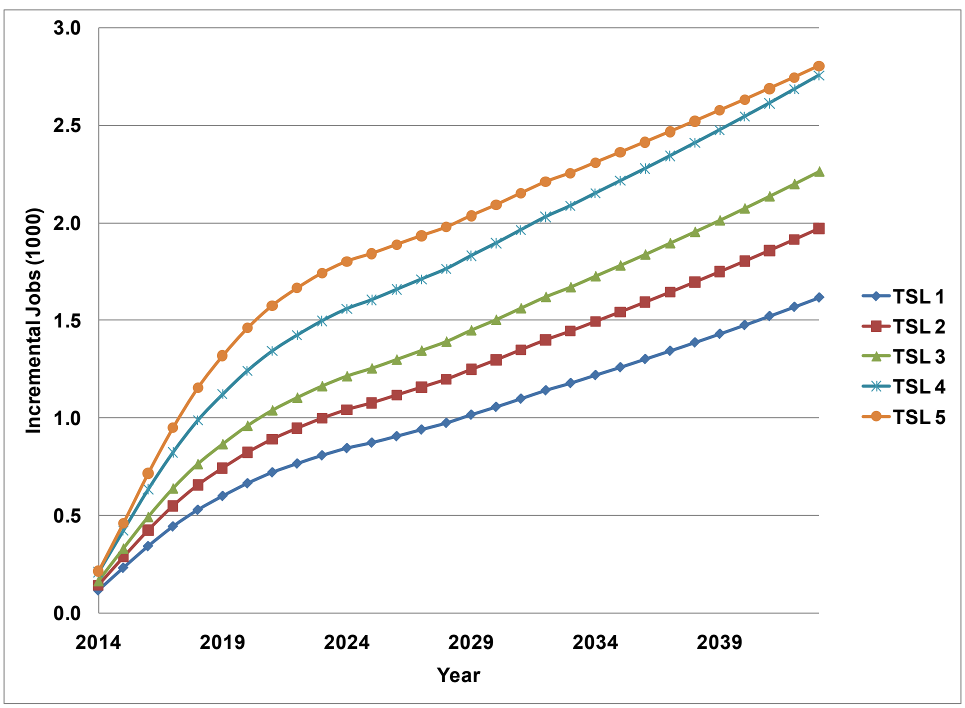

Figure 13.4.6 Compact Refrigeration Products Employment Impact of Operating Cost Savings

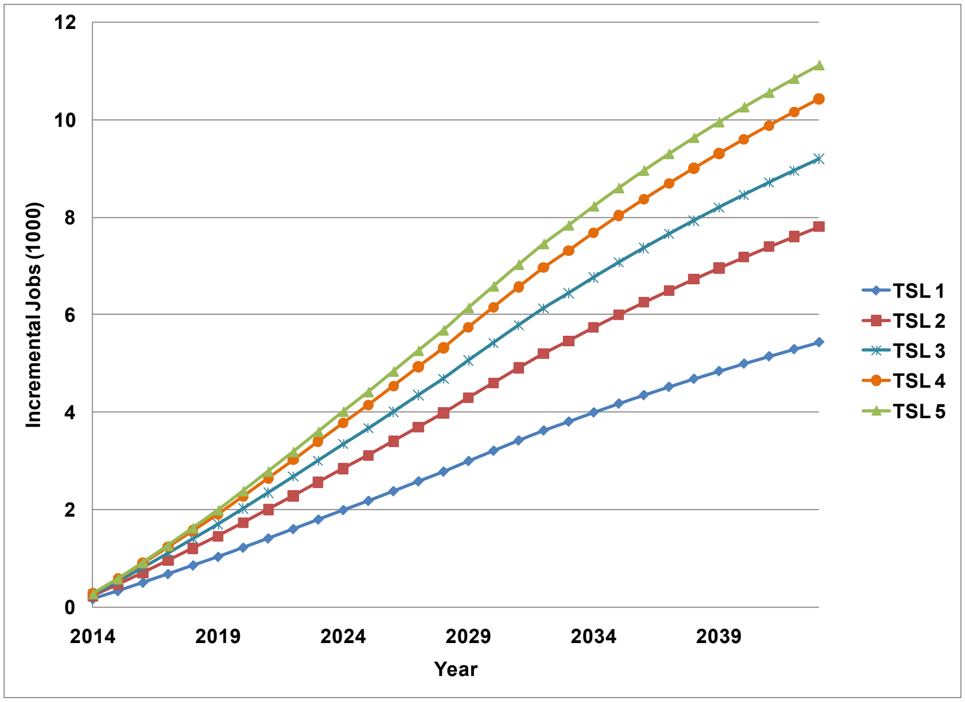

Figure 13.4.7 Freezer Employment Impact of Operating Cost Savings

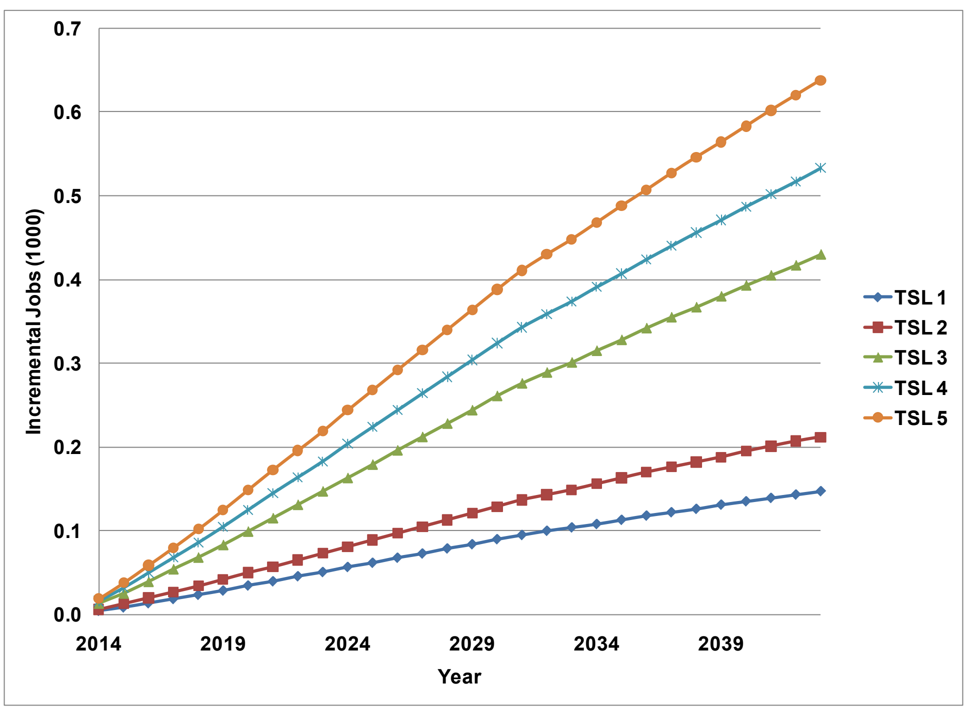

Figure 13.4.8 Built-in Refrigeration Products Employment Impact of Operating Cost Savings

Figures 13.4.9 – 13.4.12 show the employment impacts of non-energy operations and maintenance cost increases for residential refrigeration products.

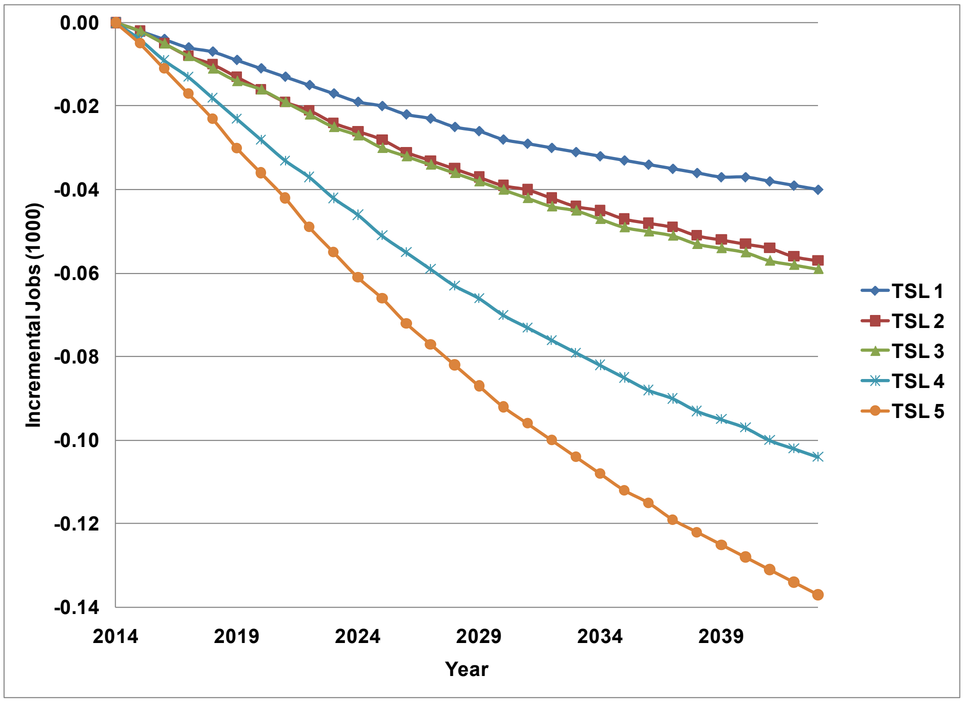

Figure 13.4.9 Refrigerator-Freezer Employment Impact of Operations and Maintenance Cost Increase

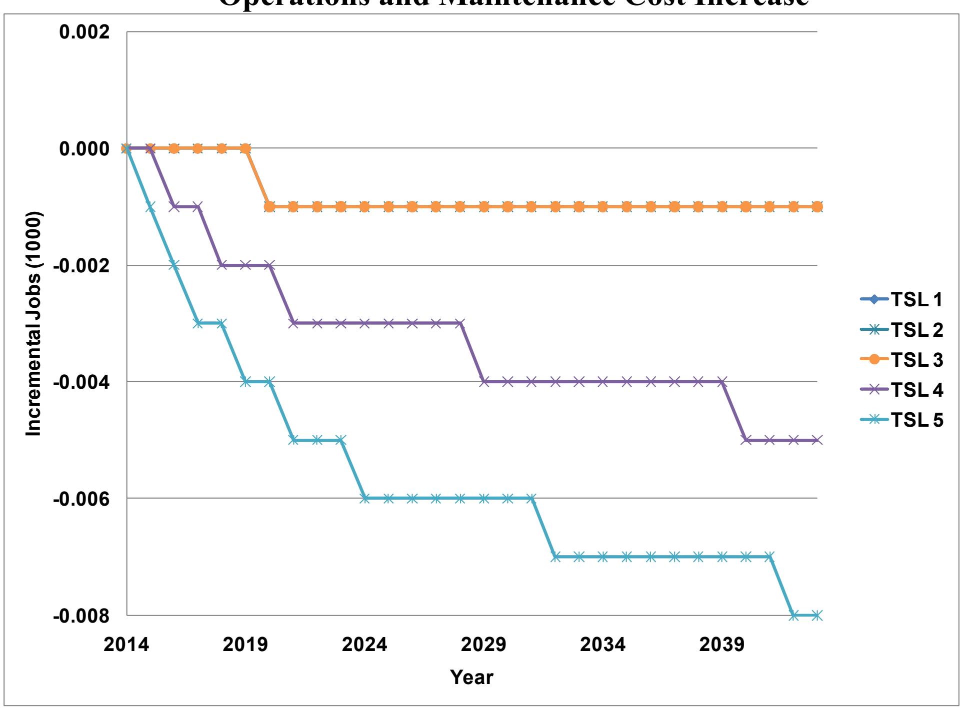

Figure 13.4.10 Compact Refrigeration Products Employment Impact of Operations and Maintenance Cost Increase

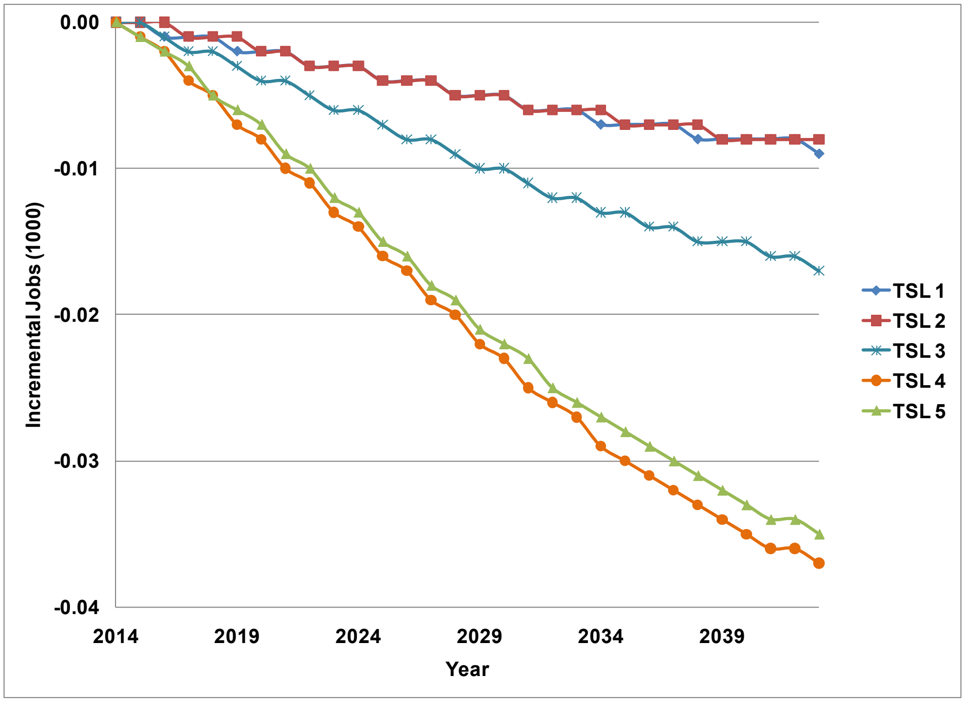

Figure 13.4.11 Freezer Employment Impact of Operations and Maintenance Cost Increase

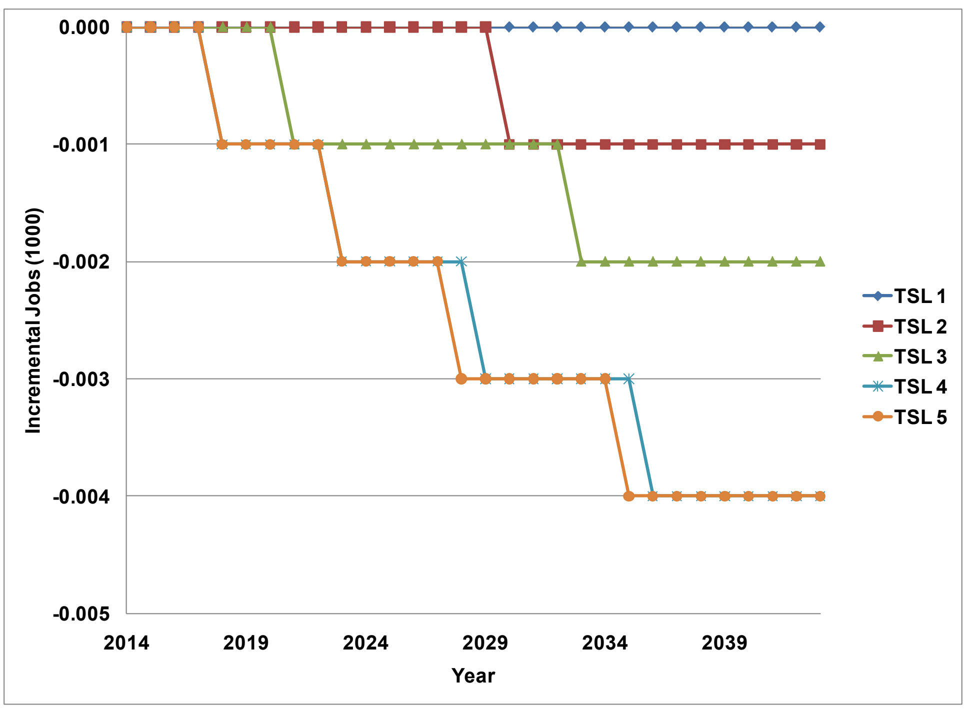

Figure 13.4.12 Built-in Refrigeration Products Employment Impact of Operations and Maintenance Cost Increase

Figures 14.4.13-14.4.16 show the estimated net national employment impacts of the residential refrigeration product trial standard levels. For any given year, these figures show the net change in the number of jobs in the economy relative to if there were no change in standards (and thus no resulting change in spending and cash flow patterns throughout the economy). These figures show the combined effects of equipment cost, operations and maintenance cost, and energy use changes due to standards.

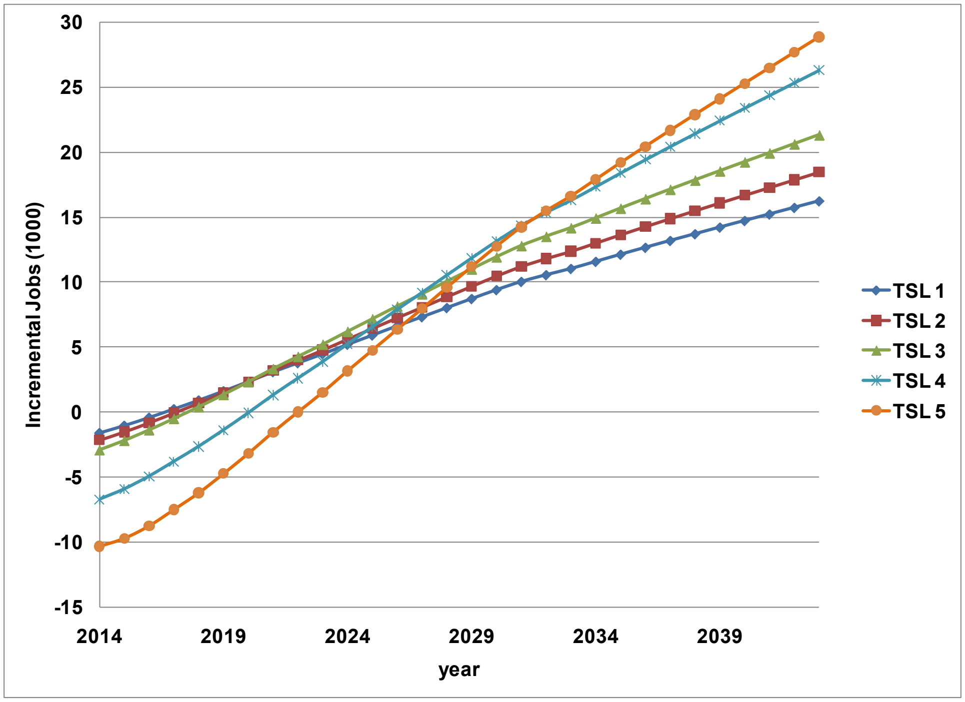

Figure 13.4.13 Standard-Size Refrigerator-Freezers Net National Change in Employment

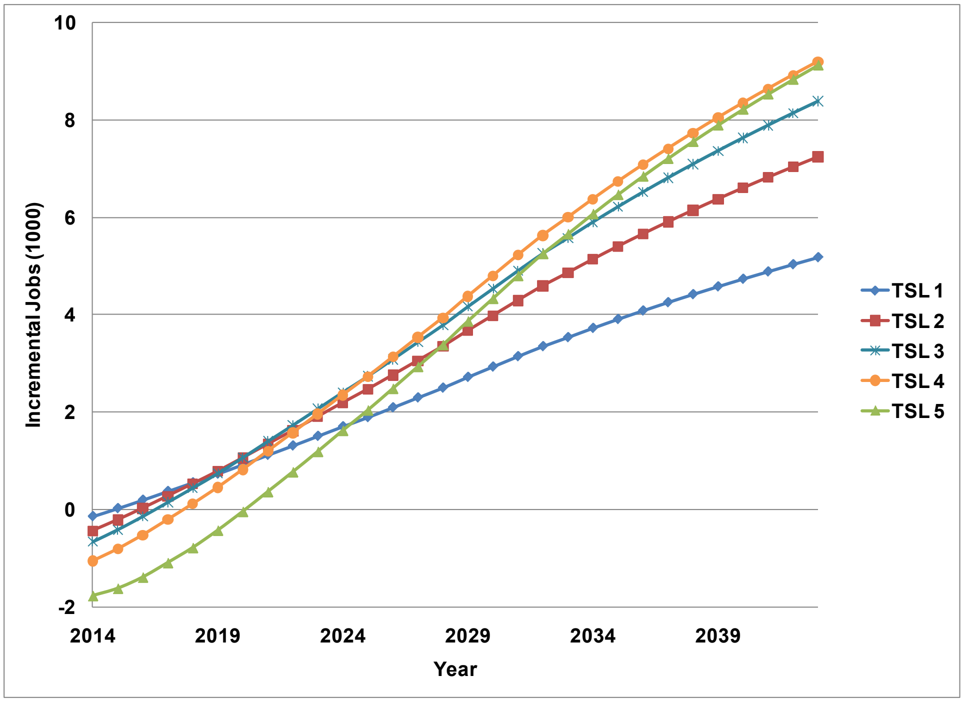

Figure 13.4.14 Standard-Size Freezers Net National Change in Employment

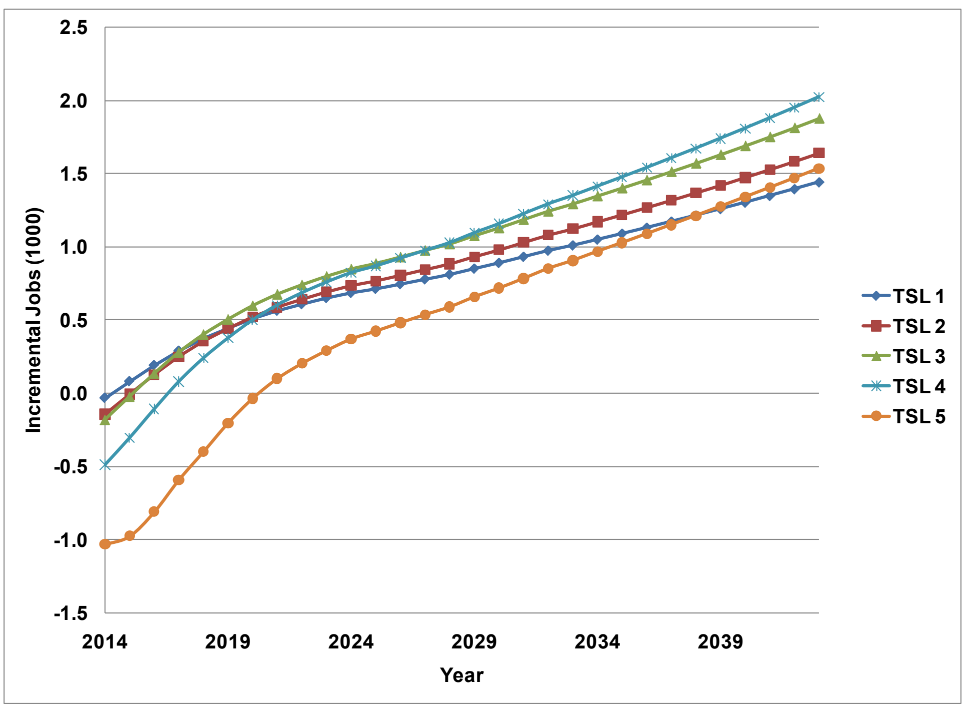

Figure 13.4.15 Compact Refrigeration Products Net National Change in Employment

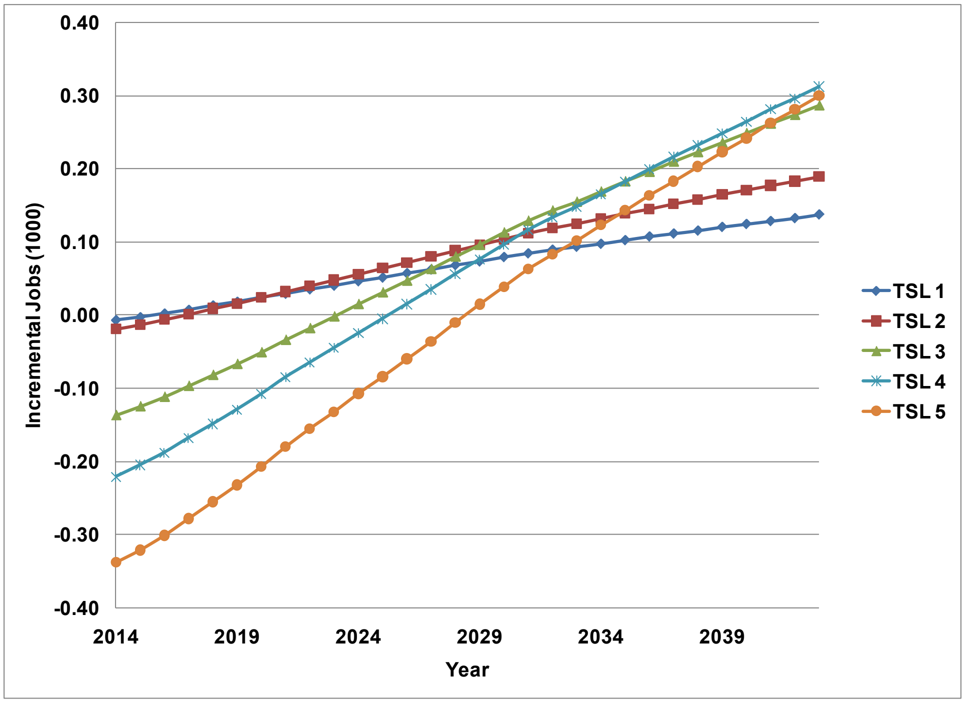

Figure 13.4.16 Built-in Refrigeration Products Net National Change in Employment

Tables 13.4.1-13.4.4 show the net national employment impact in specific years for each product, as well as the average annual employment impact over the 2014-2043 time period. The initial decrease in net employment is caused by the dominance of capital costs in early years, while the impacts of operating cost savings from reduced energy use build up slowly over time, resulting in a net positive impact on employment in later years.

Table 13.4.1 Standard-Size Refrigerator-Freezers Net National Change in Employment (Thousand jobs)

Trial Standard Level	2014	2020	2030	2043	Average 2014-2043
1	-1.60	2.35	9.40	16.24	7.85
2	-2.15	2.34	10.47	18.45	8.71
3	-2.91	2.33	11.94	21.33	9.86
4	-6.73	-0.06	13.15	26.31	10.39
5	-10.34	-3.18	12.76	28.85	9.54

Table 13.4.2 Standard-Size Freezers Net National Change in Employment

Trial Standard Level	2014	2020	2030	2043	Average 2014-2043
1	-0.14	0.93	2.93	5.18	2.59
2	-0.44	1.06	3.98	7.24	3.48
3	-0.66	1.06	4.53	8.38	3.94
4	-1.06	0.82	4.80	9.19	4.12
5	-1.77	-0.05	4.33	9.12	3.61

Table 13.4.3 Compact Refrigeration Products Net National Change in Employment

Trial Standard Level	2014	2020	2030	2043	Average 2014-2043
1	-0.03	0.51	0.89	1.44	0.82
2	-0.14	0.52	0.98	1.64	0.89
3	-0.18	0.60	1.13	1.88	1.02
4	-0.49	0.50	1.16	2.02	1.01
5	-1.03	-0.04	0.72	1.53	0.51

Table 13.4.4 Built-in Refrigeration Products Net National Change in Employment

Trial Standard Level	2014	2020	2030	2043	Average 2014-2043
1	-0.01	0.02	0.08	0.14	0.07
2	-0.02	0.02	0.10	0.19	0.09
3	-0.14	-0.05	0.11	0.29	0.08
4	-0.22	-0.11	0.10	0.31	0.06
5	-0.34	-0.21	0.04	0.30	-0.01

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2. Scott, M. J., D. J. Hostick, and D. B. Belzer, *ImBuild: Impact of Building Energy Efficiency Programs,* April, 1998. Pacific Northwest National Laboratory. Richland, WA. Report No. PNNL-11884. Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

3. Minnesota IMPLAN Group Inc., *IMPLAN Professional: User's Guide, Analysis Guide, Data Guide*, 1997. Stillwater, MN.

CHAPTER 14. UTILITY IMPACT ANALYSIS

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CHAPTER 14. UTILITY IMPACT ANALYSIS

14.1 INTRODUCTION

DOE analyzed the effects of residential refrigerator standard levels on the electric utility industry using a variant of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[a] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the *Annual Energy Outlook (AEO)*. The *AEO* for 2010 *(AEO2010)* forecasts energy supply and demand through 2035.[1] DOE used a variant of this model, referred to here as NEMS-BT,[b] to account for the impacts of refrigerator energy conservation standards. DOE's utility impact analysis consists of a comparison between model results for the *AEO2010* Reference Case and for cases in which standards are in place, and applies the same basic set of assumptions as the *AEO2010*. The *AEO2010* reference case corresponds to medium economic growth.

The utility impact analysis reports the changes in electric installed capacity and generation that result for each trial standard level (TSL) by plant type, as well as changes in residential electricity consumption.

NEMS-BT has several advantages that have led to its adoption as the forecasting tool in the analysis of energy conservation standards. NEMS-BT uses a set of assumptions that are well known and fairly transparent, due to the exposure and scrutiny each *AEO* receives. In addition, the comprehensiveness of NEMS-BT permits the modeling of interactions among the various energy supply and demand sectors, producing a complete picture of the effects of energy conservation standards. Perhaps most importantly, NEMS-BT can be used to estimate marginal effects, which yield a better estimate of the actual impact of energy conservation standards than considering only average effects.

14.2 METHOD

The utility impact analysis uses the assumptions of the *AEO2010* and treats refrigeration conservation standards as variations in policy. The effects of the policy are calculated as the difference between the *AEO2010* Reference Case and each proposed standard case, which is described as a trial standard level (TSL).

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[a] For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2003*, DOE/EIA-0581(2003), March, 2003.

[b] DOE/EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on DOE/EIA assumptions, DOE refers to it by the name NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work has been performed). NEMS-BT was previously called NEMS-BRS.

DOE used the site energy savings developed in the national impact analysis (chapter 10) for each TSL as input to NEMS-BT. The magnitude of the energy decrement that would be required for NEMS-BT to produce stable results out of the range of numerical noise is larger than the highest efficiency standard under consideration. Therefore, DOE estimated results corresponding to each TSL using interpolation. DOE ran higher energy use reduction levels in NEMS-BT, representing multipliers of each TSL, and used these outputs to linearly interpolate the results to estimate actual changes in generation and capacity due to the standard.

Policy runs are executed by reducing electricity consumption in the NEMS-BT Residential Demand Module. Energy use reductions are applied to the refrigeration end use. The reductions are divided amongst the nine U.S. Census divisions based upon the share of refrigeration and freezer energy end use consumption in each division, as given in NEMS.

Although the current time horizon of NEMS-BT is 2035, other parts of the energy conservation standards analysis extend to the year 2043. It is not feasible to extend the forecast period of NEMS-BT for the purposes of this analysis, nor does DOE/EIA have an approved method for extrapolation of many outputs beyond 2035. While it might seem reasonable to make simple linear extrapolations of results, in practice this is not advisable because outputs could be contradictory. An analysis of various trends sufficiently detailed to guarantee consistency is beyond the scope of this work, and, in any case, would involve a great deal of uncertainty. Therefore, all extrapolations beyond 2035 are simple replications of year 2035 results. To emphasize the extrapolated results wherever they appear, they are shaded in gray to distinguish them from actual NEMS-BT results.

14.3 RESULTS

This utility impact analysis reports NEMS-BT forecasts for residential-sector electricity consumption, total electricity generation by fuel type, and installed electricity generation capacity by fuel type. Results are presented in five-year increments to year 2035. Beyond year 2035, an extrapolation to 2043 for each proposed TSL represents a simple replication of the year 2035 results.

The results from the *AEO2010* Reference Case are shown in Table 14.3.1.

A separate set of TSLs is modeled for each product grouping. The results for the standard-size refrigerator-freezer TSLs are presented in Tables 14.3.2 through 14.3.6, the results for standard-size freezer TSLs are presented in Tables 14.3.7 through 14.3.12, the results for the compact refrigeration product TSLs are presented in Tables 14.3.13 through 14.3.17, and the results for the built-in refrigeration product TSLs are presented in Tables 14.3.18 to 14.3.22. Each table shows forecasts using interpolated results, as described in section 14.2, for total U.S. electricity generation and installed capacity.

The considered residential refrigerator TSLs reduce only electricity consumption compared to the *AEO2010* Reference Case. The electricity savings predicted by the NIA Model for all refrigeration products considered range from 1.43 to 3.09 percent of total residential electricity consumption in the year 2035.

Table 14.3.1 AEO2010 Reference Case Forecast

NEMS-BT Results: AEO2010 Reference

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption [1]							
Electricity Sales (TWh)[2]	1,359	1,388	1,400	1,472	1,553	1,637	1,707
Total U.S. Electric Generation [3]							
Coal (TWh)	2,013	1,828	2,038	2,090	2,130	2,209	2,305
Gas (TWh)	759	857	690	769	886	1,018	1,095
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	649	714	797	850	890
Total (TWh)[4]	4,034	4,005	4,257	4,503	4,746	5,012	5,234
Installed Generating Capacity [5]							
Coal (GW)	314	321	325	326	326	330	337
Other Fossil (GW)[6]	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	177	186	196	209
Total (GW)[7]	952	1,024	1,046	1,059	1,091	1,138	1,192

[1] Comparable to Table A2 of AEO2010: Energy Consumption, Residential

[2] Comparable to Table A8 of AEO2010: Electricity Sales by Sector

[3] Comparable to Table A8 of AEO2010: Electric Generators and Cogenerators

[4] Excludes "Other Gaseous Fuels" cogenerators and "Other" cogenerators

[5] Comparable to Table A9 of AEO2010: Electric Generators and Cogenerators Capability

[6] Includes "Other Gaseous Fuels" cogenerators

[7] Excludes Pumped Storage and Fuel Cells

Table 14.3.2 Standard-Size Refrigerator-Freezers: Trial Standard Level 1 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,470	1,550	1,633	1,702
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,208	2,303
Gas (TWh)	759	857	691	768	884	1,016	1,093
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	713	796	849	889
Total (TWh)	4,034	4,005	4,257	4,501	4,743	5,007	5,228
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	446	467	501	533
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	171	176	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,090	1,137	1,191

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.46	-1.71	-3.02	-4.29	-5.38	-6.25	-6.69
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.02	0.07	-0.34	-0.52	-1.14	-1.30	-1.30	-1.30
Gas (TWh)	0.00	0.12	0.29	-0.58	-1.75	-2.03	-2.17	-2.17	-2.17
Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.03	-0.03	-0.03
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.21	-0.21	-0.21
Renewables (TWh)	0.00	-0.13	-0.85	-0.80	-1.04	-1.13	-1.56	-1.56	-1.56
Total (TWh)	0.00	0.00	-0.50	-1.73	-3.32	-4.32	-5.26	-5.26	-5.26
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.030	-0.025	-0.027	-0.060	-0.053	-0.053	-0.053
Other Fossil (GW)	0.000	0.000	-0.081	-0.116	-0.257	-0.347	-0.395	-0.395	-0.395
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.028	-0.028	-0.028
Renewables (GW)	0.000	-0.039	-0.240	-0.234	-0.222	-0.248	-0.352	-0.352	-0.352
Total (GW)	0.000	-0.039	-0.351	-0.375	-0.506	-0.655	-0.827	-0.827	-0.827

Table 14.3.3 Standard-Size Refrigerator-Freezers: Trial Standard Level 2 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,398	1,465	1,541	1,621	1,688
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,089	2,128	2,205	2,300
Gas (TWh)	759	858	691	767	879	1,010	1,087
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	894
Renewables (TWh)	358	462	645	711	793	846	885
Total (TWh)	4,034	4,005	4,255	4,496	4,733	4,995	5,215
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	445	466	500	532
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	171	176	185	195	208
Total (GW)	952	1,024	1,045	1,057	1,089	1,136	1,189

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-1.79	-6.87	-11.94	-16.25	-19.68	-22.48	-23.99
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.06	0.27	-1.36	-2.04	-4.33	-4.75	-4.75	-4.75
Gas (TWh)	0.00	0.46	1.12	-2.35	-6.94	-7.68	-7.92	-7.92	-7.92
Petroleum (TWh)	0.00	0.00	0.00	-0.03	-0.04	-0.08	-0.10	-0.10	-0.10
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.75	-0.75	-0.75
Renewables (TWh)	0.00	-0.51	-3.30	-3.21	-4.10	-4.29	-5.72	-5.72	-5.72
Total (TWh)	0.00	0.01	-1.92	-6.95	-13.13	-16.38	-19.24	-19.24	-19.24
Installed Generating Capacity									
Coal (GW)	0.00	0.00	-0.12	-0.10	-0.11	-0.23	-0.19	-0.19	-0.19
Other Fossil (GW)	0.00	0.00	-0.31	-0.47	-1.02	-1.32	-1.45	-1.45	-1.45
Nuclear (GW)	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	-0.10	-0.10
Renewables (GW)	0.00	-0.15	-0.93	-0.94	-0.88	-0.94	-1.29	-1.29	-1.29
Total (GW)	0.00	-0.15	-1.35	-1.51	-2.00	-2.48	-3.03	-3.03	-3.03

Table 14.3.4 Standard-Size Refrigerator-Freezers: Trial Standard Level 3 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,398	1,464	1,539	1,618	1,684
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,089	2,127	2,204	2,299
Gas (TWh)	759	858	692	766	877	1,009	1,086
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	894
Renewables (TWh)	358	462	645	710	792	845	884
Total (TWh)	4,034	4,005	4,255	4,494	4,730	4,992	5,211
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	445	466	500	532
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	170	175	185	195	208
Total (GW)	952	1,024	1,044	1,057	1,088	1,135	1,189

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-2.09	-8.06	-14.05	-19.12	-23.14	-26.41	-28.17
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.07	0.31	-1.59	-2.40	-5.10	-5.59	-5.59	-5.59
Gas (TWh)	0.00	0.54	1.30	-2.76	-8.16	-9.04	-9.32	-9.32	-9.32
Petroleum (TWh)	0.00	0.00	0.00	-0.03	-0.05	-0.09	-0.11	-0.11	-0.11
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.88	-0.88	-0.88
Renewables (TWh)	0.00	-0.60	-3.85	-3.77	-4.82	-5.05	-6.72	-6.72	-6.72
Total (TWh)	0.00	0.01	-2.24	-8.16	-15.44	-19.27	-22.62	-22.62	-22.62
Installed Generating Capacity									
Coal (GW)	0.00	0.00	-0.13	-0.12	-0.12	-0.27	-0.23	-0.23	-0.23
Other Fossil (GW)	0.00	0.00	-0.37	-0.55	-1.20	-1.55	-1.70	-1.70	-1.70
Nuclear (GW)	0.00	0.00	0.00	0.00	0.00	0.00	-0.12	-0.12	-0.12
Renewables (GW)	0.00	-0.17	-1.08	-1.10	-1.03	-1.10	-1.51	-1.51	-1.51
Total (GW)	0.00	-0.18	-1.58	-1.77	-2.35	-2.92	-3.56	-3.56	-3.56

Table 14.3.5 Standard-Size Refrigerator-Freezers: Trial Standard Level 4 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,397	1,461	1,534	1,611	1,676
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,039	2,088	2,126	2,202	2,297
Gas (TWh)	759	858	692	765	874	1,006	1,082
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	894
Renewables (TWh)	358	462	643	709	790	843	881
Total (TWh)	4,034	4,005	4,254	4,492	4,725	4,986	5,203
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	445	466	499	531
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	132	170	175	185	194	207
Total (GW)	952	1,024	1,044	1,057	1,088	1,134	1,187

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-2.74	-10.80	-18.99	-25.99	-31.59	-36.17	-38.63
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.09	0.41	-2.13	-3.25	-6.93	-7.63	-7.63	-7.63
Gas (TWh)	0.00	0.71	1.71	-3.70	-11.03	-12.29	-12.72	-12.72	-12.72
Petroleum (TWh)	0.00	0.00	0.00	-0.04	-0.07	-0.12	-0.16	-0.16	-0.16
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-1.21	-1.21	-1.21
Renewables (TWh)	0.00	-0.78	-5.07	-5.05	-6.52	-6.86	-9.17	-9.17	-9.17
Total (TWh)	0.00	0.02	-2.94	-10.93	-20.87	-26.20	-30.88	-30.88	-30.88
Installed Generating Capacity									
Coal (GW)	0.00	0.00	-0.18	-0.16	-0.17	-0.37	-0.31	-0.31	-0.31
Other Fossil (GW)	0.00	0.00	-0.48	-0.73	-1.62	-2.10	-2.32	-2.32	-2.32
Nuclear (GW)	0.00	0.00	0.00	0.00	0.00	0.00	-0.17	-0.17	-0.17
Renewables (GW)	0.00	-0.23	-1.42	-1.48	-1.40	-1.50	-2.06	-2.06	-2.06
Total (GW)	0.00	-0.23	-2.08	-2.38	-3.18	-3.97	-4.86	-4.86	-4.86

Table 14.3.6 Standard-Size Refrigerator-Freezers: Trial Standard Level 5 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,397	1,459	1,531	1,606	1,670
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,039	2,088	2,126	2,201	2,296
Gas (TWh)	759	858	692	765	872	1,004	1,080
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	893
Renewables (TWh)	358	462	643	708	789	842	879
Total (TWh)	4,034	4,005	4,254	4,490	4,721	4,980	5,197
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	445	465	499	531
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	132	170	175	185	194	207
Total (GW)	952	1,024	1,044	1,056	1,087	1,133	1,186

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-3.15	-12.70	-22.54	-31.02	-37.82	-43.39	-46.38
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.10	0.47	-2.51	-3.86	-8.27	-9.13	-9.13	-9.13
Gas (TWh)	0.00	0.80	1.97	-4.35	-13.09	-14.66	-15.23	-15.23	-15.23
Petroleum (TWh)	0.00	0.00	-0.01	-0.05	-0.08	-0.14	-0.19	-0.19	-0.19
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-1.45	-1.45	-1.45
Renewables (TWh)	0.00	-0.88	-5.82	-5.94	-7.73	-8.19	-10.99	-10.99	-10.99
Total (TWh)	0.00	0.02	-3.38	-12.85	-24.77	-31.27	-36.98	-36.98	-36.98
Installed Generating Capacity									
Coal (GW)	0.00	0.00	-0.20	-0.19	-0.20	-0.44	-0.37	-0.37	-0.37
Other Fossil (GW)	0.00	0.00	-0.55	-0.86	-1.92	-2.51	-2.78	-2.78	-2.78
Nuclear (GW)	0.00	0.00	0.00	0.00	0.00	0.00	-0.20	-0.20	-0.20
Renewables (GW)	0.00	-0.26	-1.63	-1.74	-1.66	-1.79	-2.47	-2.47	-2.47
Total (GW)	0.00	-0.26	-2.39	-2.79	-3.78	-4.74	-5.82	-5.82	-5.82

Table 14.3.7 Standard-Size Freezers: Trial Standard Level 1 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,470	1,550	1,633	1,702
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,208	2,303
Gas (TWh)	759	857	691	768	884	1,016	1,093
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	713	796	849	889
Total (TWh)	4,034	4,005	4,257	4,501	4,743	5,007	5,228
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	446	467	501	533
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	171	176	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,090	1,137	1,191

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.46	-1.71	-3.02	-4.29	-5.38	-6.25	-6.69
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.02	0.07	-0.34	-0.52	-1.14	-1.30	-1.30	-1.30
Gas (TWh)	0.00	0.12	0.29	-0.58	-1.75	-2.03	-2.17	-2.17	-2.17
Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.03	-0.03	-0.03
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.21	-0.21	-0.21
Renewables (TWh)	0.00	-0.13	-0.85	-0.80	-1.04	-1.13	-1.56	-1.56	-1.56
Total (TWh)	0.00	0.00	-0.50	-1.73	-3.32	-4.32	-5.26	-5.26	-5.26
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.030	-0.025	-0.027	-0.060	-0.053	-0.053	-0.053
Other Fossil (GW)	0.000	0.000	-0.081	-0.116	-0.257	-0.347	-0.395	-0.395	-0.395
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.028	-0.028	-0.028
Renewables (GW)	0.000	-0.039	-0.240	-0.234	-0.222	-0.248	-0.352	-0.352	-0.352
Total (GW)	0.000	-0.039	-0.351	-0.375	-0.506	-0.655	-0.827	-0.827	-0.827

Table 14.3.8 Standard-Size Freezers: Trial Standard Level 2 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,470	1,550	1,633	1,702
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,208	2,303
Gas (TWh)	759	857	691	768	884	1,016	1,093
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	713	796	849	889
Total (TWh)	4,034	4,005	4,257	4,501	4,743	5,007	5,228
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	446	467	501	533
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	171	176	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,090	1,137	1,191

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.46	-1.71	-3.02	-4.29	-5.38	-6.25	-6.69
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.02	0.07	-0.34	-0.52	-1.14	-1.30	-1.30	-1.30
Gas (TWh)	0.00	0.12	0.29	-0.58	-1.75	-2.03	-2.17	-2.17	-2.17
Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.03	-0.03	-0.03
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.21	-0.21	-0.21
Renewables (TWh)	0.00	-0.13	-0.85	-0.80	-1.04	-1.13	-1.56	-1.56	-1.56
Total (TWh)	0.00	0.00	-0.50	-1.73	-3.32	-4.32	-5.26	-5.26	-5.26
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.030	-0.025	-0.027	-0.060	-0.053	-0.053	-0.053
Other Fossil (GW)	0.000	0.000	-0.081	-0.116	-0.257	-0.347	-0.395	-0.395	-0.395
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.028	-0.028	-0.028
Renewables (GW)	0.000	-0.039	-0.240	-0.234	-0.222	-0.248	-0.352	-0.352	-0.352
Total (GW)	0.000	-0.039	-0.351	-0.375	-0.506	-0.655	-0.827	-0.827	-0.827

Table 14.3.9 Standard-Size Freezers: Trial Standard Level 3 Forecast

NEMS-BT Results:	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,399	1,469	1,548	1,630	1,698
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,207	2,302
Gas (TWh)	759	857	691	768	883	1,015	1,091
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	894
Renewables (TWh)	358	462	647	712	795	848	888
Total (TWh)	4,034	4,005	4,256	4,500	4,740	5,004	5,225
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	445	467	501	533
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	171	176	186	195	209
Total (GW)	952	1,024	1,045	1,058	1,090	1,137	1,191

Difference from AEO2010 Reference Case								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.75	-2.84	-5.09	-7.26	-9.12	-10.60	-11.33
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.02	0.11	-0.56	-0.87	-1.93	-2.20	-2.20	-2.20
Gas (TWh)	0.00	0.19	0.47	-0.97	-2.95	-3.43	-3.67	-3.67	-3.67
Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.02	-0.03	-0.05	-0.05	-0.05
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.35	-0.35	-0.35
Renewables (TWh)	0.00	-0.21	-1.38	-1.33	-1.74	-1.92	-2.65	-2.65	-2.65
Total (TWh)	0.00	0.00	-0.80	-2.87	-5.59	-7.31	-8.92	-8.92	-8.92
Installed Generating Capacity									
Coal (GW)	0.00	0.00	-0.05	-0.04	-0.04	-0.10	-0.09	-0.09	-0.09
Other Fossil (GW)	0.00	0.00	-0.13	-0.19	-0.43	-0.59	-0.67	-0.67	-0.67
Nuclear (GW)	0.00	0.00	0.00	0.00	0.00	0.00	-0.05	-0.05	-0.05
Renewables (GW)	0.00	-0.06	-0.39	-0.39	-0.37	-0.42	-0.60	-0.60	-0.60
Total (GW)	0.00	-0.06	-0.57	-0.62	-0.85	-1.11	-1.40	-1.40	-1.40

Table 14.3.10 Standard-Size Freezers: Trial Standard Level 4 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,399	1,468	1,548	1,629	1,697
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,207	2,302
Gas (TWh)	759	857	691	768	882	1,014	1,091
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	894
Renewables (TWh)	358	462	647	712	795	848	887
Total (TWh)	4,034	4,005	4,256	4,499	4,740	5,003	5,224
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	445	467	501	533
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	171	176	186	195	209
Total (GW)	952	1,024	1,045	1,058	1,090	1,137	1,191

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.83	-3.20	-5.76	-8.24	-10.36	-12.03	-12.84
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.03	0.12	-0.63	-0.99	-2.20	-2.50	-2.50	-2.50
Gas (TWh)	0.00	0.21	0.52	-1.09	-3.35	-3.89	-4.17	-4.17	-4.17
Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.02	-0.04	-0.05	-0.05	-0.05
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.40	-0.40	-0.40
Renewables (TWh)	0.00	-0.24	-1.53	-1.49	-1.98	-2.18	-3.01	-3.01	-3.01
Total (TWh)	0.00	0.00	-0.89	-3.23	-6.33	-8.30	-10.13	-10.13	-10.13
Installed Generating Capacity									
Coal (GW)	0.00	0.00	-0.05	-0.05	-0.05	-0.12	-0.10	-0.10	-0.10
Other Fossil (GW)	0.00	0.00	-0.15	-0.22	-0.49	-0.67	-0.76	-0.76	-0.76
Nuclear (GW)	0.00	0.00	0.00	0.00	0.00	0.00	-0.05	-0.05	-0.05
Renewables (GW)	0.00	-0.07	-0.43	-0.44	-0.42	-0.48	-0.68	-0.68	-0.68
Total (GW)	0.00	-0.07	-0.63	-0.70	-0.97	-1.26	-1.59	-1.59	-1.59

Table 14.3.12 Standard-Size Freezers: Trial Standard Level 5 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,399	1,468	1,547	1,628	1,696
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,207	2,302
Gas (TWh)	759	857	691	768	882	1,014	1,091
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	894
Renewables (TWh)	358	462	647	712	795	848	887
Total (TWh)	4,034	4,005	4,256	4,499	4,739	5,003	5,223
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	445	467	500	533
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	171	176	186	195	209
Total (GW)	952	1,024	1,045	1,058	1,090	1,137	1,191

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.83	-3.36	-6.13	-8.82	-11.10	-12.86	-13.70
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.03	0.13	-0.66	-1.05	-2.35	-2.68	-2.68	-2.68
Gas (TWh)	0.00	0.21	0.52	-1.15	-3.56	-4.17	-4.47	-4.47	-4.47
Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.02	-0.04	-0.05	-0.05	-0.05
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.42	-0.42	-0.42
Renewables (TWh)	0.00	-0.23	-1.53	-1.57	-2.10	-2.33	-3.22	-3.22	-3.22
Total (TWh)	0.00	0.00	-0.89	-3.39	-6.74	-8.89	-10.85	-10.85	-10.85
Installed Generating Capacity									
Coal (GW)	0.00	0.00	-0.05	-0.05	-0.05	-0.12	-0.11	-0.11	-0.11
Other Fossil (GW)	0.00	0.00	-0.15	-0.23	-0.52	-0.71	-0.81	-0.81	-0.81
Nuclear (GW)	0.00	0.00	0.00	0.00	0.00	0.00	-0.06	-0.06	-0.06
Renewables (GW)	0.00	-0.07	-0.43	-0.46	-0.45	-0.51	-0.73	-0.73	-0.73
Total (GW)	0.00	-0.07	-0.63	-0.74	-1.03	-1.35	-1.71	-1.71	-1.71

Table 14.3.13 Compact Refrigeration Products: Trial Standard Level 1 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,471	1,552	1,635	1,706
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,209	2,304
Gas (TWh)	759	857	691	769	885	1,017	1,094
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	713	796	850	890
Total (TWh)	4,034	4,005	4,257	4,502	4,744	5,010	5,232
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	337
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	176	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,091	1,138	1,192

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.000	0.000	-0.368	-1.038	-1.339	-1.552	-1.774	-2.009	-2.155
Total U.S. Electric Generation									
Coal (TWh)	0.000	0.013	0.055	-0.205	-0.229	-0.414	-0.428	-0.428	-0.428
Gas (TWh)	0.000	0.098	0.230	-0.355	-0.778	-0.734	-0.714	-0.714	-0.714
Petroleum (TWh)	0.000	0.000	-0.001	-0.004	-0.005	-0.007	-0.009	-0.009	-0.009
Nuclear (TWh)	0.000	0.000	0.000	0.000	0.000	0.000	-0.068	-0.068	-0.068
Renewables (TWh)	0.000	-0.108	-0.679	-0.486	-0.459	-0.410	-0.515	-0.515	-0.515
Total (TWh)	0.000	0.002	-0.395	-1.050	-1.471	-1.565	-1.735	-1.735	-1.735
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.024	-0.015	-0.012	-0.022	-0.017	-0.017	-0.017
Other Fossil (GW)	0.000	0.000	-0.065	-0.071	-0.114	-0.126	-0.130	-0.130	-0.130
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.009	-0.009	-0.009
Renewables (GW)	0.000	-0.031	-0.191	-0.142	-0.098	-0.090	-0.116	-0.116	-0.116
Total (GW)	0.000	-0.032	-0.279	-0.228	-0.224	-0.237	-0.273	-0.273	-0.273

Table 14.3.14 Compact Refrigeration Products: Trial Standard Level 2 Forecast

NEMS-BT Results:	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,470	1,552	1,635	1,705
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,209	2,304
Gas (TWh)	759	857	691	769	885	1,017	1,094
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	713	796	850	890
Total (TWh)	4,034	4,005	4,257	4,501	4,744	5,010	5,232
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	176	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,091	1,138	1,192

Difference from AEO2010 Reference Case								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.46	-1.29	-1.65	-1.91	-2.18	-2.46	-2.63
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.02	0.07	-0.25	-0.28	-0.51	-0.53	-0.53	-0.53
Gas (TWh)	0.00	0.12	0.28	-0.44	-0.96	-0.90	-0.88	-0.88	-0.88
Petroleum (TWh)	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.08	-0.08	-0.08
Renewables (TWh)	0.00	-0.13	-0.84	-0.60	-0.57	-0.50	-0.63	-0.63	-0.63
Total (TWh)	0.00	0.00	-0.49	-1.30	-1.82	-1.93	-2.13	-2.13	-2.13
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.029	-0.019	-0.015	-0.027	-0.021	-0.021	-0.021
Other Fossil (GW)	0.000	0.000	-0.080	-0.088	-0.141	-0.155	-0.160	-0.160	-0.160
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.011	-0.011	-0.011
Renewables (GW)	0.000	-0.039	-0.236	-0.176	-0.122	-0.110	-0.142	-0.142	-0.142
Total (GW)	0.000	-0.039	-0.345	-0.283	-0.277	-0.292	-0.335	-0.335	-0.335

Table 14.3.15 Compact Refrigeration Products: Trial Standard Level 3 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,470	1,551	1,635	1,705
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,209	2,304
Gas (TWh)	759	857	691	769	884	1,017	1,094
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	713	796	850	890
Total (TWh)	4,034	4,005	4,257	4,501	4,744	5,010	5,231
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	176	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,091	1,138	1,192

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.53	-1.50	-1.93	-2.21	-2.51	-2.83	-3.02
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.02	0.08	-0.30	-0.33	-0.59	-0.61	-0.61	-0.61
Gas (TWh)	0.00	0.14	0.33	-0.51	-1.12	-1.05	-1.01	-1.01	-1.01
Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	-0.10	-0.10
Renewables (TWh)	0.00	-0.15	-0.98	-0.70	-0.66	-0.58	-0.73	-0.73	-0.73
Total (TWh)	0.00	0.00	-0.57	-1.52	-2.12	-2.23	-2.46	-2.46	-2.46
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.034	-0.022	-0.017	-0.031	-0.025	-0.025	-0.025
Other Fossil (GW)	0.000	0.000	-0.093	-0.102	-0.164	-0.179	-0.184	-0.184	-0.184
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.013	-0.013	-0.013
Renewables (GW)	0.000	-0.045	-0.274	-0.206	-0.142	-0.128	-0.164	-0.164	-0.164
Total (GW)	0.000	-0.045	-0.401	-0.330	-0.323	-0.338	-0.386	-0.386	-0.386

Table 14.3.16 Compact Refrigeration Products: Trial Standard Level 4 Forecast

NEMS-BT Results:								Difference from AEO2010 Reference Case									
																Extrapolation	
	2005	2010	2015	2020	2025	2030	2035		2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption								*Residential Sector Energy Consumption*									
Electricity Sales (TWh)	1,359	1,388	1,400	1,470	1,551	1,634	1,704	Electricity Sales (TWh)	0.00	0.00	-0.67	-1.94	-2.46	-2.79	-3.12	-3.46	-3.67
Total U.S. Electric Generation								*Total U.S. Electric Generation*									
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,208	2,304	Coal (TWh)	0.00	0.02	0.10	-0.38	-0.42	-0.74	-0.75	-0.75	-0.75
Gas (TWh)	759	857	691	768	884	1,017	1,094	Gas (TWh)	0.00	0.18	0.42	-0.66	-1.43	-1.32	-1.26	-1.26	-1.26
Petroleum (TWh)	122	45	46	47	48	48	49	Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02
Nuclear (TWh)	782	813	834	883	886	886	895	Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.12	-0.12	-0.12
Renewables (TWh)	358	462	647	713	796	849	889	Renewables (TWh)	0.00	-0.19	-1.24	-0.91	-0.84	-0.74	-0.91	-0.91	-0.91
Total (TWh)	4,034	4,005	4,256	4,501	4,743	5,009	5,231	Total (TWh)	0.00	0.00	-0.72	-1.96	-2.70	-2.81	-3.05	-3.05	-3.05
Installed Generating Capacity								*Installed Generating Capacity*									
Coal (GW)	314	321	325	326	326	330	336	Coal (GW)	0.000	0.000	-0.043	-0.029	-0.022	-0.039	-0.030	-0.030	-0.030
Other Fossil (GW)	439	468	445	446	467	501	534	Other Fossil (GW)	0.000	-0.001	-0.118	-0.132	-0.210	-0.226	-0.229	-0.229	-0.229
Nuclear (GW)	100	102	105	111	111	111	113	Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.016	-0.016	-0.016
Renewables (GW)	99	133	171	176	186	196	209	Renewables (GW)	0.000	-0.057	-0.349	-0.266	-0.181	-0.161	-0.204	-0.204	-0.204
Total (GW)	952	1,024	1,045	1,059	1,090	1,138	1,192	Total (GW)	0.000	-0.057	-0.511	-0.426	-0.412	-0.426	-0.480	-0.480	-0.480

Table 14.3.17 Compact Refrigeration Products: Trial Standard Level 5 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,399	1,469	1,551	1,634	1,704
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,129	2,208	2,304
Gas (TWh)	759	857	691	768	884	1,017	1,094
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	647	713	796	849	889
Total (TWh)	4,034	4,005	4,256	4,500	4,743	5,009	5,231
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	336
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	112
Renewables (GW)	99	133	171	176	186	196	209
Total (GW)	952	1,024	1,045	1,058	1,090	1,138	1,192

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.00	0.00	-0.73	-2.28	-2.82	-3.07	-3.32	-3.58	-3.74
Total U.S. Electric Generation									
Coal (TWh)	0.00	0.02	0.11	-0.45	-0.48	-0.82	-0.80	-0.80	-0.80
Gas (TWh)	0.00	0.18	0.46	-0.78	-1.64	-1.45	-1.34	-1.34	-1.34
Petroleum (TWh)	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02
Nuclear (TWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.13	-0.13	-0.13
Renewables (TWh)	0.00	-0.20	-1.35	-1.07	-0.97	-0.81	-0.97	-0.97	-0.97
Total (TWh)	0.00	0.00	-0.79	-2.31	-3.10	-3.10	-3.25	-3.25	-3.25
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.047	-0.034	-0.025	-0.043	-0.032	-0.032	-0.032
Other Fossil (GW)	0.000	-0.001	-0.129	-0.155	-0.240	-0.249	-0.244	-0.244	-0.244
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.017	-0.017	-0.017
Renewables (GW)	0.000	-0.058	-0.380	-0.312	-0.208	-0.177	-0.217	-0.217	-0.217
Total (GW)	0.000	-0.059	-0.556	-0.501	-0.473	-0.469	-0.511	-0.511	-0.511

Table 14.3.18 Built-In Refrigeration Products: Trial Standard Level 1 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,472	1,553	1,637	1,707
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,130	2,209	2,305
Gas (TWh)	759	857	690	769	885	1,018	1,095
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	714	797	850	890
Total (TWh)	4,034	4,005	4,257	4,503	4,746	5,012	5,234
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	337
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	177	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,091	1,138	1,192

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.000	0.000	-0.013	-0.047	-0.082	-0.113	-0.139	-0.160	-0.172
Total U.S. Electric Generation									
Coal (TWh)	0.000	0.000	0.002	-0.009	-0.014	-0.030	-0.034	-0.034	-0.034
Gas (TWh)	0.000	0.003	0.008	-0.016	-0.048	-0.054	-0.056	-0.056	-0.056
Petroleum (TWh)	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001	-0.001
Nuclear (TWh)	0.000	0.000	0.000	0.000	0.000	0.000	-0.005	-0.005	-0.005
Renewables (TWh)	0.000	-0.004	-0.023	-0.022	-0.028	-0.030	-0.040	-0.040	-0.040
Total (TWh)	0.000	0.000	-0.013	-0.048	-0.091	-0.114	-0.136	-0.136	-0.136
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001	-0.001
Other Fossil (GW)	0.000	0.000	-0.002	-0.003	-0.007	-0.009	-0.010	-0.010	-0.010
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001
Renewables (GW)	0.000	-0.001	-0.006	-0.006	-0.006	-0.007	-0.009	-0.009	-0.009
Total (GW)	0.000	-0.001	-0.009	-0.010	-0.014	-0.017	-0.021	-0.021	-0.021

Table 14.3.19 Built-In Refrigeration Products: Trial Standard Level 2 Forecast

NEMS-BT Results:	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,472	1,553	1,637	1,707
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,130	2,209	2,305
Gas (TWh)	759	857	690	769	885	1,018	1,095
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	714	797	850	890
Total (TWh)	4,034	4,005	4,257	4,503	4,746	5,012	5,234
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	337
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	177	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,091	1,138	1,192

Difference from AEO2010 Reference Case								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.000	0.000	-0.018	-0.068	-0.119	-0.164	-0.202	-0.233	-0.250
Total U.S. Electric Generation									
Coal (TWh)	0.000	0.001	0.003	-0.013	-0.020	-0.044	-0.049	-0.049	-0.049
Gas (TWh)	0.000	0.005	0.011	-0.023	-0.069	-0.078	-0.081	-0.081	-0.081
Petroleum (TWh)	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001	-0.001
Nuclear (TWh)	0.000	0.000	0.000	0.000	0.000	0.000	-0.008	-0.008	-0.008
Renewables (TWh)	0.000	-0.005	-0.033	-0.032	-0.041	-0.043	-0.059	-0.059	-0.059
Total (TWh)	0.000	0.000	-0.019	-0.069	-0.130	-0.166	-0.198	-0.198	-0.198
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
Other Fossil (GW)	0.000	0.000	-0.003	-0.005	-0.010	-0.013	-0.015	-0.015	-0.015
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001
Renewables (GW)	0.000	-0.002	-0.009	-0.009	-0.009	-0.009	-0.013	-0.013	-0.013
Total (GW)	0.000	-0.002	-0.014	-0.015	-0.020	-0.025	-0.031	-0.031	-0.031

Table 14.3.20 Built-In Refrigeration Products: Trial Standard Level 3 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,471	1,553	1,637	1,707
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,130	2,209	2,305
Gas (TWh)	759	857	690	769	885	1,018	1,095
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	714	797	850	890
Total (TWh)	4,034	4,005	4,257	4,502	4,746	5,011	5,233
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	337
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	177	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,091	1,138	1,192

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.000	0.000	-0.036	-0.136	-0.238	-0.329	-0.404	-0.467	-0.501
Total U.S. Electric Generation									
Coal (TWh)	0.000	0.001	0.005	-0.027	-0.041	-0.088	-0.098	-0.098	-0.098
Gas (TWh)	0.000	0.009	0.022	-0.046	-0.138	-0.156	-0.163	-0.163	-0.163
Petroleum (TWh)	0.000	0.000	0.000	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
Nuclear (TWh)	0.000	0.000	0.000	0.000	0.000	0.000	-0.015	-0.015	-0.015
Renewables (TWh)	0.000	-0.010	-0.066	-0.063	-0.082	-0.087	-0.117	-0.117	-0.117
Total (TWh)	0.000	0.000	-0.038	-0.137	-0.262	-0.332	-0.395	-0.395	-0.395
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.002	-0.002	-0.002	-0.005	-0.004	-0.004	-0.004
Other Fossil (GW)	0.000	0.000	-0.006	-0.009	-0.020	-0.027	-0.030	-0.030	-0.030
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.002	-0.002	-0.002
Renewables (GW)	0.000	-0.003	-0.018	-0.019	-0.018	-0.019	-0.026	-0.026	-0.026
Total (GW)	0.000	-0.003	-0.027	-0.030	-0.040	-0.050	-0.062	-0.062	-0.062

Table 14.3.21 Built-In Refrigeration Products: Trial Standard Level 4 Forecast

NEMS-BT Results:

	2005	2010	2015	2020	2025	2030	2035
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,471	1,553	1,637	1,707
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,130	2,209	2,305
Gas (TWh)	759	857	690	769	885	1,018	1,095
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	714	797	850	890
Total (TWh)	4,034	4,005	4,257	4,502	4,746	5,011	5,233
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	337
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	177	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,091	1,138	1,192

Difference from AEO2010 Reference Case

								Extrapolation	
	2005	2010	2015	2020	2025	2030	2035	2040	2043
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.000	0.000	-0.045	-0.170	-0.297	-0.408	-0.500	-0.577	-0.618
Total U.S. Electric Generation									
Coal (TWh)	0.000	0.001	0.007	-0.034	-0.051	-0.109	-0.121	-0.121	-0.121
Gas (TWh)	0.000	0.012	0.028	-0.058	-0.172	-0.193	-0.201	-0.201	-0.201
Petroleum (TWh)	0.000	0.000	0.000	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
Nuclear (TWh)	0.000	0.000	0.000	0.000	0.000	0.000	-0.019	-0.019	-0.019
Renewables (TWh)	0.000	-0.013	-0.083	-0.080	-0.102	-0.108	-0.145	-0.145	-0.145
Total (TWh)	0.000	0.000	-0.048	-0.172	-0.326	-0.412	-0.489	-0.489	-0.489
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.003	-0.003	-0.003	-0.006	-0.005	-0.005	-0.005
Other Fossil (GW)	0.000	0.000	-0.008	-0.012	-0.025	-0.033	-0.037	-0.037	-0.037
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.003	-0.003	-0.003
Renewables (GW)	0.000	-0.004	-0.023	-0.023	-0.022	-0.024	-0.033	-0.033	-0.033
Total (GW)	0.000	-0.004	-0.034	-0.037	-0.050	-0.062	-0.077	-0.077	-0.077

Table 14.3.22 Built-In Refrigeration Products: Trial Standard Level 5 Forecast

NEMS-BT Results:							
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Residential Sector Energy Consumption							
Electricity Sales (TWh)	1,359	1,388	1,400	1,471	1,553	1,637	1,707
Total U.S. Electric Generation							
Coal (TWh)	2,013	1,828	2,038	2,090	2,130	2,209	2,304
Gas (TWh)	759	857	690	769	885	1,018	1,095
Petroleum (TWh)	122	45	46	47	48	48	49
Nuclear (TWh)	782	813	834	883	886	886	895
Renewables (TWh)	358	462	648	714	797	850	890
Total (TWh)	4,034	4,005	4,257	4,502	4,746	5,011	5,233
Installed Generating Capacity							
Coal (GW)	314	321	325	326	326	330	337
Other Fossil (GW)	439	468	445	446	467	501	534
Nuclear (GW)	100	102	105	111	111	111	113
Renewables (GW)	99	133	171	177	186	196	209
Total (GW)	952	1,024	1,046	1,059	1,091	1,138	1,192

Difference from AEO2010 Reference Case								Extrapolation	
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2043**
Residential Sector Energy Consumption									
Electricity Sales (TWh)	0.000	0.000	-0.053	-0.203	-0.355	-0.488	-0.599	-0.691	-0.740
Total U.S. Electric Generation									
Coal (TWh)	0.000	0.002	0.008	-0.040	-0.061	-0.130	-0.145	-0.145	-0.145
Gas (TWh)	0.000	0.014	0.033	-0.070	-0.206	-0.231	-0.241	-0.241	-0.241
Petroleum (TWh)	0.000	0.000	0.000	-0.001	-0.001	-0.002	-0.003	-0.003	-0.003
Nuclear (TWh)	0.000	0.000	0.000	0.000	0.000	0.000	-0.023	-0.023	-0.023
Renewables (TWh)	0.000	-0.015	-0.098	-0.095	-0.122	-0.129	-0.174	-0.174	-0.174
Total (TWh)	0.000	0.000	-0.057	-0.206	-0.390	-0.492	-0.585	-0.585	-0.585
Installed Generating Capacity									
Coal (GW)	0.000	0.000	-0.003	-0.003	-0.003	-0.007	-0.006	-0.006	-0.006
Other Fossil (GW)	0.000	0.000	-0.009	-0.014	-0.030	-0.040	-0.044	-0.044	-0.044
Nuclear (GW)	0.000	0.000	0.000	0.000	0.000	0.000	-0.003	-0.003	-0.003
Renewables (GW)	0.000	-0.004	-0.028	-0.028	-0.026	-0.028	-0.039	-0.039	-0.039
Total (GW)	0.000	-0.005	-0.040	-0.045	-0.059	-0.075	-0.092	-0.092	-0.092

14.4 SUMMARY OF UTILITY IMPACT ANALYSIS

The following tables present a summary of utility impact results for all refrigeration product TSLs in the final year of the analysis period, 2043. Table 14.4.1 presents the reduction in total U.S. electricity generation in 2043. Table 14.4.2 presents the reduction in total U.S. electric generating capacity in 2043.

Table 14.4.1 Reduction in Total U.S. Electricity Generation in 2043 Under Refrigeration Product TSLs

	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	TWh				
Standard-Size Refrigerator-Freezers	16.7	19.2	22.6	30.9	37.0
Standard-Size Freezers	5.26	5.26	8.92	10.1	10.8
Compact Refrigeration Products	1.73	2.13	2.46	3.05	3.25
Built-In Refrigeration Products	0.136	0.198	0.395	0.489	0.585

Table 14.4.2 Reduction in Electric Generating Capacity in 2043 Under Refrigeration Product TSLs

	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	Gigawatts				
Standard-Size Refrigerator-Freezers	2.62	3.03	3.56	4.86	5.82
Standard-Size Freezers	0.827	0.827	1.40	1.59	1.71
Compact Refrigeration Products	0.273	0.335	0.386	0.480	0.511
Built-In Refrigeration Products	0.021	0.031	0.062	0.077	0.092

14.5 IMPACT OF STANDARDS ON ELECTRICITY PRICES AND ASSOCIATED BENEFITS FOR CONSUMERS

Using the framework of the utility impact analysis, DOE analyzed the potential impact on electricity prices resulting from the proposed standards on refrigeration products. Associated benefits for all electricity users in all sectors of the economy are then derived from these price impacts.

DOE's analysis of energy price impacts used NEMS-BT in a similar manner as described in section 14.2. Like other widely-used energy-economic models, NEMS uses elasticities to estimate the energy price change that would result from a change (increase or decrease) in energy demand. The elasticity of price to a decrease in demand is the "inverse price elasticity." The calculated inverse price elasticity based on NEMS-BT simulations differs throughout the forecast period in response to the dynamics of supply and demand for electricity.

14.5.1 Impact on Electricity Prices

DOE analyzed the electricity price effect of all refrigeration products together. The results for the proposed TSL for each of the four refrigeration product types were summed together to produce combined energy savings.[c] This allows for a single regression that represents the total impact of all refrigeration products. After generating results using higher decrements to electricity consumption, a regressed interpolation toward the origin derived the price effects associated with the combined energy savings of the proposed TSLs.

Figure 14.5.1 shows the annual change in U.S. electricity consumption for the proposed standards, relative to the base case which involves no new standards.

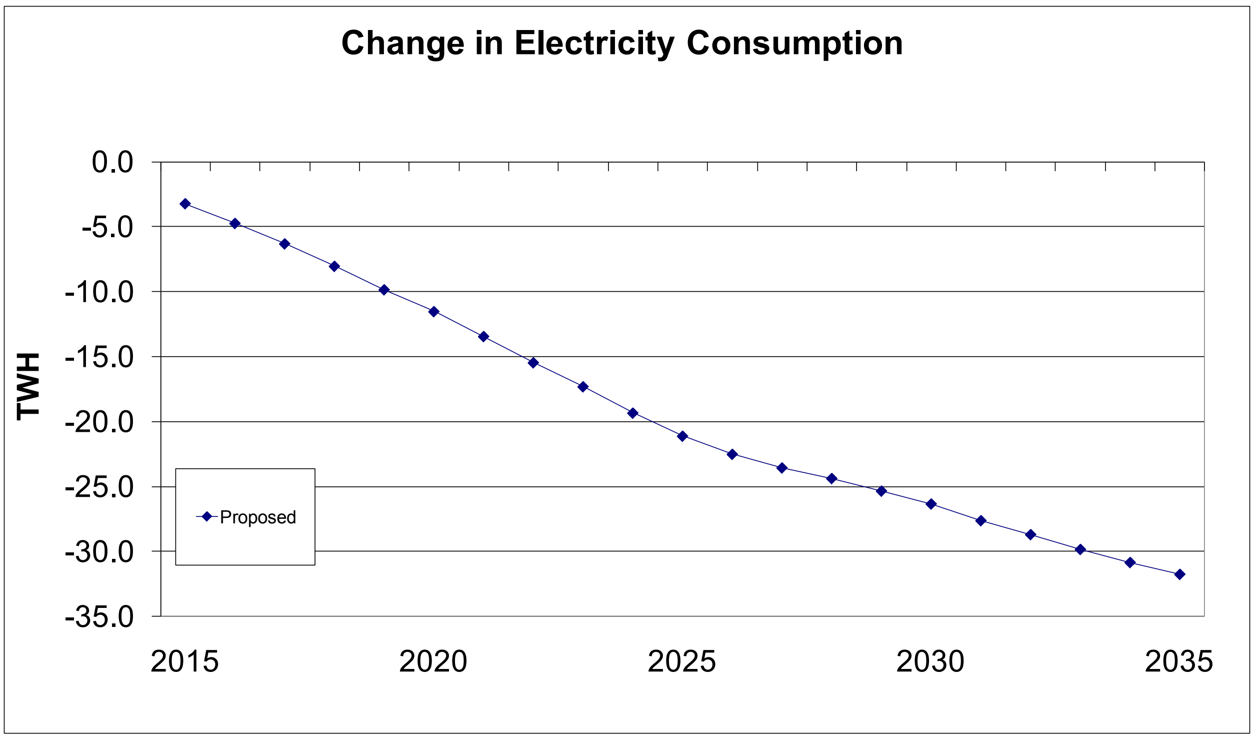

Figure 14.5.1 Change in U.S. Electricity Consumption Associated with Proposed Refrigeration Product Energy Conservation Standards

[c] The proposed standards consist of TSL 3 for standard-size refrigerator-freezers, TSL 2 for standard-size freezers, TSL 2 for compact refrigeration products, and TSL 3 for built-in refrigeration products.

Figure 14.5.2 shows the annual change in average U.S. price for electricity, relative to the Reference case, projected to result from the proposed standards. The price reduction averages 0.012 cents per kWh (in 2009$). This average price reduction equals 0.12 percent.

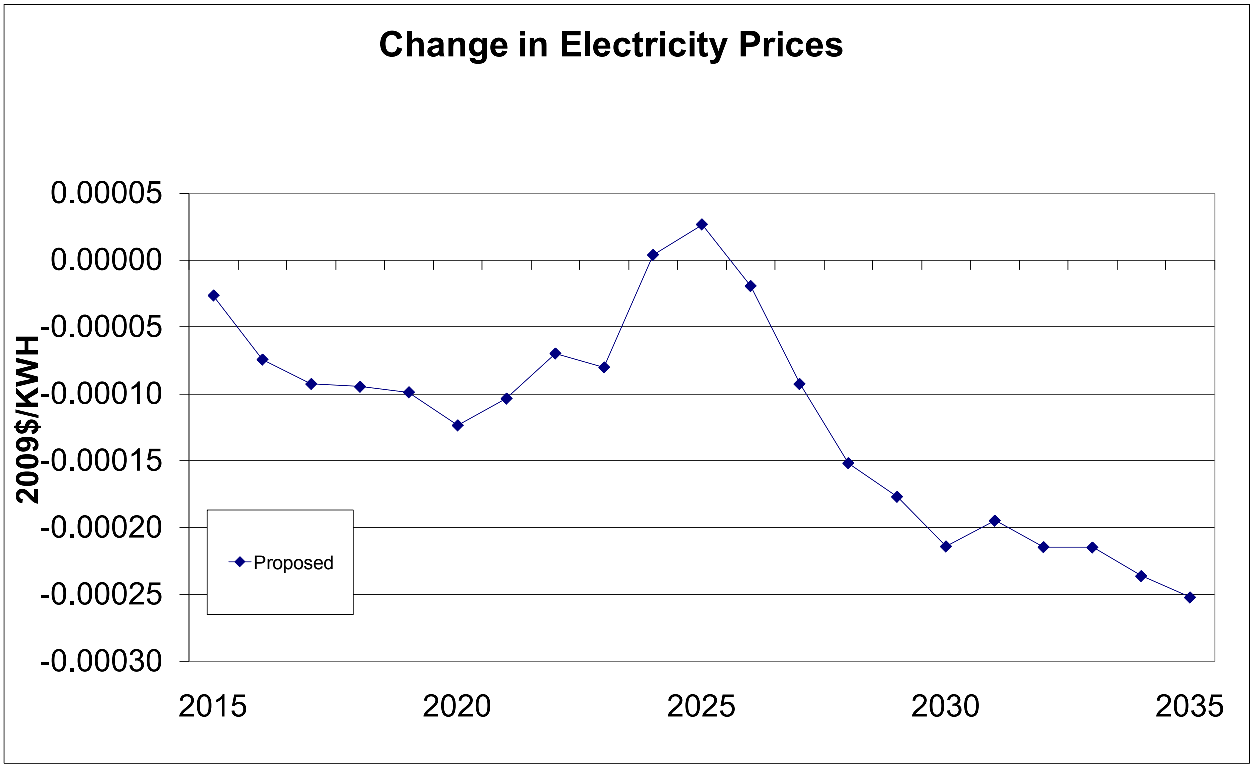

Figure 14.5.2 Effect of Proposed Refrigeration Product Energy Conservation Standards on Average U.S. Electricity Price (All Users)

14.5.2 Impact of Changes in Electricity Price on Electricity Users

Using the estimated electricity price impacts, DOE calculated the nominal savings in total electricity expenditures in each year by multiplying the annual change in the average-user price for electricity by the total annual U.S. electricity consumption forecast by NEMS, adjusted for the impact of the standards. The amended standards would continue to reduce demand for electricity after 2035 (which is the last year in the NEMS forecast). DOE's estimate for 2036–2043 (the period used to estimate the NPV of the national consumer benefits from amended standards) multiplied the average electricity price reduction in 2015–2035 by estimated total annual electricity consumption in 2036–2043.[d] DOE then discounted the stream of reduced expenditures to calculate a NPV.

Table 14.5.1 shows the calculated NPV of the economy-wide savings in electricity expenditures for each considered TSL at 3-percent and 7-percent discount rates. The need to extrapolate price effects and electricity consumption beyond 2035 suggests that one should interpret the post-2035 results as a rough indication of the benefits to electricity users in the post-2035 period.

Table 14.5.1 Cumulative NPV of the Economy-Wide Savings in Electricity Expenditures Due to the Projected Decline in Electricity Prices Resulting from the Proposed Standards for Refrigeration Products*

Discount Rate	*billion $2009*
3 percent	8.717
7 percent	4.101

* Impacts for units sold from 2014 to 2044

14.5.3 Discussion of Savings in Electricity Expenditures

Although the aggregate benefits for all electricity users are potentially large, there may be negative effects on the actors involved in electricity supply. The electric power industry is a complex mix of power plant providers, fuel suppliers, electricity generators, and electricity distributors. While the distribution of electricity is regulated everywhere, the institutional structure of the power sector varies, and has changed over time. For these reasons, an assessment of impacts on the actors involved in electricity supply from reduction in electricity demand associated with energy conservation standards is beyond the scope of this rulemaking.

In considering the potential benefits to electricity users, DOE takes under advisement the provided by the Office of Management and Budget (OMB) to Federal agencies on the development of regulatory analysis (OMB Circular A-4 (Sept. 17, 2003), section E, "Identifying and Measuring Benefits and Costs"). Specifically, at page 38, Circular A-4 instructs that transfers should be excluded from the estimates of the benefits and costs of a regulation. DOE is continuing to investigate the extent to which change in electricity prices projected to result from standards represents a net gain to society.

[d] The estimation of electricity consumption after 2035 uses the average annual growth rate in 2031-2035 of total U.S. electricity consumption forecasted by NEMS. This forecast includes the impact of the standards.

REFERENCES

1. Energy Information Administration, *Annual Energy Outlook 2010 with Projections to 2035*, 2010. Washington, DC. Report No. DOE/EIA-0383(2010). <http://www.eia.doe.gov/oiaf/aeo/>

CHAPTER 15. ENVIRONMENTAL ASSESSMENT

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CHAPTER 15. ENVIRONMENTAL ASSESSMENT

15.1 INTRODUCTION

This chapter describes potential environmental effects that may result from amended energy conservation standards for residential refrigeration products. The U.S. Department of Energy (DOE)'s energy conservation standards are not site-specific, and would apply to all 50 States and U.S. territories. Therefore, none of the standards would impact land uses, cause any direct disturbance to the land, or directly affect biological resources in any one area.

All of the trial standard levels (TSLs) are expected to reduce energy consumption in comparison to the base case. These changes in energy consumption are the primary drivers in analyzing environmental effects. The estimates of energy savings that serve as inputs to the environmental impacts analysis can be found in the utility impact analysis in chapter 14 of this technical support document (TSD).

The primary impact of the TSLs is on air emissions resulting from power plant operations. Therefore, much of this chapter describes the air emissions analysis, and the latter part of the chapter describes potential impacts to other environmental resources.

15.2 AIR EMISSIONS ANALYSIS

A primary focus of the environmental analysis is the impact on air emissions of amended energy conservation standards for residential refrigeration products. The outcomes of the environmental analysis are largely driven by changes in power plant types and quantities of electricity generated under each of the alternatives. Changes in electricity generation are described in the utility impact analysis in chapter 14.

15.2.1 Air Emissions Descriptions

For each of the TSLs, DOE calculated total power-sector emissions based on output from the NEMS-BT model (see chapter 14 for description of the model). This analysis considers three pollutants: sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury (Hg). An air pollutant is any substance in the air that can cause harm to humans or the environment. Pollutants may be natural or man-made (i.e., anthropogenic) and may take the form of solid particles (i.e., particulates or particulate matter), liquid droplets, or gases.[a] This analysis also considers carbon dioxide (CO_2).

Sulfur Dioxide. Sulfur dioxide, or SO_2, belongs to the family of sulfur oxide gases (SOx). These gases dissolve easily in water. Sulfur is prevalent in all raw materials, including crude oil, coal, and ore that contains common metals like aluminum, copper, zinc, lead, and iron. SOx gases are formed when fuel containing sulfur, such as coal and oil, is burned, and when gasoline is extracted from oil, or metals are extracted from ore. SO_2 dissolves in water vapor to

[a] More information on air pollution characteristics and regulations is available on the U.S. Environment Protection Agent (EPA)'s website at www.epa.gov.

form acid, and interacts with other gases and particles in the air to form sulfates and other products that can be harmful to people and their environment.[1]

SO_2 emissions from affected Electric Generating Units (EGUs) are subject to nationwide and regional emissions cap and trading programs, and DOE has determined that these programs create uncertainty about the standards' impact on SO_2 emissions. The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. However, if the standard resulted in a permanent increase in the quantity of unused emissions allowances, there would be an overall reduction in SO_2 emissions from the standards. While there remains some uncertainty about the ultimate effects of efficiency standards on SO_2 emissions covered by the existing cap and trade system, the NEMS-BT modeling system that DOE uses to forecast emissions reductions currently indicates that no physical reductions in power sector emissions would occur for SO_2.

Nitrogen Oxides. Nitrogen oxides**,** or NO_X, is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts. Many of the nitrogen oxides are colorless and odorless. However, one common pollutant, nitrogen dioxide (NO_2), along with particles in the air can often be seen as a reddish-brown layer over many urban areas. NO_2 is the specific form of NO_X reported in this document. NO_X is one of the main ingredients involved in the formation of ground-level ozone, which can trigger serious respiratory problems. It can contribute to the formation of acid rain, and can impair visibility in areas such as national parks. NO_X also contributes to the formation of fine particles that can impair human health.[1]

Nitrogen oxides form when fossil fuel is burned at high temperatures, as in a combustion process. The primary manmade sources of NO_X are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fossil fuels. NO_X can also be formed naturally. Electric utilities account for about 22 percent of NO_X emissions in the United States.[2]

There is a cap on NO_x emissions in 28 eastern states and the District of Columbia. All these States and D.C. have elected to reduce their NOx emissions by participating in cap-and-trade programs for EGUs. Therefore, energy conservation standards may have little or no physical effect on these emissions in the 28 eastern states and the D.C. for the same reasons that they may have little or no physical effect on SO_2 emissions.

DOE is using the NEMS-BT to estimate NOx emissions reductions from possible standards in the states where emissions are not capped.

Mercury. Coal-fired power plants emit mercury (Hg) found in coal during the burning process. While coal-fired power plants are the largest remaining source of human-generated Hg emissions in the United States, they contribute very little to the global Hg pool or to contamination of U.S. waters.[1] U.S. coal-fired power plants emit Hg in three different forms:

oxidized Hg (likely to deposit within the United States); elemental Hg, which can travel thousands of miles before depositing to land and water; and Hg that is in particulate form. Atmospheric Hg is then deposited on land, lakes, rivers, and estuaries through rain, snow, and dry deposition. Once there, it can transform into methylmercury and accumulate in fish tissue through bioaccumulation.

Americans are exposed to methylmercury primarily by eating contaminated fish. Because the developing fetus is the most sensitive to the toxic effects of methylmercury, women of childbearing age are regarded as the population of greatest concern. Children exposed to methylmercury before birth may be at increased risk of poor performance on neurobehavioral tasks, such as those measuring attention, fine motor function, language skills, visual-spatial abilities, and verbal memory.[3]

Carbon Dioxide. Carbon dioxide (CO_2) is not a criteria pollutant (see below), but it is of interest because of its classification as a greenhouse gas (GHG). GHGs trap the sun’s radiation inside the Earth’s atmosphere and either occur naturally in the atmosphere or result from human activities. Naturally occurring GHGs include water vapor, CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Human activities, however, add to the levels of most of these naturally occurring gases. For example, CO_2 is emitted to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), wood, and wood products are burned. In 2007, over 90 percent of anthropogenic (i.e., human-made) CO_2 emissions resulted from burning fossil fuels.[4]

Concentrations of CO_2 in the atmosphere are naturally regulated by numerous processes, collectively known as the “carbon cycle.” The movement of carbon between the atmosphere and the land and oceans is dominated by natural processes, such as plant photosynthesis. While these natural processes can absorb some of the anthropogenic CO_2 emissions produced each year, billions of metric tons are added to the atmosphere annually. In the United States, in 2007, CO_2 emissions from electricity generation accounted for 39 percent of total U.S. GHG emissions.[4]

Particulate Matter. Particulate matter (PM) also known as particle pollution, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.

PM impacts are of concern due to human exposures that can impact health. Particle pollution - especially fine particles - contains microscopic solids or liquid droplets that are so small that they can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including: increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing, for example; decreased lung function; aggravated asthma; development of chronic bronchitis; irregular heartbeat; nonfatal heart attacks; and premature death in people with heart or lung disease.

DOE acknowledges that particulate matter (PM) exposure can impact human health. Power plant emissions can have either direct or indirect impacts on PM. A portion of the pollutants emitted by a power plant are in the form of particulates as they leave the smoke stack. These are direct, or primary, PM emissions. However, the great majority of PM emissions associated with power plants are in the form of secondary sulfates, which are produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous (non-particulate) emissions of power plants, mainly SO_2 and NO_x. The quantity of the secondary sulfates produced is determined by a very complex set of factors including the atmospheric quantities of SO_2 and NO_x, and other atmospheric constituents and conditions. Because these highly complex chemical reactions produce PM comprised of different constituents from different sources, EPA does not distinguish direct PM emissions from power plants from the secondary sulfate particulates in its ambient air quality requirements, PM monitoring of ambient air quality, or PM emissions inventories. For these reasons, it is not currently possible to determine how the amended standard impacts either direct or indirect PM emissions. Therefore, DOE is not planning to assess the impact of these standards on PM emissions. Further, as described previously, it is uncertain whether efficiency standards will result in a net decrease in power plant emissions of SO_2 and NO_x, since those pollutants are now largely regulated by cap and trade systems.

15.2.2 Air Quality Regulation

The Clean Air Act Amendments of 1990 list 188 toxic air pollutants that EPA is required to control.[6] EPA has set national air quality standards for six common pollutants (also referred to as "criteria" pollutants), two of which are SO_2 and NO_X. Also, the Clean Air Act Amendments of 1990 gave EPA the authority to control acidification and to require operators of electric power plants to reduce emissions of SO_2 and NO_X. Title IV of the 1990 amendments established a cap-and-trade program for $SO_{2,}$ in all 50 states and the District of Columbia (D.C.), intended to help control acid rain.[6] This cap-and-trade program serves as a model for more recent programs with similar features.

In 2005, EPA issued the Clean Air Interstate Rule (CAIR) under sections 110 and 111 of the Clean Air Act (40 CFR Parts 51, 96, and 97).[7] [b] CAIR will permanently cap emissions of SO_2 and NO_X in eastern States of the United States. CAIR achieves large reductions of SO_2 and/or NO_X emissions across 28 eastern States and the District of Columbia. CAIR was designed to gradually replace the Title IV program in the 28 states and D.C. States must achieve the required emission reductions using one of two compliance options: 1) meet an emission budget for each regulated state by requiring power plants to participate in an EPA-administered interstate cap-and-trade system that caps emissions in two stages, or 2) meet an individual state emissions budget through measures of the state's choosing. Phase 1 caps for NO_X have been in place since 2009. Phase 1 caps for SO_2 are to be in place beginning in 2010. The Phase 2 caps for both NO_X and SO_2 are due in 2015.

On July 11, 2008, the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) issued its decision in North Carolina v. Environmental Protection Agency, which

[b] See http://www.epa.gov/cleanairinterstaterule/.

vacated the CAIR issued by the U.S. Environmental Protection Agency on March 10, 2005.[c] CAIR was the vehicle for capping NO_X emissions.[d] On December 23, 2008, the D.C. Circuit decided to allow CAIR to remain in effect until it is replaced by a rule consistent with the court's earlier opinion. North Carolina v. EPA, 550 F.3d 1176 (D.C. Cir. 2008) (remand of vacatur).[e] Although CAIR has been remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), see North Carolina v. EPA, 550 F.3d 1176 (D.C. Cir. 2008), it remains in effect temporarily, consistent with the D.C. Circuit's earlier opinion in North Carolina v. EPA, 531 F.3d 896 (D.C. Cir. 2008). On July 6, 2010, EPA issued the Transport Rule proposal, a replacement for CAIR, which would limit emissions from EGUs in 32 states, and may allow some amount of interstate trading. 75 FR 45210 (Aug. 2, 2010). EPA issued the final transport rule, entitled the Cross-State Air Pollution Rule, on July 6, 2011. 76 FR 48208 (August 8, 2011)[f]

With respect to Hg emissions, in 2005, EPA issued the final rule entitled "Standards of Performance for New and Existing Stationary Sources: Electric Steam Generating Units," under sections 110 and 111 of the Clean Air Act (40 CFR Parts 60, 63, 72, and 75) [8]. This rule, called the Clean Air Mercury Rule (CAMR), was closely related to the CAIR and established standards of performance for Hg emissions from new and existing coal-fired electric utility steam generating units. The CAMR regulated Hg emissions from coal-fired power plants. On February 8, 2008, the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) issued its decision in State of New Jersey, *et al.* v. Environmental Protection Agency,[g] in which the Court, among other actions, vacated the CAMR referenced above.

15.2.3 Global Climate Change

Climate change has evolved into a matter of global concern because it is expected to have widespread, adverse effects on natural resources and systems. A growing body of evidence points to anthropogenic sources of greenhouse gases, such as carbon dioxide (CO_2), as major contributors to climate change. Because this Rule, if finalized, will likely decrease CO_2 emission rates from the fossil fuel sector in the United States, the Department here examines the impacts and causes of climate change and then the potential impact of the Rule on CO_2 emissions and global warming.

Impacts of Climate Change on the Environment. Climate is usually defined as the average weather, over a period ranging from months to many years. Climate change refers to a change in the state of the climate, which is identifiable through changes in the mean and/or the

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[c] See http://www.epa.gov/cleanairinterstaterule/.

[d] *See id.* at 903.

[e] State of North Carolina, et al. v. Environmental Protection Agency, 550 F.3d 1176 (D.C. Cir. 2008).

[f] DOE notes that future iterations of the NEMS-BT model will incorporate any changes necessitated by issuance of the Cross-State Air Pollution Rule.

[g] 517 F.3d 574, 583 (D.C. Cir. 2008).

variability of its properties (e.g., temperature or precipitation) over an extended period, typically decades or longer.[9]

The World Meteorological Organization and United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) to provide an objective source of information about climate change. According to the IPCC Fourth Assessment Report (IPCC Report), published in 2007, climate change is consistent with observed changes to the world's natural systems; the IPCC expects these changes to continue.[9]

Changes that are consistent with warming include warming of the world's oceans to a depth of 3000 meters; global average sea level rise at an average rate of 1.8 mm per year from 1961 to 2003; loss of annual average Arctic sea ice at a rate of 2.7 percent per decade, changes in wind patterns that affect extra-tropical storm tracks and temperature patterns, increases in intense precipitation in some parts of the world, as well as increased drought and more frequent heat waves in many locations worldwide, and numerous ecological changes.[9]

Looking forward, the IPCC describes continued global warming of about 0.2 °C per decade for the next two decades under a wide range of emission scenarios for carbon dioxide (CO_2), other greenhouse gases (GHGs), and aerosols. After that period, the rate of increase is less certain. The IPCC Report describes increases in average global temperatures of about 1.1 °C to 6.4 °C at the end of the century relative to today. These increases vary depending on the model and emissions scenarios.[9]

The IPCC Report describes incremental impacts associated with the rise in temperature. At ranges of incremental increases to the global average temperature, IPCC reports, with either high or very high confidence, that there is likely to be an increasing degree of impacts such as coral reef bleaching, loss of wildlife habitat, loss to specific ecosystems, and negative yield impacts for major cereal crops in the tropics, but also projects that there likely will be some beneficial impacts on crop yields in temperate regions.

Causes of Climate Change. The IPCC Report states that the world has warmed by about 0.74 °C in the last 100 years. The IPCC Report finds that most of the temperature increase since the mid-20th century is very likely due to the increase in anthropogenic concentrations of CO_2 and other long-lived greenhouse gases such as methane and nitrous oxide in the atmosphere, rather than from natural causes.

Increasing the CO_2 concentration partially blocks the earth's re-radiation of captured solar energy in the infrared band, inhibits the radiant cooling of the earth, and thereby alters the energy balance of the planet, which gradually increases its average temperature. The IPCC Report estimates that currently, CO_2 makes up about 77 percent of the total CO_2-equivalent[h]

[h] GHGs differ in their warming influence (radiative forcing) on a global climate system due to their different radiative properties and lifetimes in the atmosphere. These warming influences may be expressed through a common metric based on the radiative forcing of CO_2, i.e., CO_2-equivalent. CO_2 equivalent emission is the amount of CO_2 emission that would cause the same- time integrated radiative forcing, over a given time horizon, as an emitted amount of other long- lived GHG or mixture of GHGs.

global warming potential in GHGs emitted from human activities, with the vast majority (74 percent) of the CO_2 attributable to fossil fuel use.[10] For the future, the IPCC Report describes a wide range of GHG emissions scenarios, but under each scenario CO_2 would continue to comprise above 70 percent of the total global warming potential.[10]

Stabilization of CO_2 Concentrations. Unlike many traditional air pollutants, CO_2 mixes thoroughly in the entire atmosphere and is long-lived. The residence time of CO_2 in the atmosphere is long compared to the emission processes. Therefore, the global cumulative emissions of CO_2 over long periods determine CO_2 concentrations because it takes hundreds of years for natural processes to remove the CO_2. Globally, 49 billion metric tons of CO_2 – equivalent of anthropogenic (man-made) greenhouse gases are emitted every year. Of this annual total, fossil fuels contribute about 29 billion metric tons of CO_2.[11] [i]

Researchers have focused on considering atmospheric CO_2 concentrations that likely will result in some level of global climate stabilization, and the emission rates associated with achieving the "stabilizing" concentrations by particular dates. They associate these stabilized CO_2 concentrations with temperature increases that plateau in a defined range. For example, at the low end, the IPCC Report scenarios target CO_2 stabilized concentrations range between 350 ppm and 400 ppm (essentially today's value)—because of climate inertia, concentrations in this low-end range would still result in temperatures projected to increase 2.0 °C to 2.4 °C above pre-industrial levels[j] (about 1.3 °C to 1.7 °C above today's levels). To achieve concentrations between 350 ppm to 400 ppm, the IPCC scenarios present that there would have to be a rapid downward trend in total annual global emissions of greenhouse gases to levels that are 50 to 85 percent below today's annual emission rates by no later than 2050. Since it is assumed that there would continue to be growth in global population and substantial increases in economic production, the scenarios identify required reductions in greenhouse gas emissions intensity (emissions per unit of output) of more than 90 percent. However, even at these rates, the scenarios describe some warming and some climate change is projected due to already accumulated CO_2 and GHGs in the atmosphere.[12]

The Beneficial Impact of the Rule on CO_2 Emissions. It is anticipated that the Rule will reduce energy-related CO_2 emissions, particularly those associated with energy consumption in buildings. The U.S. Energy Information Administration (EIA) reports in its 2010 Annual Energy Outlook (*AEO2010*)[13] that U.S. annual energy-related emissions of CO_2 in 2007 were about 6.0 billion metric tons, of which 1.2 billion tons were attributed to the residential buildings sector (including related energy–using products such as residential refrigeration products). Most of the greenhouse gas emissions attributed to residential buildings are emitted from fossil fuel-fired power plants that generate electricity used in this sector. In the *AEO2010* Reference Case, EIA projected that annual energy-related CO_2 emissions would grow from 5.7 billion metric tons in 2015 to 6.3 billion metric tons in 2035, an increase of 10 percent (see *AEO2010*), while

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[i] Other non-fossil fuel contributors include CO_2 emissions from deforestation and decay from agriculture biomass; agricultural and industrial emissions of methane; and emissions of nitrous oxide and fluorocarbons.

[j] IPCC Working Group 3 Table TS 2

residential emissions would grow to from 1.2 billion metric tons to 1.3 billion metric tons, an increase of 12 percent.

The estimated cumulative CO_2 emission reductions from residential refrigeration products efficiency standards (shown as a range of alternative TSLs) during the 30-year analysis period are indicated in Table 15.2.1. Estimated CO_2 emission reductions in Table 15.2.1 only come from electricity generation (i.e., power plants). The estimated CO_2 emission reductions from electricity generation are calculated using the NEMS-BT model.

Table 15.2.1 Reduction in Cumulative Energy-Related Emissions of CO_2 from 2014 through 2043 from Residential Refrigeration Products Energy Conservation Standards

	Trial Standard Levels				
	TSL 1	**TSL 2**	**TSL 3**	**TSL 4**	**TSL 5**
	Million Metric Tons				
Standard-Size Refrigerator-Freezers	154	177	208	283	338
Standard-Size Freezers	48.0	68.8	81.1	92.0	98.5
Compact Refrigeration Products	19.6	23.6	28.0	35.2	38.8
Built-In Refrigeration Products	1.23	1.79	3.58	4.45	5.32
Total	223	271	321	415	481
Percent of Total Cumulative Emissions Reduction compared with the *AEO2010* Reference Case in 2015-2043	0.30	0.36	0.43	0.56	0.65

The Incremental Impact of the Rule on Climate Change. It is difficult to correlate specific emission rates with atmospheric concentrations of CO_2 and specific atmospheric concentrations with future temperatures because the IPCC Report describes a clear lag in the climate system between any given concentration of CO_2 (even if maintained for long periods) and the subsequent average worldwide and regional temperature, precipitation, and extreme weather regimes. For example, a major determinant of climate response is “equilibrium climate sensitivity”, a measure of the climate system response to sustained radioactive forcing. It is defined as the global average surface warming following a doubling of carbon dioxide concentrations. The IPCC Report describes its estimated, numeric value as about 3 °C, but the likely range of that value is 2 °C to 4.5 °C, with cloud feedbacks the largest source of uncertainty. Further, as illustrated above, the IPCC Report scenarios for stabilization rates are presented in terms of a range of concentrations, which then correlates to a range of temperature changes. Thus, climate sensitivity is a key uncertainty for CO_2 mitigation scenarios that aim to meet specific temperature levels.

Because of how complex global climate systems are, it is difficult to know to what extent and when particular CO_2 emissions reductions will impact global warming. However, as Table 15.2.1 indicates, the rule is expected to reduce CO_2 emissions associated with energy consumption in buildings.

15.2.4 Analytical Methods for Air Emissions

Coal-fired electric generation is the single largest source of electricity in the United States. Because the mix of coals used significantly affects the emissions produced, the model includes a detailed representation of coal supply. The model considers the rank of the coal as well as the sulfur contents of the fuel used when determining optimal dispatch.[14]

Within the NEMS-BT model, planning options for achieving emissions restrictions in the Clean Air Act Amendments include installing pollution control equipment on existing power plants and building new power plants with low emission rates. These methods for reducing emission are compared to dispatching options such as fuel switching and allowance trading. Environmental regulations also affect capacity expansion decisions. For instance, new plants are not allocated SO_2 emissions allowances according to the Clean Air Act Amendments. Consequently, the decision to build a particular capacity type must consider the cost (if any) of obtaining sufficient allowances. This could involve purchasing allowances or over complying at an existing unit.

DOE's analysis assumed the presence of nationwide emission caps on SO_2 and caps on NO_X emissions in the 28 States covered by the CAIR. Any emissions reductions in NO_X calculated by the NEMS-BT modeling system that DOE plans to use are in addition to the regulatory emissions reductions modeled in AEO. The NEMS-BT modeling system currently indicates that no physical reductions in power sector emissions would occur for $SO_{2.}$

In contrast to the modeling forecasts of NEMS-BT that SO_2 emissions reductions will remain at the cap, during the years 2007 and 2008, SO_2 emissions have been below the trading cap. The difference between the emissions levels that NEMS-BT forecasts and those that EPA forecasts is an indicator of the uncertainties associated with long-range energy sector forecasts. Because of such uncertainties, DOE is unable to estimate the economic and physical benefit from SO_2 emissions reductions at this time.

As noted in chapter 14, NEMS-BT model forecasts end in year 2035. Emissions impacts beyond 2035 are assumed to be equal to the impacts in 2035.

15.2.5 Effects on Power Plant Emissions

Table 15.2.2 shows *AEO2010* reference case power plant emissions in selected years. The Reference Case emissions are the emissions shown by the NEMS-BT model to result if none of the TSLs are promulgated (the base case).

Table 15.2.2 Power Sector Emissions Forecast from *AEO2010* Reference Case

NEMS-BT Results	2010	2015	2020	2025	2030	2035
CO_2 (million metric tons)	2,218	2,278	2,341	2,421	2,534	2,636
NO_X (million tons)	2.24	2.06	2.02	2.03	2.06	2.07
Hg (tons)	40.6	30.6	30.1	30.0	30.2	30.3

Table 15.2.3 through Table 15.2.6 show the estimated changes in power plant emissions of CO_2, NO_X, and Hg in selected years for each of the TSLs.

Table 15.2.3 Power Sector Emissions Impacts Forecasts for Standard-Size Refrigerator-Freezer TSLs

NEMS-BT Results*	Difference from AEO2010 Reference Case								
							Extrapolation		Total
	2010	2015	2020	2025	2030	2035	2040	2043	2014-2043
Standard Level 1									
CO2 (Mt/yr)	0.33	0.89	-2.35	-5.52	-7.15	-7.37	-7.37	-7.37	**-154**
NOx (kt/yr)	0.34	0.81	-2.02	-4.64	-5.80	-5.78	-5.78	-5.78	**-124**
Hg (t/yr)	0.00	0.00	-0.02	-0.02	-0.04	-0.04	-0.04	-0.04	**-0.787**
Standard Level 2									
CO2 (Mt/yr)	0.38	1.02	-2.69	-6.34	-8.22	-8.50	-8.50	-8.50	**-177**
NOx (kt/yr)	0.38	0.92	-2.32	-5.32	-6.67	-6.66	-6.66	-6.66	**-142**
Hg (t/yr)	0.00	0.00	-0.02	-0.02	-0.05	-0.05	-0.05	-0.05	**-0.91**
Sandard Level 3									
CO2 (Mt/yr)	0.44	1.19	-3.16	-7.46	-9.67	-10.00	-10.00	-10.00	**-208**
NOx (kt/yr)	0.45	1.07	-2.72	-6.26	-7.85	-7.83	-7.83	-7.83	**-168**
Hg (t/yr)	0.00	0.00	-0.03	-0.02	-0.05	-0.05	-0.05	-0.05	**-1.07**
Standard Level 4									
CO2 (Mt/yr)	0.58	1.56	-4.23	-10.07	-13.15	-13.65	-13.65	-13.65	**-283**
NOx (kt/yr)	0.58	1.41	-3.64	-8.46	-10.68	-10.70	-10.70	-10.70	**-228**
Hg (t/yr)	0.01	-0.01	-0.04	-0.03	-0.07	-0.07	-0.07	-0.07	**-1.45**
Standard Level 5									
CO2 (Mt/yr)	0.66	1.79	-4.97	-11.96	-15.70	-16.34	-16.34	-16.34	**-338**
NOx (kt/yr)	0.66	1.62	-4.28	-10.05	-12.74	-12.81	-12.81	-12.81	**-272**
Hg (t/yr)	0.01	-0.01	-0.04	-0.04	-0.09	-0.09	-0.09	-0.09	**-1.73**

*CO_2 results are in metric tons, NO_X and Hg results are in short tons.

Table 15.2.4 Power Sector Emissions Impact Forecasts for Standard-Size Freezer TSLs

NEMS-BT Results*	Difference from AEO2010 Reference Case								
							Extrapolation		Total
	2010	2015	2020	2025	2030	2035	2040	2043	2014-2043
Standard Level 1									
CO2 (Mt/yr)	0.10	0.26	-0.67	-1.61	-2.21	-2.39	-2.39	-2.39	**-48.0**
NOx (kt/yr)	0.10	0.24	-0.58	-1.36	-1.79	-1.87	-1.87	-1.87	**-38.6**
Hg (t/yr)	0.001	-0.001	-0.006	-0.005	-0.012	-0.013	-0.013	-0.013	**-0.245**
Standard Level 2									
CO2 (Mt/yr)	0.14	0.37	-0.95	-2.30	-3.16	-3.42	-3.42	-3.42	**-68.8**
NOx (kt/yr)	0.14	0.33	-0.82	-1.94	-2.57	-2.68	-2.68	-2.68	**-55.3**
Hg (t/yr)	0.002	-0.001	-0.008	-0.007	-0.018	-0.019	-0.019	-0.019	**-0.351**
Sandard Level 3									
CO2 (Mt/yr)	0.16	0.42	-1.11	-2.71	-3.73	-4.04	-4.04	-4.04	**-81.1**
NOx (kt/yr)	0.16	0.38	-0.96	-2.28	-3.03	-3.17	-3.17	-3.17	**-65.1**
Hg (t/yr)	0.002	-0.002	-0.009	-0.008	-0.021	-0.022	-0.022	-0.022	**-0.413**
Standard Level 4									
CO2 (Mt/yr)	0.17	0.47	-1.25	-3.07	-4.23	-4.59	-4.59	-4.59	**-92.0**
NOx (kt/yr)	0.18	0.42	-1.08	-2.58	-3.44	-3.60	-3.60	-3.60	**-73.9**
Hg (t/yr)	0.002	-0.002	-0.010	-0.010	-0.024	-0.025	-0.025	-0.025	**-0.469**
Standard Level 5									
CO2 (Mt/yr)	0.17	0.47	-1.31	-3.27	-4.54	-4.92	-4.92	-4.92	**-98.5**
NOx (kt/yr)	0.17	0.43	-1.13	-2.75	-3.68	-3.86	-3.86	-3.86	**-79.2**
Hg (t/yr)	0.002	-0.002	-0.011	-0.010	-0.026	-0.027	-0.027	-0.027	**-0.501**

*CO_2 results are in metric tons, NO_X and Hg results are in short tons.

Table 15.2.5 Power Sector Emissions Impact Forecasts for Compact Refrigeration Product TSLs

NEMS-BT Results*	Difference from AEO2010 Reference Case								
							Extrapolation		Total
	2010	2015	2020	2025	2030	2035	2040	2043	2014-2043
Standard Level 1									
CO2 (Mt/yr)	0.089	0.232	-0.451	-0.793	-0.886	-0.872	-0.872	-0.872	**-19.6**
NOx (kt/yr)	0.090	0.210	-0.389	-0.666	-0.719	-0.684	-0.684	-0.684	**-15.8**
Hg (t/yr)	0.001	-0.001	-0.004	-0.002	-0.005	-0.005	-0.005	-0.005	**-0.104**
Standard Level 2									
CO2 (Mt/yr)	0.107	0.280	-0.546	-0.956	-1.065	-1.046	-1.046	-1.046	**-23.6**
NOx (kt/yr)	0.108	0.253	-0.470	-0.803	-0.864	-0.820	-0.820	-0.820	**-19.0**
Hg (t/yr)	0.001	-0.001	-0.005	-0.003	-0.006	-0.006	-0.006	-0.006	**-0.125**
Sandard Level 3									
CO2 (Mt/yr)	0.127	0.333	-0.652	-1.140	-1.263	-1.235	-1.235	-1.235	**-28.0**
NOx (kt/yr)	0.128	0.301	-0.562	-0.958	-1.026	-0.968	-0.968	-0.968	**-22.5**
Hg (t/yr)	0.001	-0.001	-0.005	-0.004	-0.007	-0.007	-0.007	-0.007	**-0.148**
Standard Level 4									
CO2 (Mt/yr)	0.160	0.424	-0.842	-1.457	-1.590	-1.533	-1.533	-1.533	**-35.2**
NOx (kt/yr)	0.161	0.384	-0.726	-1.224	-1.291	-1.202	-1.202	-1.202	**-28.3**
Hg (t/yr)	0.002	-0.002	-0.007	-0.005	-0.009	-0.008	-0.008	-0.008	**-0.186**
Standard Level 5									
CO2 (Mt/yr)	0.165	0.462	-0.990	-1.670	-1.753	-1.633	-1.633	-1.633	**-38.8**
NOx (kt/yr)	0.166	0.418	-0.853	-1.403	-1.423	-1.280	-1.280	-1.280	**-31.4**
Hg (t/yr)	0.002	-0.002	-0.008	-0.005	-0.010	-0.009	-0.009	-0.009	**-0.206**

*CO_2 results are in metric tons, NO_X and Hg results are in short tons.

Table 15.2.6 Power Sector Emissions Impact Forecasts for Built-In Refrigeration Product TSLs

NEMS-BT Results*	Difference from AEO2010 Reference Case								
							Extrapolation		Total
	2010	2015	2020	2025	2030	2035	2040	2043	2014-2043
Standard Level 1									
CO2 (Mt/yr)	0.003	0.007	-0.018	-0.043	-0.057	-0.060	-0.060	-0.060	**-1.23**
NOx (kt/yr)	0.003	0.006	-0.016	-0.036	-0.046	-0.047	-0.047	-0.047	**-0.99**
Hg (t/yr)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**-0.006**
Standard Level 2									
CO2 (Mt/yr)	0.004	0.010	-0.026	-0.062	-0.083	-0.087	-0.087	-0.087	**-1.79**
NOx (kt/yr)	0.004	0.009	-0.023	-0.052	-0.067	-0.068	-0.068	-0.068	**-1.44**
Hg (t/yr)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**-0.009**
Sandard Level 3									
CO2 (Mt/yr)	0.008	0.020	-0.053	-0.125	-0.166	-0.174	-0.174	-0.174	**-3.58**
NOx (kt/yr)	0.008	0.018	-0.045	-0.105	-0.134	-0.137	-0.137	-0.137	**-2.88**
Hg (t/yr)	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001	-0.001	**-0.018**
Standard Level 4									
CO2 (Mt/yr)	0.010	0.025	-0.066	-0.156	-0.206	-0.216	-0.216	-0.216	**-4.45**
NOx (kt/yr)	0.010	0.023	-0.057	-0.131	-0.167	-0.169	-0.169	-0.169	**-3.58**
Hg (t/yr)	0.000	0.000	-0.001	0.000	-0.001	-0.001	-0.001	-0.001	**-0.023**
Standard Level 5									
CO2 (Mt/yr)	0.011	0.030	-0.079	-0.187	-0.246	-0.258	-0.258	-0.258	**-5.32**
NOx (kt/yr)	0.011	0.027	-0.068	-0.157	-0.200	-0.202	-0.202	-0.202	**-4.28**
Hg (t/yr)	0.000	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	**-0.027**

*CO_2 results are in metric tons, NO_X and Hg results are in short tons.

15.2.6 Effects on Upstream Fuel-Cycle Emissions

Upstream fuel-cycle emissions refer to the emissions associated with the amount of energy used in the upstream production and downstream consumption of electricity, including energy used at the power plant.[17] Upstream processes include the mining of coal or extraction of natural gas, physical preparatory and cleaning processes, and transportation to the power plant. The NEMS-BT does a thorough accounting of emissions at the power plant due to downstream energy consumption, but does not account for upstream emissions (i.e., emissions from energy losses during coal and natural gas production). Thus, this analysis reports only power plant emissions.

However, previous DOE environmental assessment documents have developed approximate estimates of effects on upstream fuel-cycle emissions. These emissions factors provide the reader with a sense of the possible magnitude of upstream effects. These upstream emissions would be in addition to emissions from direct combustion.

Relative to the entire fuel cycle, estimates based on the work of Dr. Mark DeLuchi, and reported in earlier DOE environmental assessment documents, find that an amount approximately equal to eight percent, by mass, of emissions (including SO_2) from coal production are due to mining, preparation that includes cleaning the coal, and transportation from the mine to the power plant.[18] Transportation emissions include emissions from the fuel used by the mode of transportation that moves the coal from the mine to the power plant. In addition, based on Dr. DeLuchi's work, DOE estimated that an amount equal to approximately 14 percent of emissions from natural gas production result from upstream processes.

Emission factor estimates and corresponding percentages of contributions of upstream emissions from coal and natural gas production, relative to power plant emissions, are shown in Table 15.2.7 for CO_2 and NO_X. The percentages provide a means to estimate upstream emission savings based on changes in emissions from power plants. This approach does not address Hg emissions.

Table 15.2.7 Estimated Upstream Emissions of Air Pollutants as a Percentage of Direct Power Plant Combustion Emissions

Pollutant	Percent of Coal Combustion Emissions	Percent of Natural Gas Combustion Emissions
CO_2	2.7	11.9
NO_X	5.8	40

15.3 WETLAND, ENDANGERED AND THREATENED SPECIES, AND CULTURAL RESOURCES

Because residential refrigeration products are not water-consuming products, more efficient refrigeration would not reduce the amount of water discharged into the waste stream. As a result, refrigeration energy conservation standards do not have the effect of improving the quality of wetlands, nor threatened or endangered species that reside in these wetlands. This action is also not expected to impact cultural resources such as historical or archaeological sites.

15.4 SOCIOECONOMIC IMPACTS

DOE's analysis has shown that the increase in the first cost of purchasing more efficient refrigeration products at the proposed standard levels is, in most cases, completely offset by a reduction in the life-cycle cost (LCC) of owning a more efficient product for the average consumer. In other words, the consumer will pay less operating costs over the life of the product even through the first cost increases. The complete LCC analysis and its conclusions are presented in chapter 8 of the TSD.

For subgroups of low-income and senior consumers that purchase refrigeration products, DOE determined that the average LCC impact of the standards is similar to that for the full sample of consumers. Therefore, DOE concludes that the proposed standards would have no significant adverse socioeconomic impact. For a complete discussion on the LCC impacts on consumer subgroups, see chapter 11 of the TSD.

15.5 ENVIRONMENTAL JUSTICE IMPACTS

In view of Executive Order 12898 of February 11, 1994, “Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations,” DOE examined the effect of the energy conservation standards on low-income households. As described in the LCC subgroup analysis in Chapter 11 of the TSD, DOE found that there were no disproportionately high and adverse human health or environmental effects on low-income populations that would result from the adopted energy conservation standards.

15.6 NOISE AND AESTHETICS

Improvements in efficiency of residential refrigerators are expected to result from changes in the choice of components and other design features. These changes are described in chapter 5 of this TSD. These design changes are not expected to change noise levels in comparison to products in today’s market. Products that are currently manufactured in the existing market that would meet the standards are no louder than less efficient products. Changes to the design to improve the efficiency levels are not anticipated to affect the product aesthetics.

15.7 SUMMARY OF ENVIRONMENTAL IMPACTS

Table 15.7.1 summarizes the estimated emissions impacts for each of the TSLs for refrigeration products. It shows cumulative changes in emissions for CO_2, NO_X, and Hg for 2014 through 2043 for each of the refrigeration product TSLs. Cumulative CO_2, NO_X, and Hg emissions are reduced compared to the Reference case for all TSLs. For comparison, the cumulative power sector emissions in the *AEO2010* Reference case, over the period 2014 through 2043, are 74,571 Mt for CO_2, 61,625 kt for NO_X, and 917 tons for Hg.

Upstream fuel cycle emission of CO_2 and NO_X are described but not quantified in section 15.2.6. The text describes potential reductions in fuel cycle emissions as percentage of decreases in power plant emissions. This approach suggests that upstream fuel cycle emissions would decrease and provides a sense for the magnitude of effects; however DOE does not report actual estimates of the effects.

For subgroups of low-income and senior consumers that purchase refrigeration products, DOE determined that the average LCC impact of the standards is similar to that for the full sample of consumers. Therefore, DOE concludes that the proposed standards would have no significant adverse socioeconomic impact.

No impacts are anticipated in the areas of environmental justice, wetlands, endangered and threatened species, and cultural resources; or noise and aesthetics.

Table 15.7.1 Cumulative Emissions Reductions Under Refrigeration Product TSLs*

	TSL 1	**TSL 2**	**TSL 3**	**TSL 4**	**TSL 5**
Standard-Size Refrigerator-Freezers					
CO_2 (Mt)	154	177	208	283	338
NO_X (1000 tons)	124	142	168	228	272
Hg (tons)	0.79	0.91	1.07	1.45	1.73
Standard-Size Freezers					
CO_2 (Mt)	48	69	81	92	99
NO_X (1000 tons)	39	55	65	74	79
Hg (tons)	0.245	0.351	0.413	0.469	0.501
Compact Refrigeration Products					
CO_2 (Mt)	20	24	28	35	39
NO_X (1000 tons)	16	19	23	28	31
Hg (tons)	0.10	0.12	0.15	0.19	0.21
Built-In Refrigeration Products					
CO_2 (Mt)	1.23	1.79	3.58	4.45	5.32
NO_X (1000 tons)	0.99	1.44	2.88	3.58	4.28
Hg (tons)	0.006	0.009	0.018	0.023	0.027

* Values for CO_2 are in metric tons; values for NO_X and Hg are in short tons.

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CHAPTER 16. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

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CHAPTER 16. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

16.1 INTRODUCTION

As part of its assessment of energy conservation standards, DOE considered the estimated monetary benefits likely to result from the reduced emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_X) that are expected to result from each of the TSLs considered in this rulemaking. In order to make this calculation similar to the calculation of the NPV of consumer benefit, DOE considered the reduced emissions expected to result over the lifetime of products shipped in the forecast period. This chapter summarizes the basis for the monetary values used for each of these emissions and presents the benefits estimates considered.

16.2 MONETIZING CARBON DIOXIDE EMISSIONS

16.2.1 Social Cost of Carbon

Under section 1(b) of Executive Order 12866, "Regulatory Planning and Review," 58 FR 51735 (Oct. 4, 1993), agencies must, to the extent permitted by law, "assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs."

The purpose of the social cost of carbon (SCC) estimates presented here is to allow Federal agencies to incorporate the monetized social benefits of reducing CO_2 emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

As part of the interagency process that developed these SCC estimates, technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The social cost of carbon is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. Estimates of the SCC are provided in dollars per metric ton of carbon dioxide.

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Research Council[a] points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Consistent with the directive quoted above, the purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the agency can estimate the benefits from reduced (or costs from increased) emissions in any future year by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions. DOE does not attempt to answer that question here.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, the interagency group has set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, the interagency group will continue to explore the issues raised by this analysis and consider public comments as part of the ongoing interagency process.

16.2.2 Social Cost of Carbon Values Used in Past Regulatory Analyses

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a "domestic" SCC value of \$2 per ton of CO_2 and a "global" SCC value of \$33 per ton of CO2 for 2007 emission reductions

[a] National Research Council. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. National Academies Press: Washington, DC. 2009.

(in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at $80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of $7 per ton of CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of $0-$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of $0 to $20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA's 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as "very preliminary" SCC estimates subject to revision. EPA's global mean values were $68 and $40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted. The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

16.2.3 Current Approach and Key Assumptions

Since the release of the interim values, the interagency group reconvened on a regular basis to generate improved SCC estimates, which were considered for this proposed rule. Specifically, the group considered public comments and further explored the technical literature in relevant fields. The interagency group relied on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[b] These models are frequently cited in the peer-reviewed literature and were used in the last assessment of the Intergovernmental Panel on Climate Change. Each model was given equal weight in the SCC values that were developed.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature

[b] The models are described in appendix 16-A of the TSD.

was conducted to select three sets of input parameters for these models: (1) climate sensitivity; (2) socio-economic and emissions trajectories; and (3) discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For emissions (or emission reductions) that occur in later years, these values grow in real terms over time, as depicted in Table 16-1. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects,[c] although preference is given to consideration of the global benefits of reducing CO_2 emissions.

Table 16.2.1 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton)

	Discount Rate			
	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Research Council report mentioned above points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. There are a number of concerns and problems that should be addressed by the

[c] It is recognized that this calculation for domestic values is approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time.

research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government intends to periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

In summary, in considering the potential global benefits resulting from reduced CO_2 emissions, DOE used the most recent SCC values identified by the interagency process, adjusted to 2009$ using the GDP price deflator values for 2008 and 2009. For each of the four cases specified, the values used for emissions in 2010 were $4.9, $22.1, $36.3, and $67.1 per metric ton avoided (values expressed in 2009$). To monetize the CO_2 emissions reductions expected to result from amended standards for refrigeration products, DOE used the values identified in Table A1 of the "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," which is reprinted in appendix 16-A of this TSD, appropriately escalated to 2009$.[d] To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the specific discount rate that had been used to obtain the SCC values in each case.

16.3 VALUATION OF OTHER EMISSIONS REDUCTIONS

DOE considered the potential monetary benefit of reduced NO_X emissions from the TSLs it considered. As noted in chapter 15, new or amended energy conservation standards would reduce NO_X emissions in those 22 States that are not affected by the CAIR, in addition to the reduction in site NO_X emissions nationwide. DOE estimated the monetized value of NO_X emissions reductions resulting from each of the TSLs considered based on environmental damage estimates from the literature. Available estimates suggest a very wide range of monetary values, ranging from $370 per ton to $3,800 per ton of NO_X from stationary sources, measured in 2001$ (equivalent to a range of $447 to $4,591 per ton in 2009$).[e] In accordance with OMB guidance, DOE conducted two calculations of the monetary benefits using each of the above values used for NO_X, one using a real discount rate of 3 percent and another using a real discount rate of 7 percent.[f]

DOE is aware of multiple agency efforts to determine the appropriate range of values used in evaluating the potential economic benefits of reduced Hg emissions. DOE has decided to await further guidance regarding consistent valuation and reporting of Hg emissions before it once again monetizes Hg in its rulemakings.

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[d] Table A1 presents SCC values through 2050. For DOE's calculation, it derived values after 2050 using the 3-percent per year escalation rate used by the interagency group.

[e] For additional information, refer to U.S. Office of Management and Budget, Office of Information and Regulatory Affairs, ''2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities,'' Washington, DC.

[f] OMB, Circular A-4: Regulatory Analysis (Sept. 17, 2003).

16.4 RESULTS

Table 16-2 through Table 16-5 presents the global values of CO_2 emissions reductions by TSL for each refrigeration product group. DOE calculated domestic values as a range from 7 percent to 23 percent of the global values, and these results are presented in Table 16-6 through Table 16-9.

Table 16.4.1 Standard-Size Refrigerator-Freezers: Estimates of Global Present Value of CO_2 Emissions Reduction Under Trial Standard Levels

	billion 2009$			
TSL	**5% discount rate, average***	**3% discount rate, average***	**2.5% discount rate, average***	**3% discount rate, 95th percentile***
1	1.45	4.60	6.90	14.0
2	1.67	5.31	7.96	16.16
3	1.96	6.24	9.36	19.00
4	2.68	8.51	12.76	25.90
5	3.20	10.18	15.26	30.98

* Columns are labeled by the discount rate used to calculate the SCC and whether it is an average value or drawn from a different part of the distribution.

Table 16.4.2 Standard-Size Freezers: Estimates of Global Present Value of CO_2 Emissions Reduction Under Trial Standard Levels

	billion 2009$			
TSL	**5% discount rate, average***	**3% discount rate, average***	**2.5% discount rate, average***	**3% discount rate, 95th percentile***
1	0.48	1.51	2.25	4.58
2	0.69	2.16	3.24	6.59
3	0.81	2.55	3.81	7.76
4	0.92	2.89	4.32	8.80
5	0.98	3.09	4.62	9.41

* Columns are labeled by the discount rate used to calculate the SCC and whether it is an average value or drawn from a different part of the distribution.

Table 16.4.3 Compact Refrigeration Products: Estimates of Global Present Value of CO_2 Emissions Reduction Under Trial Standard Levels

	billion 2009$			
TSL	5% discount rate, average*	3% discount rate, average*	2.5% discount rate, average*	3% discount rate, 95th percentile*
1	0.12	0.41	0.63	1.26
2	0.15	0.51	0.77	1.54
3	0.18	0.59	0.89	1.79
4	0.22	0.74	1.12	2.25
5	0.24	0.81	1.23	2.47

* Columns are labeled by the discount rate used to calculate the SCC and whether it is an average value or drawn from a different part of the distribution.

Table 16.4.4 Built-In Refrigeration Products: Estimates of Global Present Value of CO_2 Emissions Reduction Under Trial Standard Levels

	billion 2009$			
TSL	5% discount rate, average*	3% discount rate, average*	2.5% discount rate, average*	3% discount rate, 95th percentile*
1	0.012	0.038	0.057	0.12
2	0.017	0.055	0.083	0.17
3	0.035	0.11	0.17	0.34
4	0.043	0.014	0.20	0.41
5	0.051	0.16	0.24	0.50

* Columns are labeled by the discount rate used to calculate the SCC and whether it is an average value or drawn from a different part of the distribution.

Table 16.4.5 Standard-Size Refrigerator-Freezers: Estimates of Domestic Present Value of CO_2 Emissions Reduction Under Trial Standard Levels

	billion 2009$*			
TSL	5% discount rate, average**	3% discount rate, average**	2.5% discount rate, average**	3% discount rate, 95th percentile**
1	0.10 to 0.33	0.32 to 1.06	0.48 to 1.59	0.98 to 3.22
2	0.12 to 0.38	0.37 to 1.22	0.56 to 1.83	1.13 to 3.72
3	0.14 to 0.45	0.44 to 1.44	0.66 to 2.15	1.33 to 4.37
4	0.19 to 0.62	0.60 to 1.96	0.89 to 2.93	1.81 to 5.96
5	0.22 to 0.74	0.71 to 2.34	1.07 to 3.51	2.17 to 7.13

* Domestic values are presented as a range between 7% and 23% of the global values.
** Columns are labeled by the discount rate used to calculate the SCC and whether it is an average value or drawn from a different part of the distribution.

Table 16.4.6 Standard-Size Freezers: Estimates of Domestic Present Value of CO_2 Emissions Reduction Under Trial Standard Levels

TSL	billion 2009$*			
	5% discount rate, average**	**3% discount rate, average****	**2.5% discount rate, average****	**3% discount rate, 95th percentile****
1	0.033 to 0.11	0.11 to 0.35	0.16 to 0.52	0.32 to 1.05
2	0.048 to 0.16	0.15 to 0.50	0.23 to 0.74	0.46 to 1.51
3	0.057 to 0.19	0.057 to 0.19	0.057 to 0.19	0.057 to 0.19
4	0.064 to 0.21	0.20 to 0.67	0.30 to 0.99	0.62 to 2.02
5	0.069 to 0.23	0.22 to 0.71	0.32 to 1.06	0.069 to 0.23

* Domestic values are presented as a range between 7% and 23% of the global values.
** Columns are labeled by the discount rate used to calculate the SCC and whether it is an average value or drawn from a different part of the distribution. Values presented in the table incorporate the escalation of the SCC over time.

Table 16.4.7 Compact Refrigeration Products: Estimates of Domestic Present Value of CO_2 Emissions Reduction Under Trial Standard Levels

TSL	billion 2009$*			
	5% discount rate, average**	**3% discount rate, average****	**2.5% discount rate, average****	**3% discount rate, 95th percentile****
1	0.0087 to 0.029	0.029 to 0.095	0.044 to 0.14	0.09 to 0.29
2	0.011 to 0.035	0.035 to 0.12	0.054 to 0.18	0.11 to 0.36
3	0.012 to 0.041	0.041 to 0.14	0.062 to 0.21	0.13 to 0.41
4	0.016 to 0.051	0.052 to 0.17	0.078 to 0.26	0.16 to 0.52
5	0.017 to 0.056	0.057 to 0.19	0.086 to 0.28	0.17 to 0.57

* Domestic values are presented as a range between 7% and 23% of the global values.
** Columns are labeled by the discount rate used to calculate the SCC and whether it is an average value or drawn from a different part of the distribution.

Table 16.4.8 Built-In Refrigeration Products: Estimates of Domestic Present Value of CO_2 Emissions Reduction Under Trial Standard Levels

TSL	billion 2009$*			
	5% discount rate, average**	**3% discount rate, average****	**2.5% discount rate, average****	**3% discount rate, 95th percentile****
1	0.00083 to 0.0027	0.0026 to 0.0087	0.0040 to 0.013	0.0081 to 0.026
2	0.0012 to 0.0040	0.0039 to 0.013	0.0058 to 0.019	0.012 to 0.039
3	0.0024 to 0.0080	0.0077 to 0.025	0.012 to 0.038	0.023 to 0.077
4	0.0030 to 0.010	0.010 to 0.031	0.014 to 0.047	0.029 to 0.10
5	0.0036 to 0.012	0.011 to 0.037	0.017 to 0.056	0.035 to 0.11

* Domestic values are presented as a range between 7% and 23% of the global values.
** Columns are labeled by the discount rate used to calculate the SCC and whether it is an average value or drawn from a different part of the distribution.

Table 16-10 presents the cumulative monetary value of the economic benefits associated with NO_X emissions reductions for each TSL, calculated using seven-percent and three-percent discount rates.

Table 16.4.9 Estimates of Present Value of NO_X Emissions Reduction Under Refrigeration Product Trial Standard Levels

	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	billion 2009$				
Standard-Size Refrigerator-Freezers					
7% discount rate	0.018 to 0.18	0.020 to 0.21	0.024 to 0.25	0.033 to 0.34	0.039 to 0.40
3% discount rate	0.044 to 0.45	0.051 to 0.52	0.060 to 0.62	0.082 to 0.84	0.097 to 1.00
Standard-Size Freezers					
7% discount rate	0.0055 to 0.056	0.008 to 0.081	0.009 to 0.095	0.011 to 0.107	0.011 to 0.12
3% discount rate	0.014 to 0.15	0.020 to 0.21	0.024 to 0.25	0.027 to 0.28	0.029 to 0.30
Compact Refrigeration Products					
7% discount rate	0.002 to 0.021	0.003 to 0.026	0.003 to 0.030	0.004 to 0.038	0.004 to 0.042
3% discount rate	0.004 to 0.044	0.005 to 0.054	0.006 to 0.063	0.008 to 0.079	0.009 to 0.088
Built-In Refrigeration Products					
7% discount rate	0.000 to 0.002	0.001 to 0.002	0.000 to 0.004	0.001 to 0.005	0.001 to 0.006
3% discount rate	0.000 to 0.004	0.001 to 0.005	0.001 to 0.018	0.001 to 0.013	0.002 to 0.016

CHAPTER 17. REGULATORY IMPACT ANALYSIS

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

17.1 INTRODUCTION

The U.S. Department of Energy (DOE) has determined that energy conservation standards for residential refrigerators, refrigerator-freezers, and freezers constitute an "economically significant regulatory action" under Executive Order (E.O.) 12866, Regulatory Planning and Review. 58 FR 51735, Volume 58, No. 190, page 51735. (October 4, 1993). Under 10 CFR part 430, subpart C, appendix A, section III.12, DOE committed to evaluating non-regulatory alternatives to proposed standards by performing a regulatory impact analysis (RIA). 61 FR 36981, Volume 61, No. 136, page 36978. (July 15, 1996). This RIA, which DOE has prepared pursuant to E.O. 12866, evaluates potential non-regulatory alternatives, comparing the costs and benefits of each to those of the proposed standards. 58 FR 51735, page 51741. As noted in E.O. 12866, this RIA is subject to review by the Office of Management and Budget's Office of Information and Regulatory Affairs. 58 FR 51735, page 51740.

For this Regulatory Impact Analysis, DOE used integrated NIA-RIA integrated models built on the NIA models discussed in chapter 10 for its analysis. DOE studied the impacts of the non-regulatory policies on the 11 representative product classes analyzed for the NOPR and for the final rule. It then applied the assumptions of the impacts of each policy on these representative product classes to the shipments of the remaining product classes associated with each representative class. Thus, the savings reported in this chapter represent the savings for all the considered product classes.

DOE identified six non-regulatory policy alternatives that feasibly could provide incentives for the same energy efficiency levels as the proposed standards for the products that are the subject of this rulemaking. The non-regulatory policy alternatives are listed in Table 17.1.1. DOE evaluated each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and compared the effectiveness of each to the effectiveness of the proposed standard.

Table 17.1.1 Non-Regulatory Alternatives to National Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Manufacturer Tax Credits
Voluntary Energy Efficiency Targets
Early Replacement
Bulk Government Purchases

In addition to the above six non-regulatory policy alternatives, specifically for this rulemaking DOE evaluated a super-efficient voluntary targets (SEVT) program. Sections 17.2 and 17.3 discuss the analysis of the six policies listed above. Sections 17.4 and 17.5 present the results of the six policy alternatives, and section 17.6 describes the analysis of the SEVT policy and presents the results.

17.2 NON-REGULATORY POLICIES

This section describes the method DOE used to analyze the energy savings and cost effectiveness of the six non-regulatory policy alternatives (excluding the alternative of no new regulatory action) for the identified residential refrigerators, refrigerator-freezers, and freezers. This section also describes the assumptions underlying the analysis.

17.2.1 Methodology

DOE used its integrated national impact analysis–regulatory impact analysis (NIA-RIA) spreadsheet models to calculate the national energy savings (NES) and net present value (NPV) associated with each non-regulatory policy alternative. Chapter 10 of the technical support document (TSD) describes the NIA spreadsheet models. Appendix 17-A, section 17-A.2, discusses the new NIA-RIA integrated model approach.

DOE quantified the effect of each alternative on the purchase of products that meet *target levels*, which are defined as the efficiency levels in the proposed standards. After establishing the quantitative assumptions underlying each alternative, DOE appropriately revised inputs to the NIA-RIA spreadsheet models. The primary model inputs revised were market shares of products meeting target efficiency levels and equipment replacement rates. The shipments of products for any given year reflect a distribution of efficiency levels. DOE assumed that the proposed standards would affect 100 percent of the shipments of products that did not meet target levels in the base case,[a] whereas the non-regulatory policies would affect a smaller percentage of those shipments. DOE made certain assumptions about the percentage of shipments affected by each alternative policy. DOE used those percentages to calculate the shipment-weighted average energy consumption and costs of residential refrigerators, refrigerator-freezers, and freezers attributable to each policy alternative.

Increasing the efficiency of a product often increases its average installed cost. On the other hand, operating costs generally decrease because energy consumption declines. DOE therefore calculated an NPV for each non-regulatory alternative in the same way it did for the proposed standards. In some scenarios, increases in total installed cost are mitigated by government rebates or tax credits. Because DOE assumed that consumers would re-pay credits and rebates in some way (such as additional taxes), DOE did not include rebates or tax credits as a consumer benefit when calculating national NPV. DOE's analysis also excluded any administrative costs for the non-regulatory policies; including such costs would decrease the NPVs slightly.

The following are key measures for evaluating the impact of each alternative.

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[a] The base case for the NIA is a market-weighted average of units at several efficiency levels.

- National energy savings, given in quadrillion Btus (quads), describes the cumulative national primary energy savings for products bought during the period from the effective date of the policy (2014) through the end of the analysis period (2043).

- Net present value represents the value in 2009$ (discounted to 2010) of net monetary savings from products bought during the period from the effective date of the policy (2014) through the end of the analysis period (2043).

- DOE calculated the NPV as the difference between the present value of installed equipment cost and operating expenditures in the base case and the present value of those costs in each policy case. DOE calculated operating expenses (including energy costs) for the life of the product.

17.2.2 Assumptions Regarding Non-Regulatory Policies

The effects of non-regulatory policies are by nature uncertain, because they depend on program implementation and marketing efforts and on consumers' responses to a program. Because the projected effects depend on assumptions regarding the rate of consumer participation, they are subject to more uncertainty than are the impacts of mandatory standards, which DOE assumes will meet with full compliance. To increase the robustness of the analysis, DOE conducted a literature review regarding each non-regulatory policy and consulted with recognized experts to gather information on similar incentive programs that have been implemented in the United States. By studying experiences with the various types of programs, DOE sought to make credible assumptions regarding potential market impacts. Section 17.3 presents the sources DOE relied on in developing assumptions about each alternative policy and reports DOE's conclusions as they affected the assumptions that underlie the modeling of each policy.

Each non-regulatory policy that DOE considered would improve the average efficiency of new residential refrigerators, refrigerator-freezers, and freezers relative to their base case efficiency scenarios (which involve no new regulatory action). The analysis considered that each alternative policy would induce consumers to purchase units having the same efficiency levels as required by the proposed standards (the target levels). As opposed to the standards case, however, the policy cases may not lead to 100 percent market penetration of units that meet target levels.

Tables 17.2.1 through 17.2.4 show the efficiency levels stipulated in the proposed standards for the products in this rulemaking.

Table 17.2.1 Efficiency Levels in Proposed Standard Levels for Standard-Size Refrigerator-Freezers

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	**Product classes 5, 5A, and 5I**	**Product classes 4, 4I, and 7**
	Efficiency Level (% less than baseline energy use)		
3	4 (25)*	3 (20)	4 (25)

* Level for product classes 1, 1A, and 2 is 20%.

Table 17.2.2 Efficiency Levels in Proposed Standard Levels for Standard-Size Freezers

Trial Standard Level	Upright Freezers		Chest Freezers
	Product classes 9 and 9I	**Product class 8**	**Product classes 10 and 10A**
	Efficiency Level (% less than baseline energy use)		
2	5 (30)	4 (25)	4 (25)*

* Level for product class 10A is 30%.

Table 17.2.3 Efficiency Levels in Proposed Standard Levels for Compact Refrigeration Products

Trial Standard Level	Compact Refrigerators and Refrigerator-Freezers		Compact Freezers
	Product classes 11, 11A and 12	**Product classes 13, 13I, 13A, 14, 14I, 15 and 15I**	**Product classes 16, 17, 18**
	Efficiency Level (% less than baseline energy use)		
2	4 (25)	2 (15)*	1 (10)

* Level for product class 13A is 25%, and for product classes 14 and 14I, 20%.

Table 17.2.4 Efficiency Levels in Proposed Standard Levels for Built-In Refrigeration Products

Trial Standard Level	Built-in All-Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
	Efficiency Level (% less than baseline energy use)			
3	3 (20)	2 (15)	3 (20)	4 (25)

In addition to the above policy alternatives, DOE evaluated a policy where a new, two-tiered voluntary efficiency targets program was implemented *in addition* to the proposed standards. These voluntary efficiency targets would feature speculative "super-efficient" products at efficiency levels above the current max-tech levels. The program would target consumers in the highest electricity price regions of the country, to make the products maximally cost-effective. For the purpose of evaluating the program, only standard-sized refrigerator-freezers were considered.

DOE assumed that the effects of non-regulatory policies would last from the effective date of standards—2014—through the end of the analysis period, which is 2043.

17.2.3 Policy Interactions

DOE calculated the effects of each non-regulatory policy separately from those of the other policies. In practice, some policies are most effective when implemented in combination, such as early replacement implemented with consumer rebates, or early replacement implemented with bulk government purchases. However, DOE attempted to make conservative assumptions to avoid double-counting policy impacts. The resulting policy impacts are not additive: the combined effect of several or all policies cannot be inferred from summing their results.

Section 17.4 presents graphs that show the market penetration estimated under each non-regulatory policy for residential refrigerators, refrigerator-freezers, and freezers.

17.3 NON-REGULATORY POLICY ASSUMPTIONS

The following subsections describe DOE's analysis of the impacts of the six non-regulatory policy alternatives to proposed standards for refrigerators, refrigerator-freezers, and freezers. (Because the alternative of No New Regulatory Action has no energy or NPV impacts, essentially representing the NIA base case, DOE did not perform additional analysis for that alternative.) DOE developed estimates of the market penetration of high-efficiency products both with and without each of the non-regulatory policy alternatives.

17.3.1 No New Regulatory Action

The case in which no new regulatory action is taken with regard to the energy efficiency of residential refrigeration products constitutes the base case, as described in chapter 10, National Impact Analysis. The base case provides the basis of comparison for all other policies. By definition, no new regulatory action yields zero energy savings and an NPV of zero dollars.

17.3.2 Consumer Rebates

DOE considered this scenario in which the Federal government would provide financial incentives in the form of rebates to consumers for purchasing energy efficient appliances. This policy provides a consumer rebate for purchasing refrigeration products that operate at (or above) the same efficiencies as stipulated in proposed standards (target levels).

To inform its estimate of the market impacts of consumer rebates, DOE performed a thorough search for existing rebate programs nationwide. It gathered data on hundreds of utility or agency rebates for refrigeration products throughout the country. DOE also reviewed the current State Energy Efficient Appliance Rebate Program (SEEARP) funded by the American Recovery and Reinvestment Act (ARRA).[1] , [b] This program may be considered a combination of a consumer rebate and an early replacement program, with intention to induce appliance sales during the economic recession. DOE analyzed summary material from DOE on SEEARP rebates for refrigerators and freezers.[2]

DOE based its evaluation methodology for consumer rebates on a comprehensive study of California's potential for achieving energy efficiency. This study, performed by XENERGY, Inc.,[c] summarized experiences with various utility rebate programs.[3] XENERGY's analytical method utilized graphs, or penetration curves, that estimate the market penetration of a technology based on its benefit/cost (B/C) ratio. DOE consulted with experts and reviewed other methods of estimating the effect of consumer rebate programs on the market penetration of efficient technologies. The other methods, developed after the referenced XENERGY report was published,[4], [5], [6], [7], [8], [9] used different approaches: other economic parameters (e.g., payback period), expert surveys, or model calibration based on specific utility program data rather than multi-utility data. Some models in use by energy efficiency program evaluation experts were so client-specific that generic relationships between economic parameters and consumer response could not be established.[4] DOE decided that the most appropriate available method for this RIA

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[b] DOE provided funding for State-run rebate programs for consumer purchases of new ENERGY STAR® qualified home appliances. The resulting SEEARP was implemented beginning in late 2009 by the 50 States and six U.S. territories, each selecting its own appliances, rebate levels, efficiency levels, appliance recycling requirements, and eligible populations.

[c] XENERGY is now owned by KEMA, Inc. (www.kema.com)

analysis was the XENERGY approach of penetration curves based on B/C ratio, which incorporates lifetime operating cost savings.

XENERGY's model estimates market impacts induced by financial incentives based on the premise that two types of information diffusion drive the adoption of new technologies. *Internal sources* of information encourage consumers to purchase new products primarily through word-of-mouth from early adopters. *External sources* affect consumer purchase decisions through marketing efforts and information from outside the consumer group. Appendix 17-A, section 17-A.3.1, contains additional details on internal and external information diffusion.

XENERGY's model equation accounts for the influences of both internal and external sources of information by superimposing the two components. Combining the two mechanisms for information diffusion, XENERGY's model generates a set of penetration (or implementation) curves for a measure. XENERGY then calibrated the curves based on participation data from utility rebate programs. The curves illustrate the increased penetration (i.e., increased market share) of efficient products driven by consumer response to changes in B/C ratio induced by rebate programs. The penetration curves depict various diffusion patterns based on perceived barriers (from no barriers to extremely high barriers) to consumer purchase of high-efficiency products.

DOE adjusted the XENERGY penetration curves based on expert advice founded on more recent utility program experience.[7], [10] DOE also devised an interpolation method to create penetration curves based on relationships between the actual base case market penetrations and actual B/C ratios for each representative product class. Appendix 17-A, sections 17-A.3.2 and 17-A.3.3, contain discussion on DOE's methodology for adjusting and interpolating the curves.

DOE modeled the effects of a consumer rebate policy for refrigerators, refrigerator-freezers, and freezers by determining the increase in market penetration of products meeting the target level relative to their market penetration in the base case. It did this using the interpolated penetration curves created for each representative product class based on the XENERGY methodology to best reflect the market barrier levels faced by each product class. The next section (on standard-size refrigerator-freezers) shows examples of these interpolated curves. Appendix 17-A, section 17-A.3.4, displays the curves developed for the remaining product groups.[d]

17.3.2.1 Standard-Size Refrigerator-Freezers

For standard-size refrigerator-freezers, DOE estimated the effect of increasing the B/C ratio via a rebate that would pay part or all of the increased installed cost of a unit that met the

[d] The four product groups are Standard-Size Refrigerator-Freezers, Standard-Size Freezers, Compact Refrigeration Products, and Built-in Refrigeration Products.

target efficiency level compared to one meeting the baseline efficiency level.[e] DOE based the rebate amounts on a large sample of utility and agency rebate programs for refrigerator-freezers.

For standard-size refrigerator-freezers, DOE gathered data on 129 rebate programs initiated by 115 utilities or agencies in States throughout the country. (Appendix 17-A, section 17-A.5.1, identifies the rebate programs.) To represent the rebate level for standard-size refrigerator-freezers, DOE used the simple average of the rebate amounts in these 129 programs. DOE assumed that this average would apply to models at all efficiency levels at or above the target level for each representative product class. For each of these efficiency levels, the rebate amount represented a certain percent of the increase in total installed cost.

Since nearly all the utility/agency rebate programs had an efficiency requirement at the ENERGY STAR level, while the proposed standard levels for standard-size refrigerators were set at a higher efficiency level, DOE sought data on rebates requiring levels higher than ENERGY STAR to determine whether to adjust this average rebate level amount. The sample size of utility/agency rebates above the ENERGY STAR level was very small. From the set of SEEARP rebates for States whose programs included refrigerators, DOE compared the average rebate amounts for units meeting ENERGY STAR levels to the average rebate amounts for units meeting CEE Tier 2 and CEE Tier 3 levels. It found that the national average rebate amounts for ENERGY STAR refrigerators were actually higher than those for rebates at either of the CEE levels (both of which comprised a much smaller sample than the set of SEEARP rebates for the ENERGY STAR level). Based on this anomalous result, DOE did not perform an adjustment to the utility/agency rebate amount reported above, but rather assumed that the average rebate amount would not vary significantly by efficiency level.

DOE assumed that rebates would remain in effect at the same levels throughout the forecast period (2014–2043).

For standard-size refrigerator-freezers, DOE first calculated B/C ratios without a rebate using the difference in total installed costs and lifetime operating cost savings between the unit meeting the target level and the baseline unit. It then calculated B/C ratios given a rebate for the unit meeting the target efficiency level. Because the rebate reduced the incremental cost, the unit receiving the rebate had a larger B/C ratio. Table 17.3.1 shows the effects of consumer rebates on B/C ratios for standard-size refrigerator-freezers. Each B/C ratio value for units with rebates represents a weighted average[f] of the values for the efficiency levels at or above the target level to which the rebate would apply.

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[e] The baseline technology for each product class is defined in the engineering analysis, chapter 5, as the technology that represents the basic characteristics of products in that class. A baseline unit typically is one that just meets current Federal energy conservation standards and provides basic consumer utility.

[f] The weighting factor is the 2014 base case market share of each of the corresponding efficiency levels.

Table 17.3.1 Benefit/Cost Ratios Without and With Rebates for Standard-Size Refrigerator-Freezers (2009$)

	Top-Mount Refrigerator Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
B/C Ratio Without Rebate	4.3	10.3	11.3
Rebate Amount	$52	$52	$52
B/C Ratio With Rebate	11.3	Inf.	Inf.
Calculated Market Barrier Curve	Moderate – High	No – Low	Moderate - High

Inf. = infinite B/C ratio, which occurs when the rebate pays the full incremental cost.

DOE used the B/C ratios along with the penetration curves shown in Figures 17.3.1 through 17.3.3 to estimate the percentage of consumers who would purchase standard-size refrigerator-freezers that meet the target levels both with and without a rebate incentive.

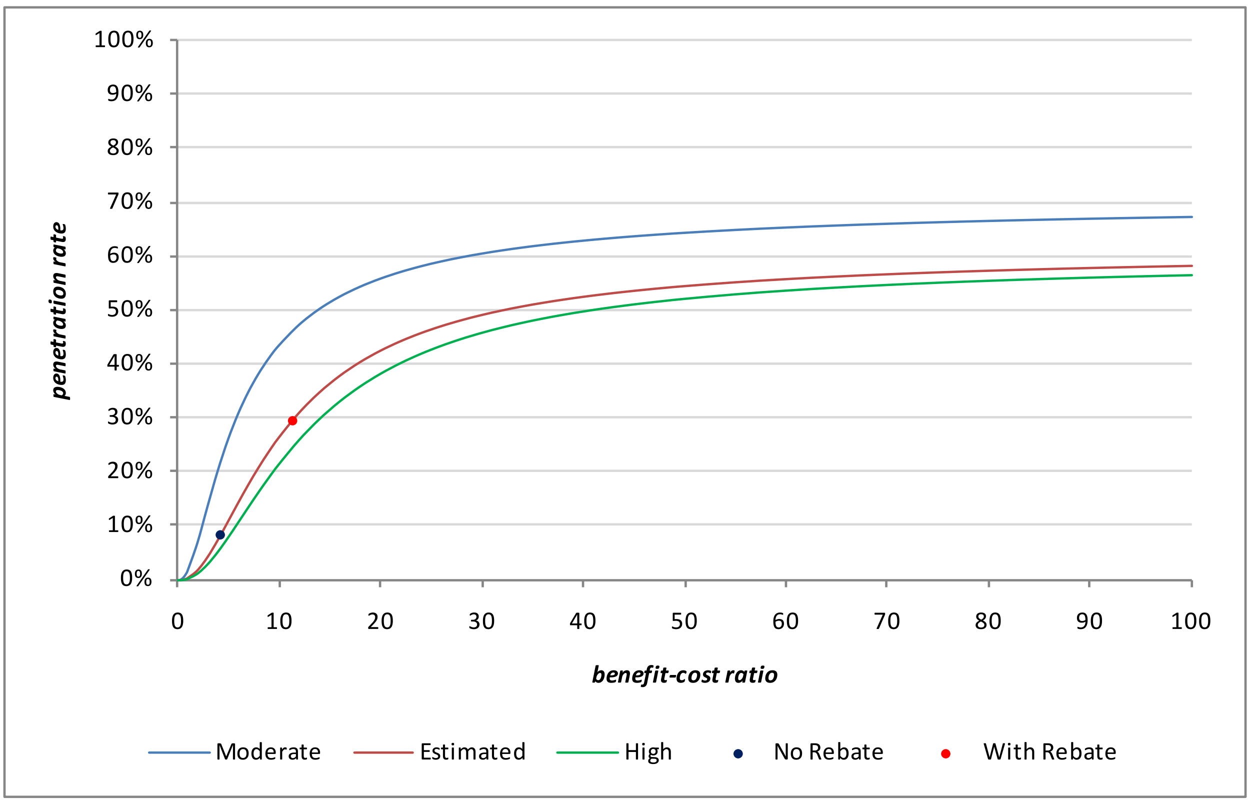

Figure 17.3.1 Market Penetration Curve for Top-Mount Refrigerator-Freezers

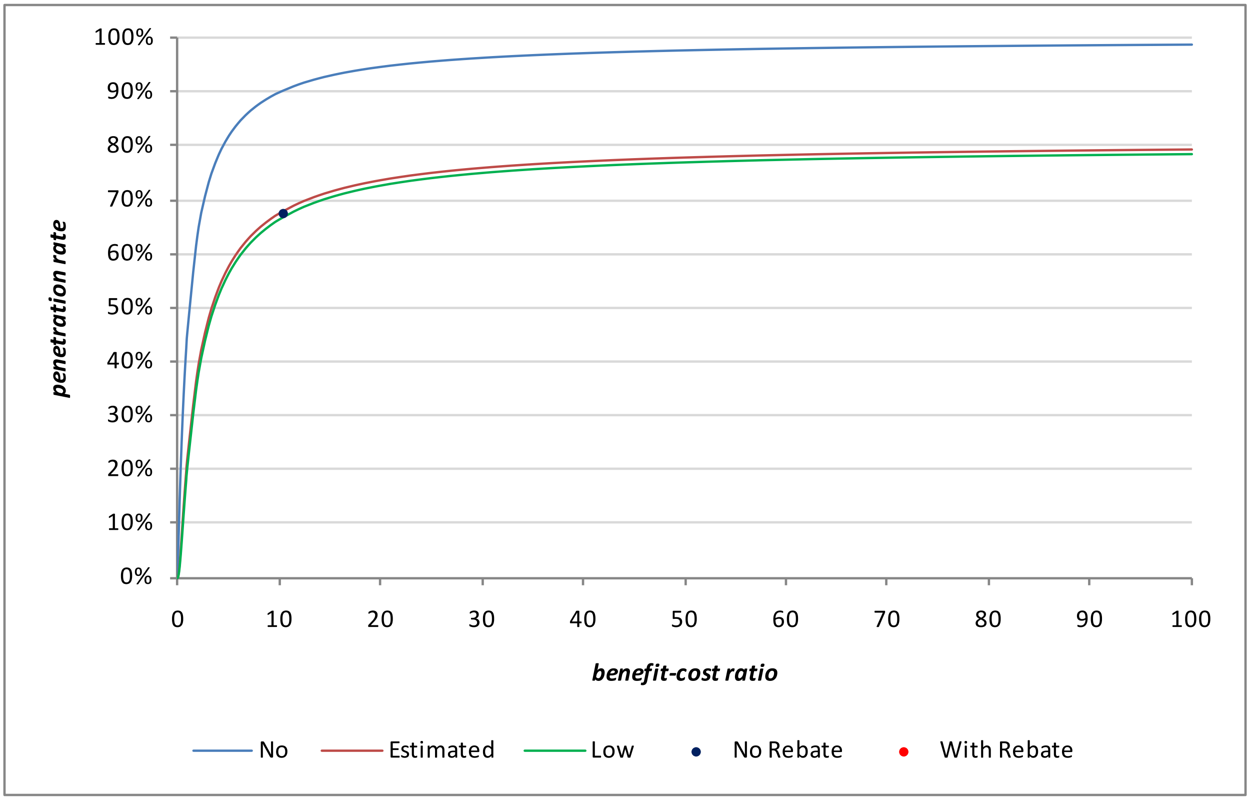

Figure 17.3.2 Market Penetration Curve for Bottom-Mount Refrigerator-Freezers

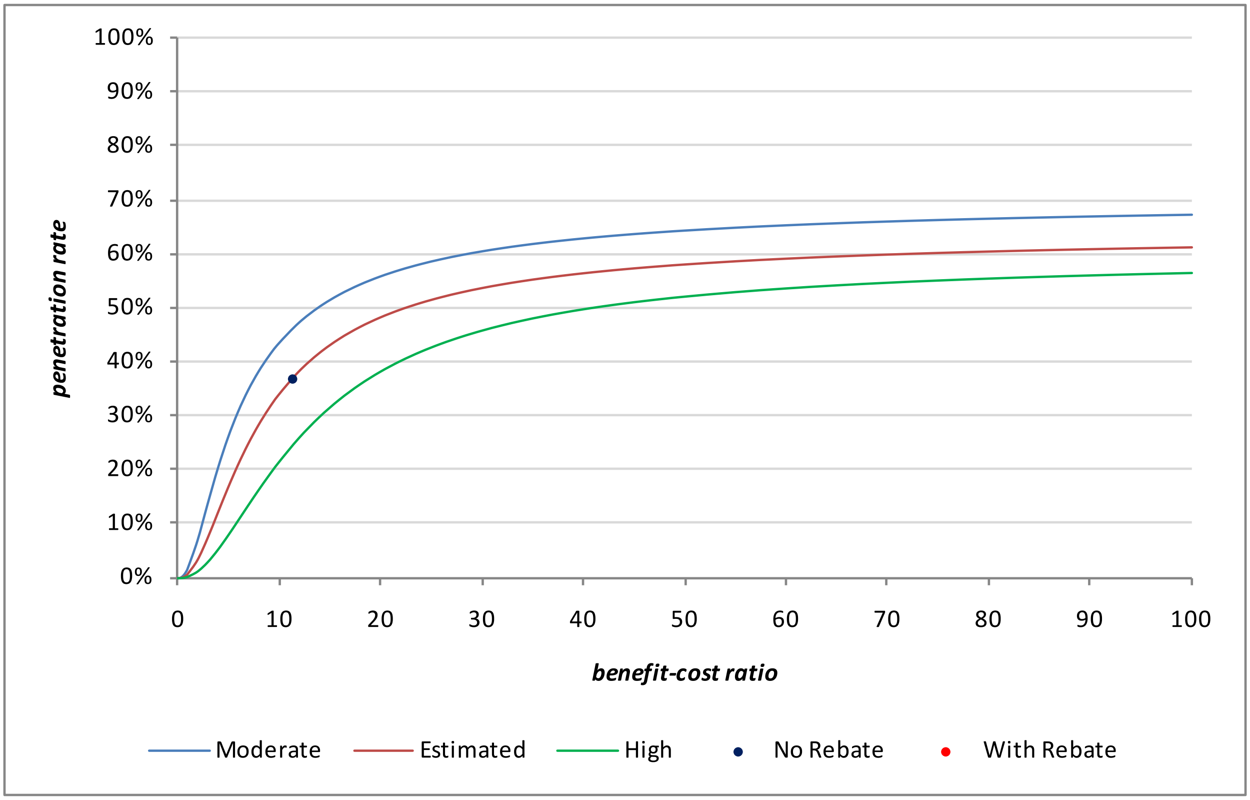

Figure 17.3.3 Market Penetration Curve for Side-by-Side Refrigerator-Freezers

The curve calculated by DOE to represent the market behavior for top-mount refrigerator-freezers was in between the *moderate barriers* and *high barriers* penetration curves. For bottom-mount refrigerator-freezers the curve was between the *no barriers* and *low barriers* penetration curves. For side-by-side refrigerator-freezers the curve was between the *moderate* and *high barriers* penetration curves.

For each product class, DOE next estimated the percent increase represented by the change in penetration rate shown on the penetration curve. It then added that percent increase to the market share of units that meet the target level in the base case to obtain the market share of units that meet the target level in the rebate case. Table 17.3.2 summarizes the market shares of standard-size refrigerator-freezers in 2014.

Table 17.3.2 Market Penetrations in 2014 Without and With Rebates for Standard-Size Refrigerator-Freezers

	Top-Mount Refrigerator-Freezers %	Bottom-Mount Refrigerator-Freezers %	Side-by-Side Refrigerator-Freezers %
Base-Case Market Share of Units that Meet Target Levels	0	68	0
Market Share of Units that Meet Target Levels With Rebates	21	81	27
Increased Market Share of Units that Meet Target Level With Rebates	21	13	27

Appendix 17-A, Table 17-A.4.1, shows the annual increases in market shares for standard-size refrigerator-freezers meeting target efficiency levels under a rebate policy. DOE used these increases in market shares as inputs to represent the policy case scenarios in its NIA-RIA model. Section 17.4 presents the resulting efficiency trends for the policy case of consumer rebates for refrigerator-freezers.

17.3.2.2 Standard-Size Freezers

For standard-size freezers, DOE estimated the effect of increasing the B/C ratio via a rebate that would pay part or all of the increased installed cost of a unit that met the target efficiency level compared to the cost of a unit meeting the baseline level. DOE based the rebate amounts on a large sample of utility and agency rebate programs for standard-size freezers.

DOE gathered data on 62 rebate programs provided by 59 utilities or agencies in various States. (Appendix 17-A, section 17-A.5.2, identifies the rebate programs.) To represent the rebate level for standard-size freezers, DOE used the simple average of the rebate amounts in these 62 programs. DOE assumed that this average amount would apply to models at all efficiency levels at or above the target level for each representative product class. For each of these efficiency levels, the rebate amount represented a certain percent of the increase in total installed cost. Since all of the utility/agency rebates were for freezers at the ENERGY STAR level, while the proposed standard levels for standard-size freezers were set at a higher efficiency level, DOE again sought data on rebates requiring levels higher than ENERGY STAR to determine whether to adjust this average rebate level amount. However, all of the SEEARP freezer rebates were also for the ENERGY STAR efficiency level. Hence DOE did not have any data with which to adjust the rebate amount, but rather assumed that the average rebate amount would not vary significantly by efficiency level.

DOE assumed that rebates would remain in effect until the market had been transformed; that is, the shift in market share of efficient units seen in the first year of the rebate program would be maintained throughout the forecast period (2014–2043).

For standard-size freezers, DOE first calculated B/C ratios without a rebate using the difference in lifetime operating costs and total installed costs between the unit meeting the target level and the baseline unit. It then calculated B/C ratios given a rebate for the unit meeting the target efficiency. Because the rebate reduced the incremental cost, the unit receiving the rebate had a larger B/C ratio. Table 17.3.3 shows the effects of consumer rebates on B/C ratios for standard-size freezers. Each B/C ratio value for units with rebates represents a weighted average[g] of the values for the efficiency levels at or above the target level to which the rebate would apply.

Table 17.3.3 Benefit/Cost Ratios Without and With Rebates for Standard-Size Freezers

	Upright Freezers	Chest Freezers
B/C Ratio Without Rebate	6.9	9.1
Rebate Amount	$43	$43
B/C Ratio With Rebate	11.9	Inf.
Calculated Market Barrier Curve	Extremely High	Extremely High

Inf. = infinite B/C ratio, which occurs when the rebate pays the full incremental cost.

DOE used these B/C ratios, along with the penetration curves shown in Appendix 17-A, section 17-A.3.4, to estimate the percentage of consumers who would purchase standard-size freezers that meet the target efficiency level both with and without a rebate incentive. The curves calculated by DOE to represent the market behavior for upright freezers and for chest freezers were close to the *extremely high barriers* penetration curve.

For each product class, DOE next estimated the percent increase represented by the change in penetration rate shown on the penetration curve. It then added that percent increase to the market share of units that meet the target level in the base case to obtain the market share of units that meet the target level in the rebate case. Table 17.3.4 summarizes market shares of target-level standard-size freezers estimated for 2014.

[g] The weighting factor is the 2014 base case market share of each of the corresponding efficiency levels.

Table 17.3.4 Market Penetration in 2014 Without and With Rebates for Standard-Size Freezers

	Upright Freezers %	Chest Freezers %
Base-Case Market Share of Units that Meet Target Levels	0	0
Market Share of Units that Meet Target Levels With Rebates	5	45
Increased Market Share of Units that Meet Target Level With Rebates	5	45

See Appendix 17-A, Table 17-A.4.1, for the annual increases in market shares for standard-size freezers meeting target efficiency levels under a rebate policy. DOE used the increased market shares attributable to the rebate policy as inputs to the NIA-RIA model. Section 17.4 presents the resulting efficiency trends for the policy case of consumer rebates for standard-size freezers.

17.3.2.3 Compact Refrigeration Products

For compact refrigeration products, DOE estimated the effect of increasing the B/C ratio via a rebate that would pay part or all of the increased installed cost of a unit that met the target efficiency level compared to the cost of a unit meeting the baseline level. DOE based the rebate amounts on a sample of utility and agency rebate programs for compact refrigeration products.

For compact refrigerators and compact freezers, DOE gathered data on 12 rebate programs provided by utilities or agencies in several States. (Appendix 17-A, sections 17-A.5.1 and 17-A5.2, identify the rebate programs.) To represent the rebate level for compact refrigerators, DOE used the simple average of the rebate amounts in these 12 programs. For compact freezers, the corresponding sample included only two rebate programs, whose simple average was higher than the average rebate for compact refrigerators; in contrast, the average rebate for standard-size freezers was lower than that for standard-size refrigerator-freezers. Rather than rely on such a small sample, DOE instead estimated the compact freezer rebate amount by multiplying the compact refrigerator amount ($38) by the ratio of the standard-size freezer rebate amount to the standard-size refrigerator-freezer rebate amount, resulting in an estimate of $31. DOE assumed that these rebate amounts would apply to models at all efficiency levels at or above the target level for each representative product class. For each of these efficiency levels, the rebate amount represented a certain percent of the increase in total installed cost.

DOE assumed that rebates would remain in effect until the market had been transformed; that is, the shift in market share of efficient units seen in the first year of the rebate program would be maintained throughout the forecast period (2014–2043).

For compact refrigeration products, DOE first calculated B/C ratios without a rebate using the difference in lifetime operating costs and total installed costs between the unit meeting the target level and the baseline unit. It then calculated B/C ratios given a rebate for the unit meeting the target efficiency. Because the rebate reduced the incremental cost, the unit receiving the rebate had a larger B/C ratio. Tables 17.3.5 shows the effects of consumer rebates on B/C ratios for compact refrigeration products. Each B/C ratio value for units with rebates represents a weighted average[h] of the values for the efficiency levels at or above the target level to which the rebate would apply.

Table 17.3.5 Benefit/Cost Ratios Without and With Rebates for Compact Refrigeration Products

	Compact Refrigerators (PC 11, 11A, 12)	Compact Refrigerators (PC 13, 13I, 13A, 14, 14I, 15, 15I)	Compact Freezers (PC 16, 17, 18)
B/C Ratio Without Rebate	11.6	13.9	14.3
Rebate Amount	$38	$38	$31
B/C Ratio With Rebate	Inf.	Inf.	Inf.
Calculated Market Barrier Curve	Extremely High	Extremely High	Extremely High

Inf. = infinite B/C ratio, which occurs when the rebate pays the full incremental cost.

DOE used these B/C ratios, along with the penetration curves shown in Appendix 17-A, section 17-A.3.4, to estimate the percentage of consumers who would purchase compact refrigeration products that meet the target efficiency level both with and without a rebate incentive. The curves calculated by DOE to represent the market behavior for compact refrigerators and for compact freezers were close to the *extremely high barriers* penetration curve.

For each product class, DOE next estimated the percent increase represented by the change in penetration rate shown on the penetration curve. It then added that percent increase to the market share of units that meet the target level in the base case to obtain the market share of units that meet the target level in the rebate case. Table 17.3.6 summarizes market shares of target-level compact refrigeration products estimated for 2014.

[h] The weighting factor is the 2014 base case market share of each of the corresponding efficiency levels.

Table 17.3.6 Market Penetration in 2014 Without and With Rebates for Compact Refrigeration Products

	Compact Refrigerators (PC 11, 11A, 12) %	Compact Refrigerators (PC 13, 13I, 13A, 14, 14I, 15, 15I) %	Compact Freezers %
Base-Case Market Share of Units that Meet Target Levels	1	0	5
Market Share of Units that Meet Target Levels With Rebates	43	40	44
Increased Market Share of Units that Meet Target Level With Rebates	42	40	39

See Appendix 17-A, Table 17-A.4.1, for the annual increases in market shares for compact refrigeration products meeting target efficiency levels under a rebate policy. DOE used the increased market shares attributable to the rebate policy as inputs to the NIA-RIA model. Section 17.4 presents the resulting efficiency trends for the policy case of consumer rebates for standard-size freezers.

17.3.2.4 Built-In Refrigeration Products

For built-in refrigeration products, DOE estimated the effect of increasing the B/C ratio via a rebate that would pay part or all of the increased installed cost of a unit meeting the target efficiency level compared to one meeting the baseline level. DOE based the rebate amounts on the same sample of utility and agency rebate programs as it used for standard-size refrigerator-freezers, shown in Appendix 17-A, section 17-A.5.1. Since this sample did not indicate separate rebates for built-in products, DOE assumed that the rebate amount would be the same as that calculated for standard-size refrigerator freezers. DOE assumed that this rebate amount would apply to models at all efficiency levels at or above the target level for each representative product class. For each of these efficiency levels, the rebate amount represented a certain percent of the increase in total installed cost.

DOE assumed that rebates would remain in effect at the same levels throughout the forecast period (2014–2043).

For built-in refrigeration products, DOE first calculated B/C ratios without a rebate using the difference in total installed costs and lifetime operating cost savings between the unit meeting the target level and the baseline unit. It then calculated B/C ratios given a rebate for the unit meeting the target efficiency level. Because the rebate reduced the incremental cost, the unit receiving the rebate had a larger B/C ratio. Table 17.3.7 shows the effects of consumer rebates on B/C ratios for built-in refrigeration products that meet target efficiency levels. Each B/C ratio value for units with rebates represents a weighted average[i] of the values for the efficiency levels at or above the target level to which the rebate would apply.

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[i] The weighting factor is the 2014 base case market share of each of the corresponding efficiency levels.

Table 17.3.7 Benefit/Cost Ratios Without and With Rebates for Built-in Refrigeration Products (2009$)

	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
B/C Ratio without Rebate	2.4	2.2	1.5	2.2
Rebate Amount	$52	$52	$52	$43
B/C Ratio with Rebate	3.7	3.3	1.8	2.8
Calculated Market Barrier Curve	Moderate - High	No	No - Low	High - Ext. High

Inf. = infinite B/C ratio, which occurs when the rebate pays the full incremental cost.

DOE used these B/C ratios, along with the penetration curves shown in Appendix 17-A, section 17-A.3.4, to estimate the percentage of consumers who would purchase built-in refrigeration products that meet the target efficiency level both with and without a rebate incentive. The curve calculated by DOE to represent the market behavior for built-in top-mount refrigerator-freezers was between the *moderate barriers and high barriers* penetration curves. For built-in bottom-mount refrigerator-freezers the curve was close to the *no barriers* penetration curve. For built-in side-by-side refrigerator-freezers the curve was between the *no* and *low barriers* penetration curves. For built-in upright freezers the curve was between the *high barriers* and *extremely high barriers* penetration curves.

For each product class, using the penetration curves, DOE estimated that a rebate policy would result in a certain percent market share of products that meet the target efficiency level. DOE estimated the percent market share increase represented by the change in penetration rate shown on the penetration curve. It then added that percent increase to the market share of units that meet the target level in the base case to obtain the market share of units that meet the target level in the rebate case.

Table 17.3.8 summarizes market shares of target-level built-in refrigeration products estimated for 2014.

Table 17.3.8 Market Penetrations in 2014 Without and With Rebates for Built-in Refrigeration Products

	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
Base-Case Market Share of Units that Meet Target Levels	8	87	37	1
Market Share of Units that Meet Target Levels With Rebates	16	96	41	1
Increased Market Share of Units that Meet Target Level With Rebates	8	9	4	0

See Appendix 17-A, Table 17-A.4.1, for the annual increases in market shares for built-in refrigeration products meeting target efficiency levels under a rebate policy. DOE used these increases in market shares as inputs to represent the policy case scenarios in its NIA-RIA model. Section 17.4 presents the resulting efficiency trends for the policy case of consumer rebates for built-in refrigerator-freezers.

17.3.3 Consumer Tax Credits

DOE estimated the effects of tax credits on consumer purchases based on its previous analysis of consumer participation in tax credits. DOE supported its approach using data from Oregon State's tax credit program for energy efficient appliances. DOE also incorporated previous research that disaggregated the effect of rebates and tax credits into a *direct price effect*, which derives from the savings in purchase price, and an *announcement effect*, which is independent of the amount of the incentive.[11], [12] The announcement effect derives from the credibility that a technology receives from being included in an incentive program, as well as changes in product marketing and modifications in markup and pricing. DOE assumed that the rebate and consumer tax credit policies would encompass both direct price effects and announcement effects, and that half the increase in market penetration associated with either policy would be due to the direct price effect and half to the announcement effect.

In estimating the effects of a tax credit on purchases of consumer products that meet new efficiency standards, DOE assumed the amount of the tax credits for each product class would be the same as the corresponding rebate amounts discussed above.

DOE estimated that fewer consumers would participate in a tax credit program than would take advantage of a rebate. Research has shown that the delay required for a consumer to receive a tax credit, plus the added time and cost in preparing the tax return, make a tax credit incentive less effective than a rebate received at the time of purchase. Based on previous analyses, DOE assumed that only 60 percent of the consumers who would take advantage of a rebate would take advantage of a tax credit.[13]

In preparing its assumptions, DOE also reviewed other tax credit programs that have been offered at both the Federal and State levels for energy efficient appliances.

The Energy Policy Act of 2005 (EPACT 2005) included Federal tax credits for consumers who purchase energy efficient equipment, including water heaters, furnaces, and furnace fans for new or existing homes.[14] Those tax credits were in effect in 2006 and 2007, expired in 2008, and were reinstated for 2009–2010 by ARRA.[1], [15] DOE reviewed Internal Revenue Service data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. However, DOE did not find data specific enough to refrigerators to warrant adjusting its analysis method for the Consumer Tax Credits policy case. Appendix 17-A, section 17-A.6.1, contains more information on Federal consumer tax credits.

DOE reviewed data on Oregon's state tax credit program for standard-size refrigerators. However, the data series for this product exhibited too much annual variation, due to periodic updates in efficiency requirements and other program changes, to show a meaningful trend.

DOE also reviewed its previous analysis on Oregon's tax credits for clothes washers to provide support for its assumptions.[16] In the previous analysis, DOE compared the market shares of ultra-high efficiency (UHE) residential clothes washers in Oregon, which offered both State tax credits and utility rebates, with those in Washington State, which offered only utility rebates during the same period. Based on this analysis, DOE estimated that in Oregon the impact of tax credits was 62 percent of the impact of rebates for UHE clothes washers having equivalent efficiency. This finding supports its original assumption that participation in a tax credit program would be about 60 percent of participation in a rebate program. Additional discussion of State tax credits for Oregon and other states is in Appendix 17-A, section 17-A.6.3.

In summary, DOE identified no data on Federal or State consumer tax credits for refrigeration products to directly use in estimating the impacts of consumer tax credits for those products. As mentioned above, however, DOE used its analysis of Oregon data for residential clothes washers as support for its assumption that tax credits induce the participation of about 60 percent as many consumers as rebates inspire. DOE used that percentage in its analysis of consumer tax credits for all refrigeration products.

DOE applied the assumed 60 percent participation described above to the penetration rates estimated for the rebate policy to estimate penetration rates attributable to consumer tax credits. In doing so, DOE incorporated the assumptions for consumer response to financial incentives from the penetration curves selected for each product class.

Tables 17.3.9 through 17.3.12 summarize DOE's assumptions for each refrigeration product group regarding the market penetration of units in 2014 that meet target efficiency levels given a consumer tax credit.

Table 17.3.9 Market Penetrations in 2014 Attributable to Consumer Tax Credits for Standard-Size Refrigerator-Freezers

	Top-Mount Refrigerator-Freezers %	Bottom-Mount Refrigerator-Freezers %	Side-by-Side Refrigerator-Freezers %
Base-Case Market Share of Units that Meet Target Levels	0	68	0
Market Share of Units that Meet Target Levels With Consumer Tax Credits	13	75	16
Increased Market Share of Units that Meet Target Level With Consumer Tax Credits	13	8	16

Table 17.3.10 Market Penetrations in 2014 Attributable to Consumer Tax Credits for Standard-Size Freezers

	Upright Freezers %	Chest Freezers %
Base-Case Market Share of Units that Meet Target Levels	0	0
Market Share of Units that Meet Target Levels With Consumer Tax Credits	3	27
Increased Market Share of Units that Meet Target Level With Consumer Tax Credits	3	27

Table 17.3.11 Market Penetrations in 2014 Attributable to Consumer Tax Credits for Compact Refrigeration Products

	Compact Refrigerators (PC 11, 11A, 12) %	Compact Refrigerators (PC 13, 13I, 13A, 14, 14I, 15, 15I) %	Compact Freezers %
Base-Case Market Share of Units that Meet Target Levels	1	0	5
Market Share of Units that Meet Target Levels With Consumer Tax Credits	26	24	28
Increased Market Share of Units that Meet Target Level With Consumer Tax Credits	25	24	23

Table 17.3.12 Market Penetrations in 2014 Attributable to Consumer Tax Credits for Built-in Refrigeration Products

	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
Base-Case Market Share of Units that Meet Target Levels	8	87	37	1
Market Share of Units that Meet Target Levels With Consumer Tax Credits	13	93	39	1
Increased Market Share of Units that Meet Target Level With Consumer Tax Credits	5	6	2	0

DOE assumed that this policy would transform the market permanently, so that the increase in market share seen in the first year of the program for refrigeration products would be maintained throughout the forecast period. See Appendix 17-A, Table 17-A.4.1, for the annual increases in market shares for refrigeration products that meet target efficiency levels.

The increased market shares attributable to consumer tax credits shown in Tables 17.3.9 through 17.3.12 and Appendix 17-A, Table 17-A.4.1, were used as inputs to the NIA-RIA model. Section 17.4 presents the resulting efficiency trends for the policy case of consumer tax credits for refrigeration products that meet target efficiency levels.

17.3.4 Manufacturer Tax Credits

To analyze the potential effects of a policy that offers tax credits to manufacturers that produce refrigeration products that meet target efficiency levels, DOE assumed that a manufacturer tax credit would lower the consumer's purchase cost by an amount equivalent to that provided by the consumer rebates or tax credits described above. DOE further assumed that manufacturers would pass on some of their reduced costs to consumers, causing a direct price effect. DOE assumed that no announcement effect would occur, because the program would not be visible to consumers.[j] Because the direct price effect is approximately equivalent to the announcement effect,[11] DOE estimated that a manufacturer tax credit would induce half the number of consumers assumed to take advantage of a consumer tax credit to purchase more efficient products. This assumed participation rate is equal to 30 percent of the number of consumers who would participate in a rebate program.

[j] Note that this is a conservative assumption, since it is possible that manufacturers or utility/agency efficiency programs might promote the models for which manufacturers increase production due to the tax credits, which in turn might induce some announcement effect. However, DOE found no data on such programs on which to base an estimate of the magnitude of this possible announcement effect on consumer behavior.

DOE attempted to investigate manufacturer response to the Energy Efficient Appliance Credits for manufacturers mandated by EPACT 2005.[17] Those manufacturer tax credits were in effect for models produced in 2006 and 2007 and reinstated for 2009 and 2010. DOE was unable to locate data from the Internal Revenue Service or other sources on manufacturer response to the Federal credits. Appendix 17-A, section 17-A.6.2, presents details on Federal manufacturer tax credits.

DOE applied the assumption of 30 percent participation to the penetration rates predicted for the rebate policy to estimate the effects of a manufacturer tax credit policy. In doing so, the Department incorporated the assumptions for consumer response to financial incentives from the penetration curves selected for each product class.

Tables 17.3.13 through 17.3.16 summarize DOE's assumptions for each refrigeration product group regarding the market penetration of units in 2014 meeting target efficiency levels given a manufacturer tax credit.

Table 17.3.13 Market Penetrations in 2014 Attributable to Manufacturer Tax Credits for Standard-Size Refrigerator-Freezers

	Top-Mount Refrigerator-Freezers %	Bottom-Mount Refrigerator-Freezers %	Side-by-Side Refrigerator-Freezers %
Base-Case Market Share of Units that Meet Target Levels	0	68	0
Market Share of Units that Meet Target Levels With Manufacturer Tax Credits	6	72	8
Increased Market Share of Units that Meet Target Level With Manufacturer Tax Credits	6	4	8

Table 17.3.14 Market Penetrations in 2014 Attributable to Manufacturer Tax Credits for Standard-Size Freezers

	Upright Freezers %	Chest Freezers %
Base-Case Market Share of Units that Meet Target Levels	0	0
Market Share of Units that Meet Target Levels With Manufacturer Tax Credits	2	14
Increased Market Share of Units that Meet Target Level With Manufacturer Tax Credits	2	13

Table 17.3.15 Market Penetrations in 2014 Attributable to Manufacturer Tax Credits for Compact Refrigeration Products

	Compact Refrigerators (PC 11, 11A, 12) %	Compact Refrigerators (PC 13, 13I, 13A, 14, 14I, 15, 15I) %	Compact Freezers %
Base-Case Market Share of Units that Meet Target Levels	1	0	5
Market Share of Units that Meet Target Levels With Manufacturer Tax Credits	13	12	16
Increased Market Share of Units that Meet Target Level With Manufacturer Tax Credits	13	12	12

Table 17.3.16 Market Penetrations in 2014 Attributable to Manufacturer Tax Credits for Built-in Refrigeration Products

	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
Base-Case Market Share of Units that Meet Target Levels	8	87	37	1
Market Share of Units that Meet Target Levels With Manufacturer Tax Credits	11	90	38	1
Increased Market Share of Units that Meet Target Level With Manufacturer Tax Credits	2	3	1	0

DOE assumed that this policy would transform the market permanently, so that the increase in market share seen in the first year of the program for refrigeration products would be maintained throughout the forecast period. See Appendix 17-A, Table 17-A.4.1, for the annual increases in market shares for units that meet target efficiency levels.

The increased market shares attributable to a manufacturer tax credit, shown in Tables 17.3.13 through 17.3.16 and Appendix 17-A, Table 17-A.4.1, were used as inputs to the NIA-RIA model. Section 17.4 presents the resulting efficiency trends for the policy case of manufacturer tax credits for refrigeration products.

17.3.5 Voluntary Energy Efficiency Targets

For each product, DOE assumed that voluntary energy efficiency targets would be achieved as manufacturers gradually stopped producing units that operated below the target efficiency levels. DOE assumed that the impetus for phasing out production of low-efficiency units would be a program similar to the ENERGY STAR labeling program conducted by the Environmental Protection Agency (EPA) and DOE. The ENERGY STAR program specifies the minimum energy efficiencies that various products, including refrigeration products, must have to receive the ENERGY STAR label. ENERGY STAR encourages consumers to purchase efficient products via marketing that promotes consumer label recognition, various incentive programs that adopt the ENERGY STAR specifications, and manufacturers' promotion of their qualifying appliances. ENERGY STAR projects market penetration of compliant appliances and estimates the percentage of sales of compliant appliances that are attributable to the ENERGY STAR program.

Researchers have analyzed the ENERGY STAR program's effects on sales of several consumer products. Program efforts generally involve a combination of information dissemination and utility or agency rebates. The analyses have been based on State-specific data on percentages of shipments of various appliances that meet ENERGY STAR specifications. The analyses generally have concluded that the market penetration of ENERGY STAR-qualifying appliances is higher in regions or States where ancillary promotional programs have been active.[18], [19], [20]

17.3.5.1 Standard-Size Refrigerator-Freezers

To model the effects of a voluntary energy efficiency policy for standard-size refrigerator-freezers, DOE assumed that such a program would be an expansion of existing ENERGY STAR efforts for this product. The ENERGY STAR program developed projections for 1996–2025 of increased market penetration attributable to its program for standard-size refrigerators.[21] DOE estimated that an expanded ENERGY STAR program would increase the annual market share of efficient units by 50 percent more than the increase that was attributable to the existing ENERGY STAR program for refrigerators, which began in 1996. Using ENERGY STAR's forecast for 1996 – 2025, DOE first performed a linear regression to smooth out fluctuations due to periodic program specification updates. From this adjusted forecast, DOE calculated the annual percent increases in market share for refrigerators represented by an additional 50 percent market share that would result from an enhanced program. DOE added those percent increases to the market shares of standard-size refrigerator-freezers that meet the target level in the RIA base case, [k] starting in 2014, to obtain the annual market shares of units meeting the target efficiency level in the voluntary efficiency targets policy case.

DOE estimated that the programs developed in support of the voluntary efficiency targets policy would increase market shares of efficient units by the percentages shown in Appendix 17-A, Table 17-A.4.2. Section 17.4 presents the resulting efficiency trends for the policy case of voluntary energy efficiency targets for standard-size refrigerator-freezers that meet target efficiency levels.

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[k] The base case projections for refrigeration products incorporate assumptions on the percentage of qualifying shipments under the current ENERGY STAR program.

17.3.5.1 Standard-Size Freezers

While there is an ENERGY STAR program for standard-size freezers that began in 2003, DOE was unable to obtain a projection of the program impacts for this product. DOE instead based its estimates of market penetration for standard-size freezers on the ENERGY STAR projections for standard-size refrigerators of market penetration attributable to its program for 2003–2025. DOE estimated that the percentage of market shares attributable to the existing ENERGY STAR program for standard-size freezers would be half of the percentages attributable to standard-size refrigerator-freezers, based on the relative size of the market shares for these two products in its shipments analysis for the national impact analysis. DOE then estimated that an expanded ENERGY STAR program for standard-size freezers would increase the annual market share of efficient units by 50 percent more than the increase attributable to the existing ENERGY STAR program, starting in 2003, in the projection that was calculated as described above. It assumed that an enhanced program would produce the same patterns of annual increases in market penetration beginning in 2014; from 2037 – 2043 the market penetration is extrapolated as equivalent to the penetration in 2036. From this forecast DOE calculated the annual percent increases in market share for units represented by the shipments attributed to ENERGY STAR. DOE added those percent increases to the market shares of standard-size freezers that met the target levels in the RIA base case, starting in 2014, to obtain the annual market shares of units meeting the target efficiency level in the voluntary efficiency targets case. Appendix 17-A, Table 17-A.4.2, shows the annual projected increases in market shares of standard-size freezers that would result from a voluntary energy efficiency policy. Section 17.4 presents the resulting efficiency trends for the policy case of voluntary energy efficiency targets for standard-size freezers.

17.3.5.2 Compact Refrigeration Products

DOE did not analyze the potential effects of voluntary energy efficiency targets for compact refrigeration products because it was unable to obtain an ENERGY STAR forecast for these products.

17.3.5.3 Built-in Refrigeration Products

DOE did not analyze the potential effects of voluntary energy efficiency targets on built-in refrigeration products because it was unable to obtain an ENERGY STAR forecast for these products.

17.3.6 Early Replacement

The non-regulatory policy of early replacement refers to a program to replace residential appliances before the ends of their useful lives. The purpose of such a policy is to replace old, inefficient units with higher efficiency units. The economic feasibility of early replacement depends on the vintage of the unit being replaced, the installed cost of the new unit, and the energy cost savings.

DOE examined several reports on field experience with early replacement programs to inform its analysis of the policy. The most recent set of reports evaluated residential appliance recycling programs conducted by California utilities that targeted refrigerators and freezers.[22], [23], [24] These studies evaluated data from programs carried out by Southern California Edison, Pacific Gas and Electric, and San Diego Gas and Electric in 2004 - 2008. DOE analyzed the number of units collected by these programs and compared them to the eligible population of refrigerators or freezers in each utility service territory to estimate the percentage reached by each program. For refrigerators, the percentages for the three utilities ranged from 7.1 percent to 1.3 percent, with an average of 4.2 percent. For freezers, the percentages for the three utilities ranged from 4.1 percent to 0.6 percent, with an average of 2.8 percent.

Another report detailed the Connecticut Retirement Program (ARP), which was conducted June through December 2004 by Nexus Market Research, Inc., and RLW Analytics, Inc., for Northeast Utilities–Connecticut Light and Power and the United Illuminating Company's State programs.[25] The purpose of the ARP was to help Connecticut utility customers overcome barriers to recycling room air conditioners (RACs), secondary refrigerators, and freezers. The program picked up used appliances at customers' homes or at turn-in events, paid participants to retire their units, and educated customers about the costs of operating older appliances. In addition, the program provided consumers with financial incentives to replace inefficient RACs with ENERGY STAR-qualified units. DOE considered the RAC program to most closely resemble the early replacement policy scenario for the four refrigeration products considered herein, because consumers replaced primary units rather than retiring second units. Nexus/RLW used program data and surveys to estimate the number of RACs retired by ARP participants, the percentage of retired units that were replaced with an ENERGY STAR model, and the number of RACs replaced by non-participants during the program. According to the Nexus/RLW analysis, about 7 percent of all RACs retired during the program were retired through the ARP, and 63 percent of those were replaced with ENERGY STAR models. Thus the program resulted directly in about 4 percent of total eligible RAC consumers deciding on early replacement of inefficient units.

In 2006, GDS Associates, Inc performed a study of the potentials for electric energy efficiency for the State of Vermont.[26] The report estimated the potentials for reducing electricity use and peak demand through energy efficiency and fuel conversion measures. The study took an aggressive, multi-program approach, one aspect of which was early replacement of appliances. GDS considered that under the program residential appliances, including RACs, would be replaced during four years (2006–2009). GDS estimated achievable market penetrations assuming that consumers would receive a financial incentive equal to 50 percent of the incremental cost of each measure. GDS assumed an 80 percent penetration limit. For early replacement of RACs, GDS estimated a maximum achievable participation of 5 percent of eligible single-family or multi-family homes in the year before the program began (2005).

DOE also reviewed an earlier study it conducted in the 1990s, under Energy Policy Act of 1992 (EPACT 1992), which analyzed the feasibility of a Federal program to promote early replacement of appliances.[27] The study identified policy options for early replacement that included a direct national program; replacement of Federally-owned appliances; and promotion through equipment manufacturers, consumer incentives, incentives to utilities, and building regulations.

While the SEEARP rebate program has been an early replacement program, the program was still in process during the preparation of this TSD. The amount of money available for rebates for each State, apportioned between several appliances per State, may not have been adequate to demonstrate the full market potential of an early replacement program targeted at one appliance.

For this RIA analysis, DOE analyzed a program that would target installed units having efficiency levels that are lower than target levels and encourage their early replacement with products that perform at target levels. For each product, DOE modeled the effects of the early replacement policy by increasing by a certain percentage per year the retirement rate of units that were in the stock in the first year of the analysis period (2014). For standard-sized and compact refrigerators DOE used the 4.2 percent rate from the California studies, because they were based on the recent actual program experience, noting that this rate was bounded by the Connecticut and the Vermont analysis results. For standard-sized and compact freezers, DOE assumed that the accelerated replacement rate would be 2.8 percent, based on the recent California experience with freezer replacement programs.

DOE assumed that the early replacement program would continue until it had facilitated the replacement of all eligible residential refrigerators, refrigerator-freezers, and freezers in the stock in the year the program began (2014). Shipments of new units in 2014 and beyond were not affected by the program, but remained at base-case efficiency levels. After the stock of inefficient units was completely replaced, the policy would produce no additional impacts.

An early replacement policy would create a fairly immediate jump in shipments of products that meet target efficiency levels relative to the base case, as shown in Figures 17.3.4 through 17.3.7. High-efficiency units would be brought quickly into the stock, leading to an immediate gain in the market share of efficient units compared to the base case. As opposed to the policy cases discussed previously, however, an early replacement policy results in market shares of efficient units returning to base-case percentages as the eligible market is depleted. In addition, as the figures illustrate, because units removed early from the stock would have been replaced later (at the ends of their useful lives) without the program, the number of shipments in later years drops slightly below the base-case shipments forecast for a period of years.

The shipments shown in Figures 17.3.4 through 17.3.7 represent units that replace existing units (replacement shipments). Note that built-in refrigeration products were analyzed together with standard-size refrigerator-freezers and standard-size freezers for this policy, so separate shipments graphs are not available for built-ins. Appendix 17.A, Table 17-A.4.2, shows the projected market shares due to the early replacement policy. Section 17.4 presents the resulting efficiency trends for the policy case of early replacement for refrigeration products.

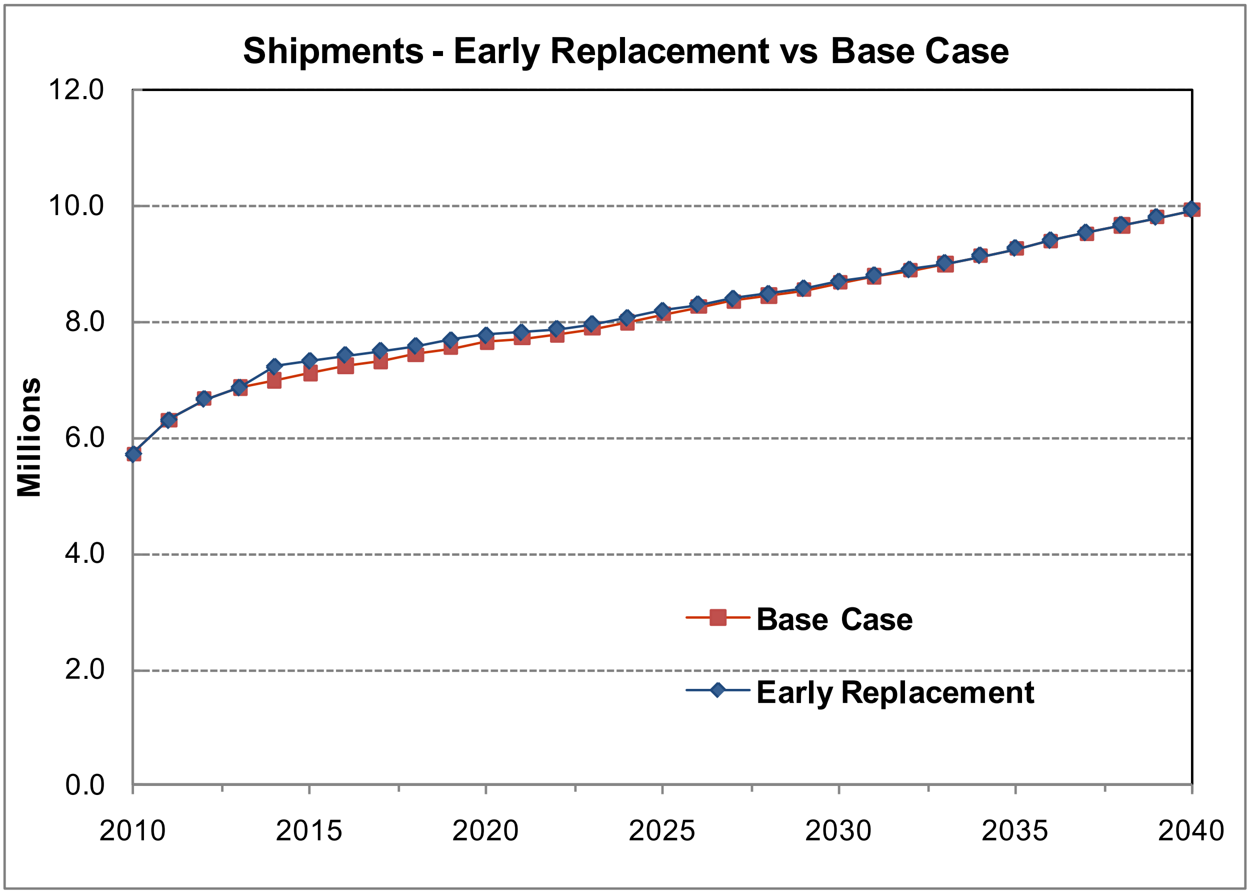

Figure 17.3.4 Estimated Replacement Shipments of Standard-Size Refrigerator-Freezers With and Without an Early Replacement Program

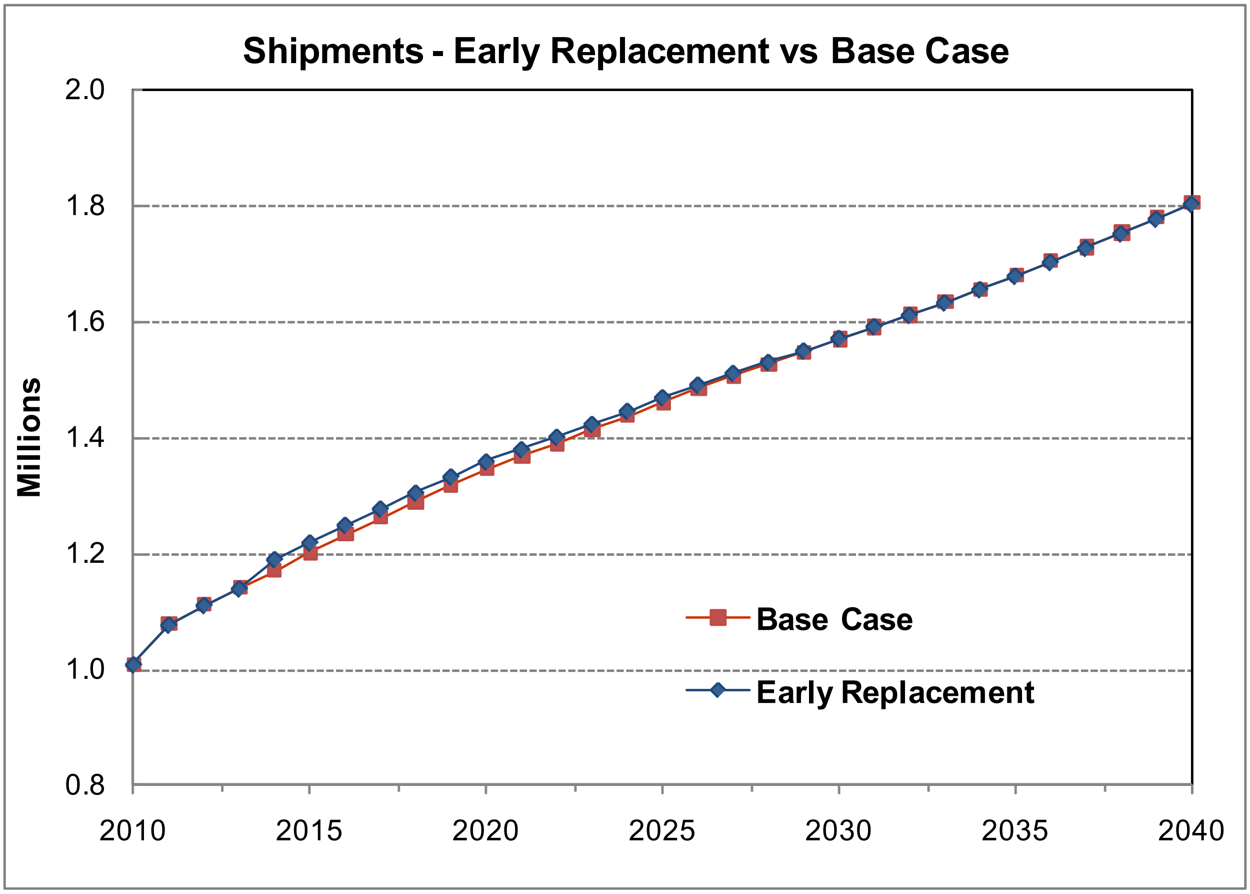

Figure 17.3.5 Estimated Replacement Shipments of Standard-Size Freezers With and Without an Early Replacement Program

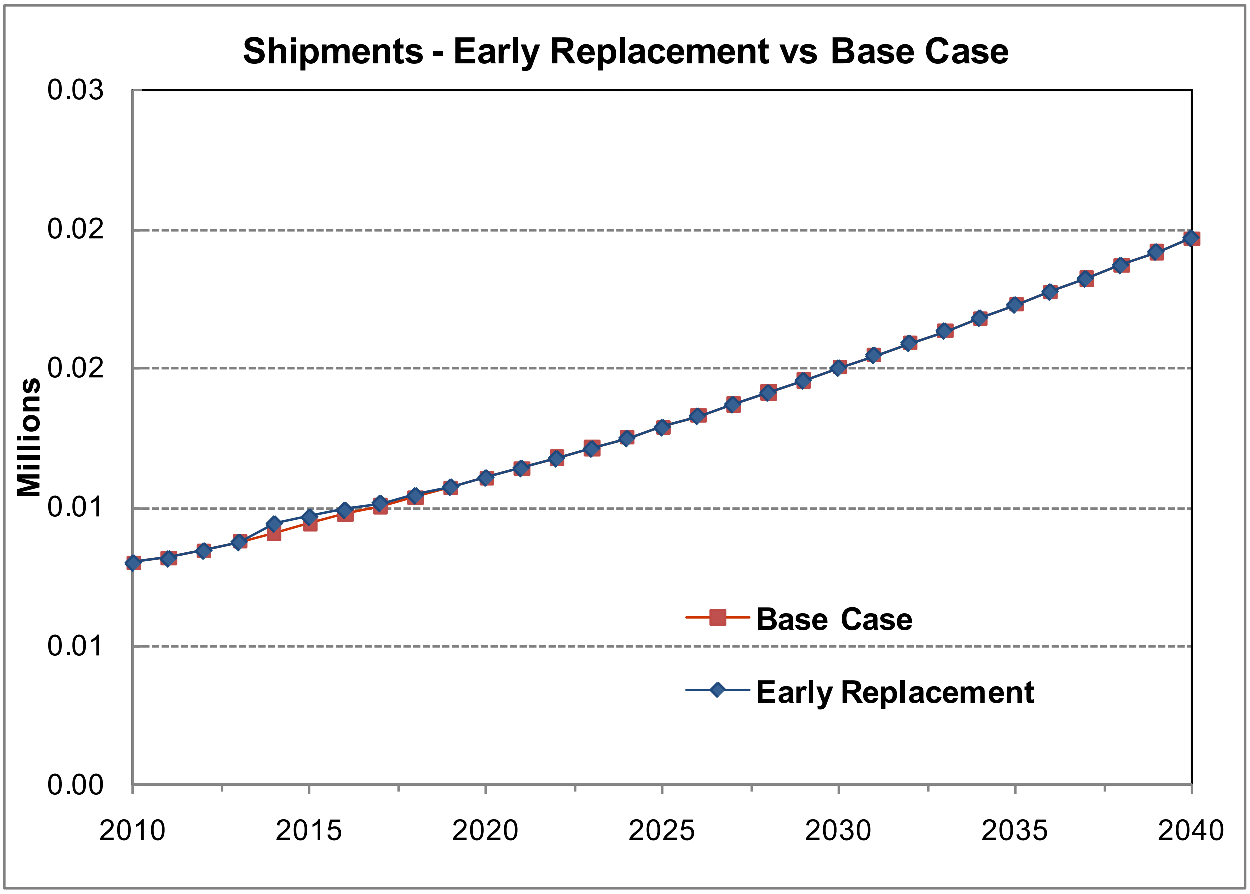

Figure 17.3.6 Estimated Replacement Shipments of Compact Refrigerators With and Without an Early Replacement Program

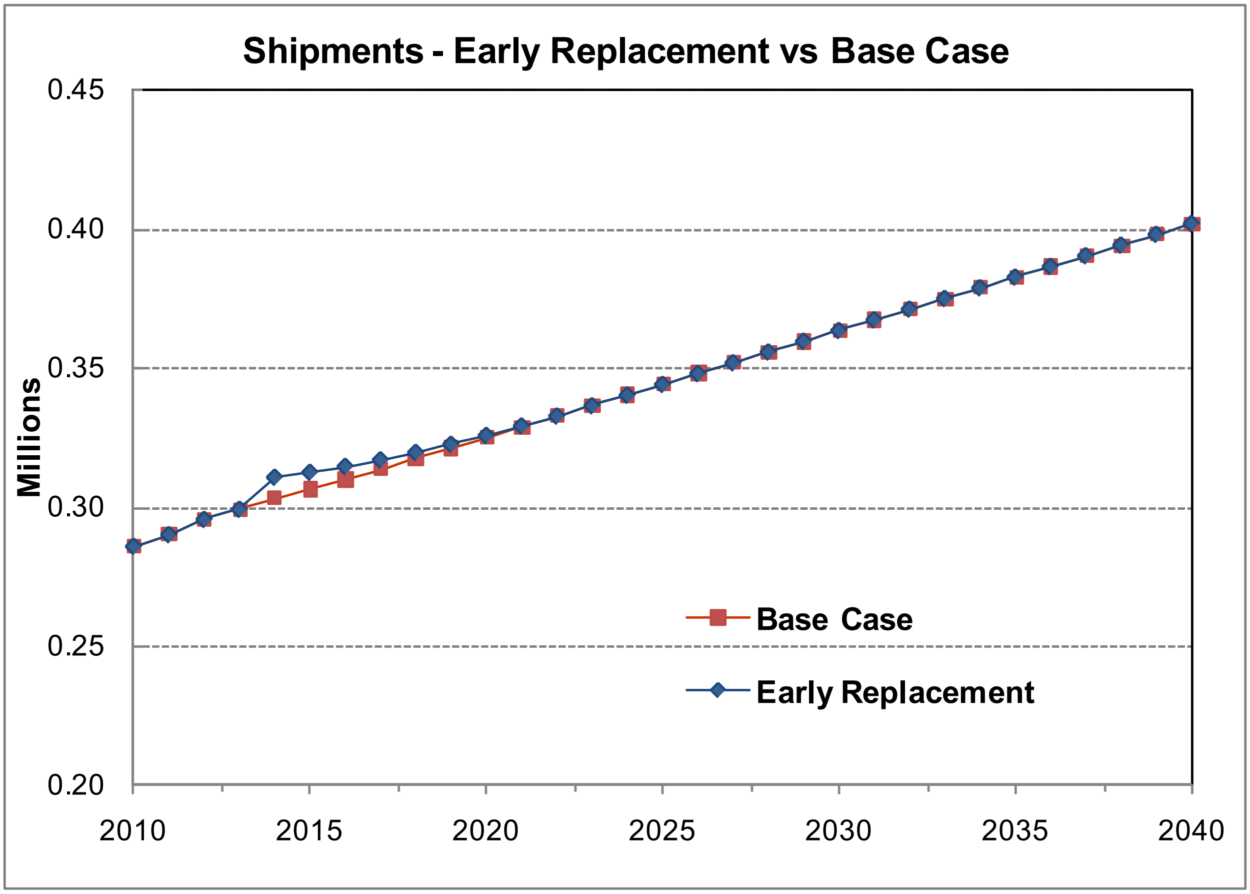

Figure 17.3.7 Estimated Replacement Shipments of Compact Freezers With and Without an Early Replacement Program

17.3.7 Bulk Government Purchases

DOE assumed that a policy requiring bulk government purchases would lead to Federal, State, and local governments purchasing products that meet target efficiency levels. Combining the market demands of multiple public sectors also would provide a market signal to manufacturers and vendors that some of their largest customers seek products that meet an efficiency target at favorable prices. Such a program also could induce "market pull," whereby manufacturers and vendors would achieve economies of scale for high-efficiency products.

Most of the previous bulk government purchase (procurement) initiatives at the Federal, State, and municipal levels have not tracked data on number of purchases or degree of compliance with procurement specifications. In many cases, procurement programs are decentralized, being part of larger State or regional initiatives. DOE based its assumptions regarding the effects of a policy calling for bulk government purchases on studies the Federal Energy Management Program (FEMP) performed regarding the savings potential of its procurement specifications for appliances and other equipment. FEMP, however, does not track purchasing data, because of the range of complex the purchasing systems, number of vendors, etc. States, counties, and municipalities have demonstrated increasing interest and activity in "green purchasing." Although many of the programs target office equipment, the growing infrastructure for developing and applying efficient purchasing specifications indicates that bulk government purchase programs are feasible.[28], [29]

DOE assumed that government agencies, such as the Department of Housing and Urban Development, would administer a bulk purchasing program for refrigeration products. The bulk purchasing policy also could be incorporated at the Federal level into the FEMP program, which has established procurement guidelines. Federal construction requirements include the FEMP guidelines for installing or replacing equipment. The FEMP program currently has procurement guidelines in place for standard-size and compact refrigerators and for standard-size and compact freezers. [30] , [31]

DOE also reviewed its own previous research on the potential for market transformation through bulk government purchases. Its major study analyzed several scenarios based on the assumption that 20 percent of Federal equipment purchases in the year 2000 already incorporated energy efficiency requirements based on FEMP guidelines. One scenario in the DOE report showed energy efficient Federal purchasing ramping up during 10 years from 20 percent to 80 percent of all Federal purchases.[32]

17.3.7.1 Standard-Size Refrigerator-Freezers

Based on its study described above, DOE estimated that a bulk government purchase program instituted within a 10-year period would result in 80 percent of government-purchased standard-size refrigerator-freezers meeting target efficiency levels.

DOE assumed that bulk government purchases would affect a subset of housing units for which government agencies purchased or influenced the purchase of standard-size refrigerator-freezers. This subset would consist primarily of public housing and housing on military bases. DOE defined this subset based on publicly owned housing identified in the American Housing Survey (AHS) for 2009, which was 1.8 million households, or about 1.4 percent of all U.S. households.[33] (The AHS reports 130.0 million U.S. households[34]). According to the 2005 Residential Energy Consumption Survey (RECS 2005), 97.5 percent of publicly owned households had refrigerators.[35] DOE therefore estimated that 1.4 percent of U.S. housing units represent publicly owned households using standard-size refrigerator-freezers, which constitutes the populations to which this policy would apply.

Based on the above percentages, DOE estimated that, by the end of the first year of the bulk government purchase policy (2014), an additional 0.1 percent of shipments of government-purchased standard-size refrigerator-freezers beyond the base case would meet target efficiency levels. DOE estimated that by 2024 bulk government purchasing programs would result in 80 percent of the standard-size refrigerator market for publicly owned housing meeting target levels. DOE modeled the bulk government purchase program assuming that the market share for each product achieved in 2024 would be maintained throughout the rest of the forecast period. Section 17.4 presents the resulting efficiency trends for the policy case of bulk government purchase of standard-size refrigerator-freezers. Appendix 17.A, Table 17-A.4.2, shows the projected market shares due to the bulk government purchases policy.

17.3.7.2 Standard-Size Freezers

DOE did not analyze the potential effects of bulk government purchases of standard-size freezers, because the market share of those products in publicly owned housing is small. According to RECS 2005, only 6.4 percent of publicly owned housing units use standard-size freezers.

17.3.7.3 Compact Refrigeration Products

DOE analyzed the market for compact refrigeration products and determined that compact refrigerators are sold to the residential, commercial lodging, and commercial "other" building types. DOE did not analyze the potential impacts of bulk government purchases of compact freezers, because it assumed that the penetration of this product in publicly owned buildings was very small. RECS 2005 reports that the percentage of compact freezers in use in publicly owned housing units is very low and DOE lacked data to estimate their percentages in publicly owned commercial buildings.

Based on its study described above, DOE estimated that a bulk government purchase program instituted within a 10-year period eventually would result in 80 percent of government-purchased compact refrigerators meeting target efficiency levels.

For the residential sector, DOE assumed that bulk government purchases would affect a subset of housing units for which government agencies purchased or influenced the purchase of compact refrigerators. DOE defined this subset based on publicly owned housing identified in the American Housing Survey (AHS) for 2009, which was 1.8 million households, or about 1.4 percent of all U.S. households.[33] The AHS reports 130.0 million U.S. households.[34]) According to the 2005 Residential Energy Consumption Survey (RECS 2005), 2.6 percent of publicly owned households used compact refrigerators.[35] DOE therefore estimated that 0.04 percent of U.S. housing units represent publicly owned households using compact refrigerators, to which this policy would apply.

For the commercial sector, DOE assumed that bulk government purchases would affect a subset of buildings for which government agencies purchased or influenced the purchase of compact refrigerators. DOE defined this subset based on publicly owned buildings identified in the 2003 Commercial Buildings Energy Consumption Survey.[36] DOE assumed that compact refrigerators were used in lodging (including hotels, motels, and dormitories) and in "other commercial" building types, such as offices. According to CBECS, 0.3 percent of lodging buildings' floor space and 24 percent of other commercial buildings' floor space was publicly owned. From CBECS, 39 percent of publicly owned lodging building floor space and 63 percent of publicly owned other commercial building floor space had compact refrigerators. DOE therefore estimated that 0.1 percent of U.S. lodging floor space and 15 percent of U.S. other commercial building floor space represent publicly owned building floor space using compact refrigerators, to which this policy would apply.

DOE further calculated that of the 2014 building stock with compact refrigerators, 29 percent were in the residential sector, 18 percent in commercial lodging and 54 percent in other commercial buildings. Using stock as a proxy for shipments, and the public building percentages and saturations reported above, DOE estimated that 0.7 percent of shipments of compact refrigerators beyond the base case would meet target efficiency levels in the first year of the bulk government purchase policy (2014) for each product class. DOE estimated that by 2024 bulk government purchasing programs would result in 80 percent of the compact refrigerator market for publicly owned buildings meeting target levels. DOE modeled the bulk government purchase program assuming that the market share for each product achieved in 2024 would be maintained throughout the rest of the forecast period. Section 17.4 presents the resulting efficiency trends for the policy case of bulk government purchase of compact refrigerators. Appendix 17.A, Table 17-A.4.2, shows the projected market shares due to the bulk government purchases policy.

17.3.7.4 Built-in Refrigeration Products

DOE did not analyze the potential impacts of bulk government purchases of built-in-refrigeration products, because those products are not used in publicly owned housing. RECS 2005 does not report any built-in-refrigeration products in use in publicly owned housing units.

17.4 IMPACTS OF NON-REGULATORY ALTERNATIVES

Figures 17.4.1 through 17.4.4 show the effects of each of the non-regulatory policy cases on market shares of units meeting the target level for standard-size refrigerator-freezers, standard-size freezers, compact refrigeration products and built-in refrigeration products, respectively.

Figure 17.4.1 shows the effects of each non-regulatory policy on market penetration for standard-size refrigerator-freezers. Note that the market share of products that meet the target level is forecasted to increase over time in the base case (i.e., the case with neither standards nor non-regulatory policies). Relative to the base case, every policy case increases the market share of products that meet the target level. As shown in Figure 17.4.1, consumer rebates are most effective in increasing the market share of standard-size refrigerators that meet the target level, while early replacement is least effective. Recall that the standards (not shown in Figure 17.4.1) would result in a 100 percent market penetration of products that meet target efficiency levels.

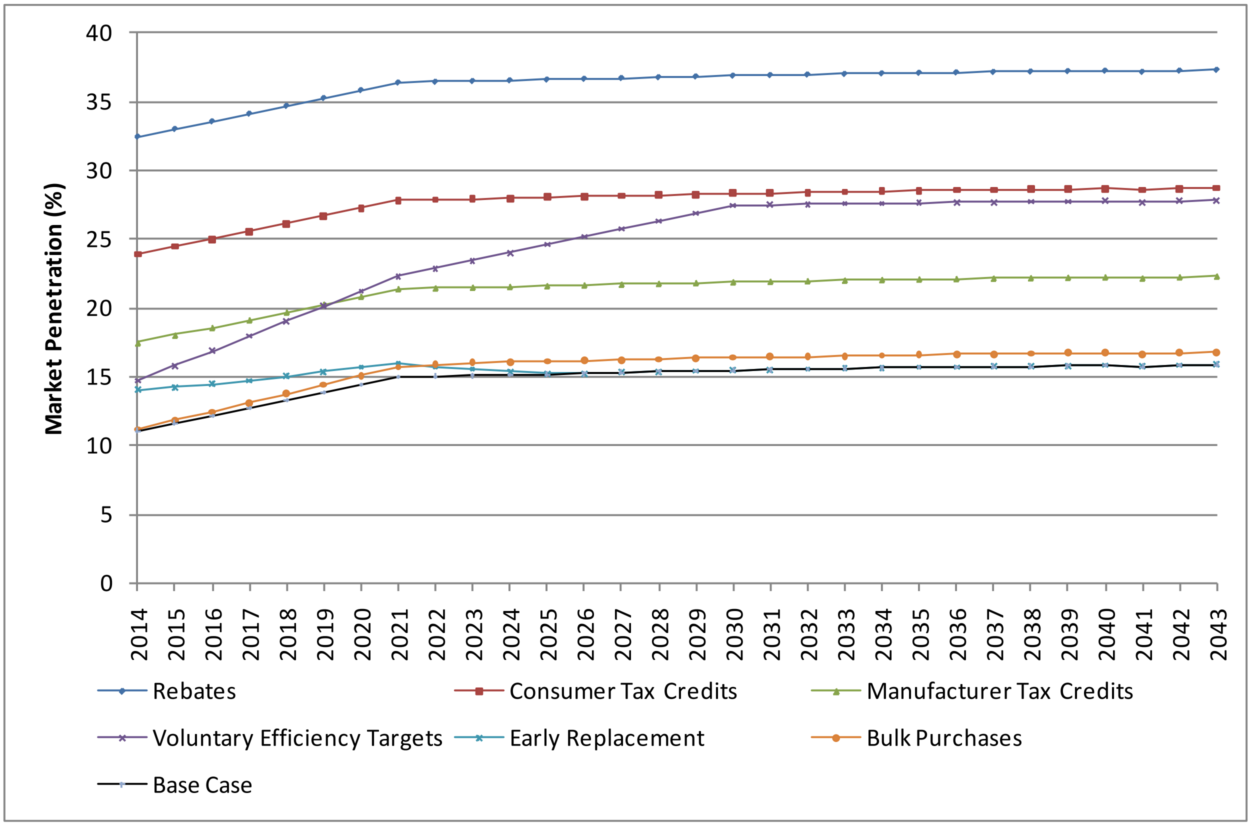

Figure 17.4.1 Market Penetration of Standard-Size Refrigerator-Freezers Meeting Target Level in Policy Cases

Figure 17.4.2 shows the effects of each non-regulatory policy on market penetration for standard-size freezers. The market share of products that meet the target level is forecasted to increase over time in the base case. Relative to the base case, all policy cases increase the market share of standard-size freezers that meet the target level (with the exception of bulk government purchases, which was not analyzed). Consumer rebates are projected to be the most effective and early replacement the least effective of the policy cases analyzed. Recall that the proposed standards (not shown in Figure 17.4.2) would result in a 100 percent market penetration of products that meet the target efficiency level.

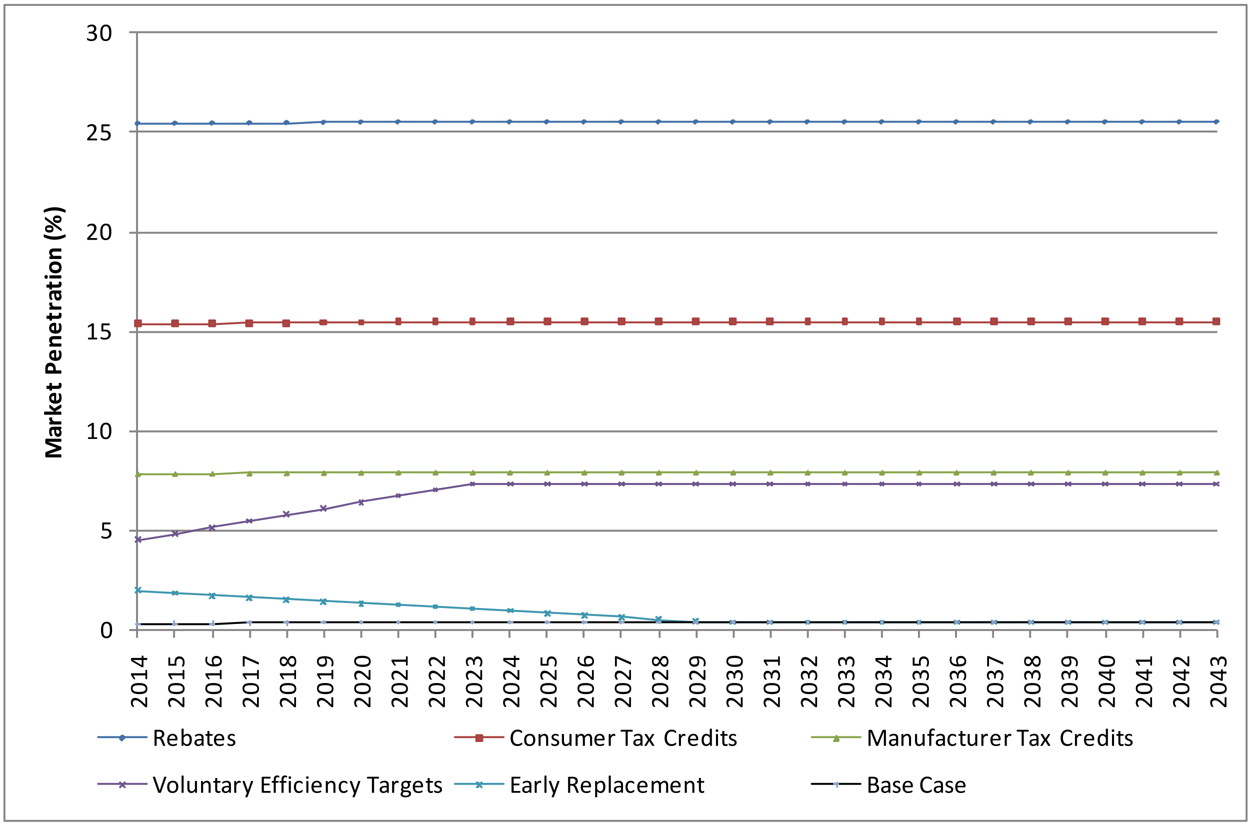

Figure 17.4.2 Market Penetration of Standard-Size Freezers Meeting Target Level in Policy Cases

Figure 17.4.3 shows the effects of each non-regulatory policy on the market penetration for compact refrigeration products. In the base case, the market share of products that meet the target level is forecasted to be constant over time. Relative to the base case, all policy cases increase the market share of compact refrigeration products that meet target efficiency levels (with the exception of voluntary efficiency targets, which was not analyzed). Consumer rebates are projected to be the most effective and early replacement the least effective of the policy cases analyzed. Recall that the proposed standards (not shown in Figure 17.4.3) would result in a 100 percent market penetration of products that meet the target efficiency level.

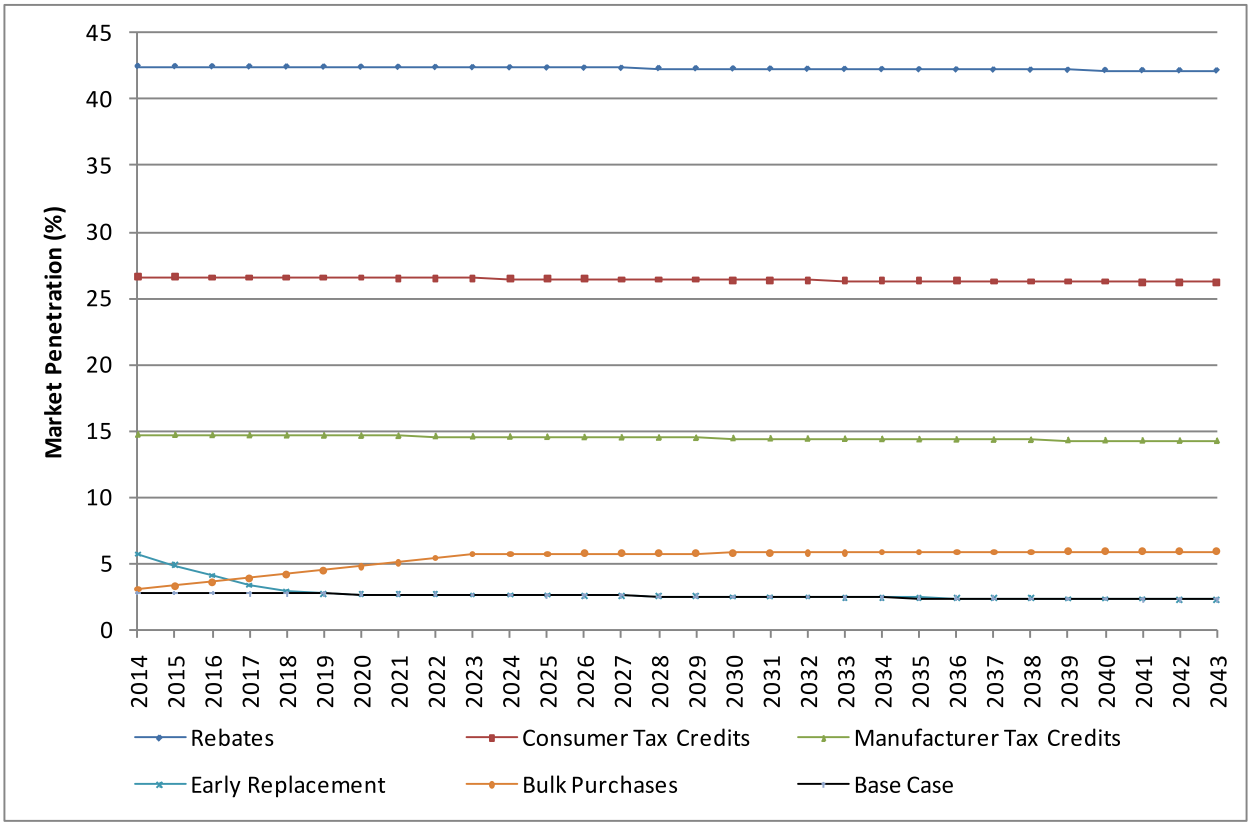

Figure 17.4.3 Market Penetration of Compact Refrigeration Products Meeting Target Level in Policy Cases

Figure 17.4.4 shows the effects of each non-regulatory policy on the market penetration for built-in refrigeration products. In the base case, the market share of products that meet the target level is forecasted to be constant over time. Relative to the base case, the non-regulatory policy cases increase the market share of built-in refrigeration products that meet the target efficiency level (with the exception of voluntary efficiency targets and bulk government purchases, which were not analyzed). Consumer rebates are the most effective policy throughout the forecast period, and early replacement is the least effective. Recall that the proposed standards (not shown in Figure 17.4.4) would result in a 100 percent market penetration of products that meet the target efficiency level.

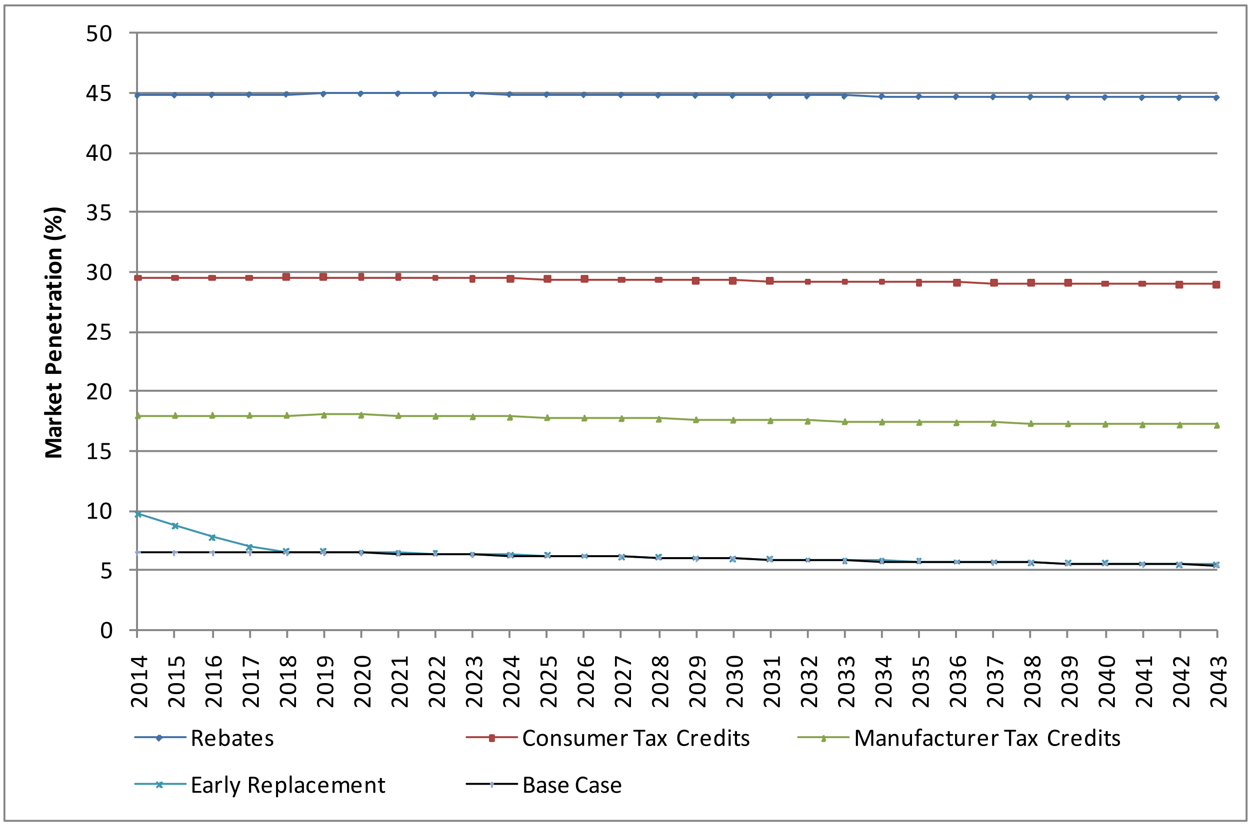

Figure 17.4.4 Market Penetration of Built-in Refrigeration Products Meeting Target Level in Policy Cases

17.5 SUMMARY OF RESULTS FOR NON-REGULATORY ALTERNATIVES

Tables 17.5.1 through 17.5.4 show the national energy savings and net present value (NPV) for each of the six non-regulatory policies analyzed in detail for residential refrigerators, refrigerator-freezers, and freezers, where the target level for each policy equals the efficiency level in the corresponding proposed standard. Table 17.5.5 shows the results for all refrigeration products together.

The cases in which no regulatory action is taken with regard to residential refrigerators, refrigerator-freezers, and freezers constitute the base cases (or "No New Regulatory Action" scenarios), in which energy savings and NPV zero by definition. For comparison, the tables include the impacts of the proposed standards. Energy savings are given in quadrillion British thermal units (quads). The NPVs shown in Tables 17.5.1 through 17.5.5 are based on two discount rates, 7 percent and 3 percent. Negative NPVs are shown in parentheses.

Table 17.5.1 Impacts of Non-Regulatory Alternatives for Standard-Size Refrigerator-Freezers that Meet the Proposed Standard (TSL 3)

Policy Alternative	Primary Energy Savings quads	Net Present Value* billion 2009$	
		7% discount rate	3% discount rate
Consumer Rebates	0.83	1.44	5.57
Consumer Tax Credits	0.51	0.88	3.40
Manufacturer Tax Credits	0.25	0.44	1.70
Voluntary Energy Efficiency Targets	0.35	0.61	2.51
Early Replacement	0.00	0.00	0.00
Bulk Government Purchases	0.03	0.05	0.21
Proposed Standards	3.27	5.16	20.90

* For products shipped in 2014─2043

Table 17.5.2 Impacts of Non-Regulatory Alternatives for Standard-Size Freezers that Meet the Proposed Standard (TSL 2)

Policy Alternative	Primary Energy Savings quads	Net Present Value* billion 2009$	
		7% discount rate	3% discount rate
Consumer Rebates	0.29	0.51	2.09
Consumer Tax Credits	0.17	0.31	1.27
Manufacturer Tax Credits	0.09	0.15	0.64
Voluntary Energy Efficiency Targets	0.07	0.22	0.72
Early Replacement	0.00	0.00	0.00
Bulk Government Purchases†			
Proposed Standards	1.14	3.41	10.83

* For products shipped in 2014─2043

† DOE did not evaluate the bulk government purchase policy for standard-size freezers because the market share associated with publicly owned housing is minimal.

Table 17.5.3 Impacts of Non-Regulatory Alternatives for Compact Refrigeration Products that Meet the Proposed Standard (TSL 2)

Policy Alternative	Primary Energy Savings quads	Net Present Value* billion 2009$	
		7% discount rate	3% discount rate
Consumer Rebates	0.19	0.29	0.80
Consumer Tax Credits	0.12	0.17	0.49
Manufacturer Tax Credits	0.06	0.09	0.25
Voluntary Energy Efficiency Targets†			
Early Replacement	0.00	0.00	0.00
Bulk Government Purchases	0.02	0.03	0.10
Proposed Standards	0.37	0.63	1.69

* For products shipped in 2014─2043

† DOE did not evaluate the voluntary energy efficiency target policy for compact refrigeration products because it had no market data on which to base an analysis.

Table 17.5.4 Impacts of Non-Regulatory Alternatives for Built-in Refrigeration Products that Meet the Proposed Standard (TSL 3)

Policy Alternative	Primary Energy Savings quads	Net Present Value* billion 2009$	
		7% discount rate	3% discount rate
Consumer Rebates	0.01	(0.01)	0.00
Consumer Tax Credits	0.00	(0.01)	0.00
Manufacturer Tax Credits	0.00	0.00	0.00
Voluntary Energy Efficiency Targets			
Early Replacement	0.00	0.00	0.00
Bulk Government Purchases†			
Proposed Standards	0.06	(0.15)	(0.06)

* For products shipped in 2014─2043

† DOE did not evaluate the voluntary energy efficiency target policy for built-in refrigeration products because it had no market data on which to base an analysis. DOE did not evaluate the bulk government purchase alternative for built-in refrigeration products because the market share associated with publicly owned housing is minimal.

Table 17.5.5 Summary of Impacts of Non-Regulatory Alternatives for All Refrigeration Products that Meet the Proposed Standards

Policy Alternative	Primary Energy Savings <u>quads</u>	Net Present Value* billion 2009$	
		7% discount rate	3% discount rate
Consumer Rebates	1.32	2.22	8.46
Consumer Tax Credits	0.80	1.35	5.15
Manufacturer Tax Credits	0.40	0.68	2.59
Voluntary Energy Efficiency Targets	0.43	0.81	3.23
Early Replacement	0.00	0.00	0.00
Bulk Government Purchases	0.05	0.08	0.30
Proposed Standards	5.03	9.07	36.84

* For products shipped in 2014–2043

17.6 SUPER-EFFICIENT VOLUNTARY TARGETS

In addition to the above policy alternatives, DOE evaluated a policy where a new, two-tiered voluntary efficiency target program was implemented in addition to the proposed standards. The voluntary efficiency targets would feature speculative "super-efficient" products at two efficiency levels (designated Tier 1 and Tier 2) above the current max-tech levels. The program would target consumers in the highest electricity price regions of the country, to make the products maximally cost-effective. For the purpose of evaluating the program, only standard-sized refrigerator-freezers were considered. Table 17.6.1 shows the targeted efficiency levels and assumed market shares of shipments in 2014 and in 2019 and beyond, as well as the assumed level of electricity prices relative to the national average.[37], [38]

Table 17.6.1 Super-efficient Voluntary Targets Program Parameters for Standard-Size Refrigerator-Freezers

	Product Class		
	Top-Mount Refrigerator-Freezers*	**Bottom-Mount Refrigerator-Freezers****	**Side-by-Side Refrigerator-Freezers†**
Efficiency Level (% below baseline)			
Proposed Standards (TSL 3)	25%	20%	25%
Super-efficient Tier 1	35%	35%	35%
Super-efficient Tier 2	45%	45%	41%
Market share of shipments			
2014			
Super-efficient Tier 1	4%	4%	4%
Super-efficient Tier 2	2%	2%	2%
2019+			
Super-efficient Tier 1	20%	20%	20%
Super-efficient Tier 2	10%	10%	10%
Relative electricity price (% of national average)			
Super-efficient Tier 1	120%	120%	120%
Super-efficient Tier 2	150%	150%	150%

* Includes product classes 1, 1A, 2, 3A, 3I and 6 as well as product class 3
** Includes product classes 5A and 5I as well as product class 5
† Includes product classes 4 and 4I as well as product class 7

The incremental cost of super-efficient technology was estimated from the same engineering data used to construct the cost-efficiency curves discussed in Chapter 5, but assuming a higher efficiency of vacuum insulation panel technology, and the availability of more efficient linear variable-speed compressor technology. The resulting maximum efficiency levels achieved in this manner were 45% below baseline for top- and bottom-mount refrigerator-freezers, and 41% below baseline for side- mount refrigerator-freezers.

It was assumed that the incremental cost of this super-efficient technology would follow the same price decline curve as calculated in Chapter 8. This is considered a conservative assumption, since the cost of advanced technology tends to fall faster than typical technology, owing to the smaller cumulative base of manufacturing experience for these more advanced components.

Table 17.6.2 shows the incremental total price of super-efficient products in selected model years, along with the incremental total price of products under the proposed standards (TSL 3).

Table 17.6.2 Super-efficient Voluntary Targets Program Incremental Total Price for Standard-Size Refrigerator-Freezers

	Product Class		
Incremental Total Price	**Top-Mount Refrigerator-Freezers***	**Bottom-Mount Refrigerator-Freezers****	**Side-by-Side Refrigerator-Freezers†**
Proposed standards (TSL 3)			
2014	$121	$42	$108
2019	$107	$37	$95
2029	$85	$29	$76
2043	$64	$22	$57
Super-efficient Tier 1			
2014	$182	$189	$223
2019	$161	$168	$197
2029	$128	$133	$157
2043	$96	$100	$117
Super-efficient Tier 2			
2014	$377	$415	$375
2019	$334	$368	$332
2029	$266	$293	$264
2043	$199	$219	$197

* Includes product classes 1, 1A, 2, 3A, 3I and 6 as well as product class 3
** Includes product classes 5A and 5I as well as product class 5
† Includes product classes 4 and 4I as well as product class 7

Additional savings from the super-efficient voluntary targets program in addition to the proposed standards (TSL 3) are shown in Table 17.6.3. Overall, DOE estimates that an additional 1.92 quads of energy savings and an additional NPV of consumer benefit of $6.04 billion (at 7 percent discount rate) would be realized under this program beyond the savings from the proposed standards.

Table 17.6.3 Super-efficient Voluntary Targets Program: Additional Savings Relative to Proposed Standards for Standard-Size Refrigerator-Freezers

	Product Class			
	Top-Mount Refrigerator-Freezers	**Bottom-Mount Refrigerator-Freezers**	**Side-by-Side Refrigerator-Freezers**	**All Standard-Sized Refrigerator-Freezers***
Energy Savings (Cumulative through 2043) (quads)	0.98	0.35	0.59	1.92
Discounted Incremental Equipment Cost (billion 2009$)†	1.95	1.10	1.23	4.28
Discounted Operating Cost Savings (billion 2009$)†	5.69	1.36	3.27	10.32
Net Present Value (billion 2009$)†	3.74	0.26	2.04	6.04

* Includes product classes 1, 1A, 2, 3, 3A, 3I, 4, 4I, 5, 5A, 5I , 6 as well as product class 7

† Using 7-percent discount rate

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APPENDIX 4-A. INVESTIGATION OF VIP SUPPLY

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APPENDIX 4-A. INVESTIGATION OF VIP SUPPLY

4-A.1 INTRODUCTION

This appendix discusses DOE's investigation of potential supply issues for vacuum-insulated panels (VIPs), a consideration in deciding that this technology passes screening and can be considered as a design option in the engineering analysis. DOE had received comments concerning the viability of VIPs as a design option following the preliminary analysis. In particular, stakeholders pointed out that achieving cost-effective efficiency levels as determined by the DOE preliminary analysis depended on increase of VIP supply to a level of millions of panels per year, which stakeholders asserted the VIP industry could not achieve and/or would lead to significant price increase. DOE conducted an assessment of the VIP market and the required ramp-up of VIP production and concluded that the market does not show ramp-up to be a critical issue leading to price pressure.

DOE contacted several VIP suppliers to better assess the current production capacity and the ability of the industry to ramp up to expected demand by 2014. These suppliers include Porextherm (Germany)[1], Va-Q-tec (Germany)[2], ThermoCor (U.S.)[3], NanoPore Insulation LLC (U.S.)[4], Glacier Bay (U.S.)[5], and ThermalVisions (U.S.)[6]. DOE did not receive a response from any Asian companies it attempted to contact during this phase, but Porextherm estimated that there are five VIP producers based in China and Japan.

4-A.2 VIP DEMAND

VIPs have been used in refrigerators for more than 20 years, but only in high-end models until recent years. In the U.S., major refrigerator manufacturers have started using VIPs in commodity models, driven by the manufacturer tax credit available in 2008-2010.[a] DOE estimates that the current worldwide VIP market is in the range of 2.5 to 5 million square meters based on input from VIP manufacturers. This is a wide range due to the variation in estimates provided by vendors providing information and also due to the lack of information obtained from Asian suppliers, particularly from Japan, which is reported to have experienced the greatest use of VIPs to date. Va-Q-tec estimated that world production is approximately 2 million square meters. ThermoCor estimated it to be about 5 million square meters. Other vendors interviewed declined to provide estimates.

DOE used its NOPR analysis results to estimate the projected VIP demand in the U.S. in 2014 based on the proposed standard levels. DOE first estimated the VIP surface area required per unit for each of the eleven directly-analyzed product classes at the proposed standard level. The estimates are based on use of VIPs as determined in the engineering analysis.

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[a] Energy Improvement and Extension Act of 2008 (EIEA 2008; Public Law 110-343). Manufacturers can receive $200 per unit for units at least 30 percent more efficient than the standard.

For the conventional products, DOE conducted thorough energy and cost analysis for two products of each product class. The reported estimate of VIP demand for these product classes is based on the average of the surface areas required at the proposed standard level for the two analyzed products. For built-in products, DOE assumed that the product analyzed in the engineering analysis was representative of all products in that class. DOE used the product shipment projections for 2014 as calculated in the shipments analysis to convert the per-unit demand to national demand in terms of VIP surface area. The resulting demand estimate is 5.8 million square meters of VIPs in 2014. Table 4-A-1 shows the breakdown of this estimate by product class. The demand could be lower or higher depending on the decisions manufacturers make regarding use of design options in designs to meet the new standards.

Table 4-A-1: U.S. Demand at Proposed Standard Levels

Product Classes	Estimated Total VIP Demand in 2014 (million m^2)
3	4.0
5	0.0
7	1.3
9	0.0
10	0.0
11	0.0
18	0.0
3- Built-In	0.1
5- Built-In	0.0
7- Built-In	0.3
9- Built-In	0.2
Total:	5.8

DOE also considered the potential increase in demand for VIPs in Europe and India. As part of this examination, DOE reviewed European directives aimed at improving energy efficiency. The European Energy Labeling Directive (94/2/EC) for cold appliances, which was issued by the European Commission on January 21, 1994, established 7 efficiency levels for these products, from least efficient G to most efficient A. In 2003, additional higher efficiency levels A+ and A++ were established. These levels all represent different percentages of reference energy use, called Energy Efficiency Index (EEI), from less than 30 for A++ (the most efficient) to 125 for G. The European Union established efficiency standards for residential refrigeration products with EU Council Directive 96/57/EC dated 3 September 1996. Maximum energy use standards were established for 10 “product categories”, the equivalent to different product classes associated with DOE regulations. Commission Regulation (EC) No 643/2009 requires that the maximum allowable EEI will become 55 starting July 1, 2010. This level will drop to 44 on July 1, 2012, and to 42 (equivalent to current efficiency level A+) on July 1, 2014.

DOE received estimates from various VIP manufacturers that European demand is expected to rise to a level in a range from 2 to 5 million square meters in response to the new standards. Information obtained from a manufacturer that has used VIPs in multiple products suggests that VIPs will be used primarily for A++ products, which may be considered the equivalent of the current U.S. ENERGY STAR products. The 2 to 5 million square meter estimate is consistent with the use of VIPs primarily for A++ products, assuming that these products will represent 10 to 20 percent of the market.

Along similar lines, India introduced a labeling program in 2006 that was initially voluntary but became mandatory in January 2010. The program establishes efficiency levels represented by ranges of energy use. The product label is required to indicate the product's efficiency level. The allowable maximum energy use values associated with the efficiency levels are scheduled to be reduced in three steps between 2010 and 2014. However, based on discussions with manufacturers, India's proposed standards for 2014 are not expected to be as stringent as in the U.S. or Europe and are not expected to require use of VIPs.

Taking into account the markets discussed above, worldwide VIP demand is expected to reach a level in the range 10 to 15 million square meters, based on available information as shown in Table 4-A-2. DOE's understanding of the Asian market is limited. DOE expects that demand will be small in other markets such as Australia and New Zealand and India due to less stringent standards and/or much lower population.

Table 4-A-2: Current and Projected VIP Demand

Key Markets	Current Demand in 2010 (million m^2)	Projected Demand in 2014 (million m^2)
United States	1 to 3	6
Europe	0.5	2 to 5
Asia	1 to 2	2 to 4
Total	2.5 to 5.5	10 to 15

4-A.3 ABILITY OF VIP SUPPLIERS TO MEET DEMAND

The projected demand of 10 to 15 million m^2 represents a growth factor in the range of 2 to 6, depending on which ends of the current and projected ranges are most accurate. While the high end of this range represents dramatic growth, it is not inconsistent with the growth that the market has experienced recently for which VIP vendors have successfully ramped up their production.

Several VIP manufacturers are currently expanding their facilities, while others have plans to expand if the demand becomes more reliable. Overall, the VIP manufacturers interviewed were confident that neither the time nor the capital investment is a limiting factor as long as they have a stable backlog. Five of the manufacturers commented on their recent expansion efforts:

- Manufacturer 1 has increased its production capacity by 10 times between 2008 and Spring 2010 to reach a level of about 1.5 million m^2.
- Manufacturer 2 has doubled its capacity to about 120,000 m^2 in the last 6 months.
- Manufacturer 3 has doubled its capacity to about 1 million m^2 in the last 9 months.
- Manufacturer 4 has taken 1.5 years to reach capacity of about 300,000 m^2.
- Manufacturer 5 has recently doubled its capacity and has plans to expand to 0.9 million m^2 capacity by 2010.

In total, the production capacity of the VIP vendors that participated in the discussions has increased from about 0.1 million m^2 prior to 2008 to about 3 million m^2 in 2010, suggesting an order-of-magnitude increase at a rate of nearly 1.5 million m^2 per year, not including vendors from whom DOE did not receive capacity growth information. In order to meet the estimates of projected demand above, an overall growth rate of production capacity serving the US and EU markets of 1.5 to 4 million m^2 per year is needed.

Estimates by VIP manufacturers of the time required to bring a new minimum-capacity efficient plant on-line range from 6 to 18 months, as shown in Table 4-A-3.[b] If each of the six manufacturers interviewed expanded at their stated minimum rate, they could generate an increase of over 9 million m^2 by 2014. This estimated expansion falls within the range of estimates of required ramp-up without considering other existing manufacturers, or factoring in the potential for new manufacturers to enter the market.

[b] A minimum-capacity efficient plant is a plant with a capacity at the low end of the range needed to achieve costs that are sufficiently minimized to be competitive.

Table 4-A-3: New Manufacturing Facility Ramp-Up Time

	Minimum-Capacity Efficient Plant Size (million m^2 annual capacity)	**Time to Bring On-line (months)**
Manufacturer 1	1.5	12
Manufacturer 2	0.2	6
Manufacturer 3	0.4	9
Manufacturer 4	0.3	12
Manufacturer 5	0.5	18

The variation in the time to build a new plant depends on whether existing production technology is replicated, or whether further improvements in production technology are designed into new plants. Possible improvements to lower cost and increase production capacity include more automation of the panel assembly and a switch to continuous processing. Automation may be applied to the drying of the core material and the cutting of the bag and core. DOE visited a VIP production facility during the course of this investigation and concluded that the estimates provided by VIP vendors of time required to bring new production capacity online are consistent with the production process, given the equipment used.

Several VIP manufacturers have considered joint ventures and licensing opportunities with refrigerator manufacturers. Manufacturers of VIPs suggest that transferring the knowledge and expertise of VIP production would be a straightforward process. A new VIP fabrication facility would need to have a production capacity between 300,000 and 1.5 million square meters per year to be cost-effective at today's VIP price levels. The capacity will typically vary based on the manufacturer, the panel type, and the facility location.

VIP manufacturers do not anticipate the supply of raw materials to be an issue as production ramps up. The industry uses multiple suppliers for both the barrier film and the fill material. Materials used for the fill include glass fiber, fumed silica, and aerogel. Glass fiber is produced for a wide range of applications worldwide. Fumed silica, used as fill by some VIP manufacturers, is currently produced on a much smaller scale. Asked if the more limited range of uses of fumed silica could present material supply issues due to capacity ramp-up delays or intellectual property issues, Porextherm noted that intellectual property would not be a barrier for suppliers to building new fumed silica plants, citing several new production facilities that have come online recently in Asia. They also noted that the solar collector business in particular is helping to expand the production of pure silica, of which fumed silica is a by-product. Va-Q-tec estimates that there is enough fumed silica production today to produce 100 million m^2 of VIPs, and a new fumed silica plant would require 2.5 years to be built. Thermal Visions did not anticipate suppliers needing more than one year to respond to the ramp-up in production.

In summary, DOE concludes that the VIP industry has the ability to ramp up to meet the potential demand for VIPs within the three year gap between the rulemaking final rule and the date the standard takes effect.

[1] Personal communication with Porextherm, February & August 2010.

[2] Personal communication with Va-Q-tec, February & August 2010.

[3] Personal communication with ThermoCor, February & August 2010.

[4] Personal communication with NanoPore, March 2010.

[5] Personal communication with Glacier Bay, February 2010.

[6] Personal communication with Thermal Visions, February & August 2010.

APPENDIX 5-A. ENGINEERING DATA

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APPENDIX 5-A. ENGINEERING DATA

5-A.1 INTRODUCTION

DOE used the Energy-efficient Refrigerator Analysis Program (ERA) to calculate energy use for baseline and energy-saving configurations for the various product classes of refrigeration products. Inputs to this program were generated from reverse-engineering teardowns of select refrigerator and refrigerator-freezer models currently available. The values for the input variables are shown in tabular format in section 5-A.2.

The incremental cost curves describing costs to attain each analyzed efficiency level are based on the energy use output from the ERA program. Development of costs for these curves is described in chapter 5. The tables in section 5-A.3 show these incremental cost curves in tabular format, with identification of the design options required to reach each efficiency level shown.

As part of the engineering analysis, DOE solicited input from manufacturers on a range of technical topics affecting energy use in refrigeration products. The questionnaire used to facilitate these interviews is shown in section 5-A.4.

5-A.2 ERA INPUTS

The ERA inputs for each of the units selected for reverse-engineering analysis are shown below. Some general notes regarding the data include the following:

1. Compressor compartment insulation thickness is specified directly in Windows ERA, while DOS ERA used bottom wall thickness.

2. The ERA input for door openings is not provided, since DOE conducted analysis based on closed doors.

3. Windows ERA includes separate input for the air in the compressor compartment. DOS ERA used the air temperature underneath the cabinet for this region.

4. DOE conducted all analyses using single evaporator system configuration with HFC-134a refrigerant.

5. The tube and fin heat exchanger configuration implies forced convection air flow.

6. See the Windows ERA program for definitions of air flow directions for forced convection wire fin condensers.

7. Some products analyzed had spine fin evaporators, which are not supported by ERA. Input for a separate spine fin analysis spreadsheet calculation is provided in the tables below for these products.

8. Windows ERA does not allow superheat or subcooling input of 0 ˚C, although DOS ERA does. Suggested input is 0.5 ˚C in cases where input of 0 ˚C is indicated.

Table 5-A.2.1: ERA Inputs for Top-Mount Refrigerator-Freezers (Product Class 3)

Top-Mount Refrigerator-Freezers	16 ft^3 Baseline	21 ft^3 Baseline	21 ft^3 E*
General Data			
Fresh Food Volume (ft^3)	11.6	15.3	15.3
Freezer Volume (ft^3)	4.1	5.3	5.3
Total Volume (ft^3)	15.7	20.6	20.6
Adjusted Volume (ft^3)	18.3	23.9	23.9
Rated Energy Use (kWh/yr)	455	509	408
Calculated Max. Energy Use (kWh/yr)	455	511	511
Rated Energy Use Below Maximum (%)	0.0	0.3	20.1
Cabinet Dimensions			
Category	Top-mount	Top-mount	Top-mount
Cabinet Height (cm)	146.7	165.6	165.6
Cabinet Width (cm)	70.8	75.3	75.3
Depth, from Door Flange (cm)	62.6	74.3	74.3
Depth, from Door Outer Surface (cm)	71.1	80.7	80.7
Liner Properties			
Outer Liner Thickness (mm)	0.4	0.4	0.4
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	1.0	1.5	2.0
Liner Conductivity (W/m-C)	0.16	0.16	0.16
Compressor Compartment Dimensions			
Top Depth (cm)	12.7	12.4	12.4
Bottom Depth (cm)	21.6	25.8	25.8
Height (cm)	26.0	16.0	16.0
Wall (vertical) (cm)	43	5.9	5.9
Wall (horizontal) (cm)	4.3	6.4	6.4
Freezer Section			
Insulation Thickness			
Top Wall (cm)	5.3	7.1	7.1
Side Wall (cm)	5.5	7.5	7.5
Back Wall (cm)	7.0	7.9	7.9
Door (cm)	6.2	7.2	7.2
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.50
Wedge/Flange Dimensions			
Freezer Wedge Depth (cm)	7.6	7.0	7.0
Freezer Flange Width (cm)	3.8	3.8	3.8
Heat Paths			
Freezer Gasket Heat Leak (W/m-100C)	9.0	9.0	9.0
Fzr Cabinet Penetration Heat Leak (W)	1.5	0.0	0.0
Fresh Food Section			
Insulation Thickness			
Side Wall (cm)	3.8	4.8	4.8

Top-Mount Refrigerator-Freezers	16 ft^3 Baseline	21 ft^3 Baseline	21 ft^3 E*
Back Wall (cm)	5.0	4.9	4.9
Bottom Wall (cm)	4.3	5.1	5.1
Door (cm)	4.1	4.7	4.7
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.50
Wedge/Flange Dimensions			
Fresh Food Wedge Depth (cm)	0.1	7.6	7.6
Fresh Food Flange Width (cm)	3.8	3.8	3.8
Heat Paths			
FF Gasket Heat Leak (W/m-100C)	9.0	9.0	9.0
FF Cabinet Penetration Heat Leak (W)	1.5	0.0	0.0
Mullion			
Distance to Top (cm)	44.5	50.8	50.8
Thickness w/Liners (cm)	5.7	7.1	7.1
Resistivity w/Liners (m2-C/W-cm)	0.5	0.5	0.5
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Freezer Section (°C)	-15	-15	-15
Fresh Food Section (°C)	7.2	7.2	7.2
Air Under Cabinet (°C)	35.0	35.0	35.0
Compressor Compartment (˚C)	35.0	35.0	35.0
Air Entering Condenser (°C)	32.2	33.0	33.0
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Automatic	Automatic	Automatic
Timer Interval (Hr)	14.0	10.5	10.5
Heater On-Time (Min)	8.0	4.8	4.8
Defrost Power (W)	390	413	413
Other Cycle-Dependent Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	0.3	0.3	0.3
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	0	0	0
Outside Cabinet (W)	0	0	0
Liquid Refrigerant Line Anti-Sweat			
Freezer Door Flange			
Cycle Average Energy (W)	4	3.8	3.8
Fraction Heat Leak (0-1)	0.5	0.3	0.3
Fresh Food Door Flange			
Cycle Average Energy (W)	0	0	0
Fraction Heat Leak (0-1)	0	0	0
Mullion			

Top-Mount Refrigerator-Freezers	**16 ft^3 Baseline**	**21 ft^3 Baseline**	**21 ft^3 E***
Cycle Average Energy (W)	1.5	1.3	1.3
Heat Leak to Freezer (0-1)	0.25	0.25	0.25
Heat Leak to Fresh Food (0-1)	0.25	0.25	0.25
Evaporator Design			
Exit Superheat	2	2	0
Fin Type (plain, wavy, herringbone)	Spine	Plain	Plain
Fan Motor Type	AC-Input BLDC	Shaded Pole	Shaded Pole
Fan Power (W)	3.5	6.1	5.7
Air Flow Rate (Liter/s)	16.6	21.3	21.3
Tube Characteristics			
Width of Tube Row	52.1	45.7	45.7
Tube OD (mm)	9.4	7.9	7.9
Tube Wall Thickness (mm)	0.76	0.6	0.6
# of Tubes Deep	7	4	4
Tube Pitch (cm)	2.5	3.8	3.8
# of Tubes Normal to Airflow	2	6	6
Normal Tube Pitch (cm)	2.5	1.9	1.9
Fin Characteristics			
Fin Thickness (mm)	0.25	0.13	0.13
Fin Pitch (mm)	9.5	6.3	6.3
Fin Conductivity (W/m-K)	190	190	190
Fraction Finned (0-1)	0.93	0.89	0.89
Spine Fin Input Data			
Spine Height (mm)	10.5	NA	NA
Spine Width (mm)	0.79	NA	NA
Condenser Design		[a]	[a]
Exit Subcooling (°C)	2	0	0
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin	Tube & Fin	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Wire	Wire	Wire
Fan Motor Type	Shaded Pole	Shaded Pole	AC-input BLDC
Fan Power (W)	11.2	9.4	3.3
Air Flow Rate (Liter/s)	30.0	26.0	31.2
Tube Characteristics			
Airflow Direction (W, L, H)	W	W	W
Tube OD (mm)	4.8	4.8	4.8
Tube Wall Thickness (mm)	0.8	0.6	0.6

[a] Surface areas calculated by the condenser routine were increased by a factor of 2.56 for the 21 ft^3 top-mount refrigerators to calibrate with test data for condensing temperatures.

Top-Mount Refrigerator-Freezers	16 ft^3 Baseline	21 ft^3 Baseline	21 ft^3 E*
Length of Tube in "L" Direction	59.6	20.1	20.1
# of Tubes in H Direction	1	8	8
Tube Pitch (cm)	2.5	2.5	2.5
# of Tubes in W Direction	14	6	6
Tube Pitch (cm)	2.5	2.5	2.5
Fraction Air through Exchanger (0-1)	0.6	0.9	0.9
Fin Characteristics			
Wire OD (mm)	1.5	1.1	1.1
# of Wires on 1-side per layer	95	29	29
Wire Mounting (1-side, 2-sides)	2-sides	2-sides	2-sides
Wire Fin Pitch (mm)	5.1	5.1	5.1
Wire Length (cm)	34.9	14.0	14.0
Wire Conductivity (W/m-K)	44.7	44.7	44.7
Compressor Data			
Manufacturer	Matsushita	Matsushita	Matsushita
Model #	DGS57C84RAU	SF51C97RAU6	DHS57C85RAU
Cycles per hour	1.0	1.0	1.0
Interchanger			
Effectiveness (0-1)	0.9	0.95	0.95
Component Adjustment Factors			
Condenser UA Multiplier	1.0	2.56	2.56

Table 5-A.2.2: ERA Inputs for Built-in All-Refrigerators (Product Class 3A-BI)

Built-in All-Refrigerators	**21 ft^3 E***
General Data	
Upper Compartment Volume (ft^3)	13.4
Lower Compartment Volume (ft^3)	7.5
Total Volume (ft^3)	20.9
Adjusted Volume (ft^3)	20.9
Rated Energy Use (kWh/yr)	376
Calculated Max. Energy Use (kWh/yr)	480
Rated Energy Use Below Maximum (%)	21.7
Cabinet Dimensions	
Category (from ERA selection)	Bottom-Mount
Cabinet Height (cm)	172.9
Cabinet Width (cm)	90.8
Depth, from Door Flange (cm)	57.2
Depth, from Door Outer Surface (cm)	61.0
Liner Properties	
Outer Liner Thickness (mm)	1.5
Outer Liner Conductivity (W/m-C)	44.7
Inner Liner Thickness (mm)	0.9
Liner Conductivity (W/m-C)	190
Lower Compartment Cabinet	
Insulation Thickness	
Side Wall (cm)	4.9
Back Wall (cm)	4.4
Bottom (cm)	4.2
Door (cm)	5.2
Insulation Resistivity	
Side Wall (m2-C/W-cm)	0.73
Back Wall (m2-C/W-cm)	0.88
Bottom (m2-C/W-cm)	0.76
Door (m2-C/W-cm)	0.68
Wedge/Flange Dimensions	
Lower Compartment Flange Width (cm)	3.6
Lower Compartment Wedge Depth (cm)	6.7
Resistivity (m2-C/W-cm)	0.5
Heat Paths	
Lower Compartment Gasket Heat Leak (W/m-100C)	9.0
Lower Compartment Penetration Heat Leak (W)	0.0
Upper Compartment Cabinet	
Insulation Thickness	
Top Wall (cm)	3.6

Built-in All-Refrigerators	**21 ft^3 E***
Side Wall (cm)	4.9
Back Wall (cm)	4.4
Door (cm)	3.6
Insulation Resistivity	
Top Wall (m2-C/W-cm)	0.50
Side Wall (m2-C/W-cm)	0.50
Back Wall (m2-C/W-cm)	0.50
Door (m2-C/W-cm)	0.87
Wedge/Flange Dimensions	
Upper Compartment Flange Width (cm)	3.6
Upper Compartment Wedge Depth (cm)	6.7
Resistivity (m2-C/W-cm)	0.5
Heat Paths	
Upper Gasket Heat Leak (W/m-100C)	9.0
Upper Cabinet Penetration Heat Leak (W)	0.0
Mullion	
Distance to Top (cm)	102.9
Thickness w/Liners (cm)	10.1
Resistivity w/Liners (m2-C/W-cm)	0.50
Air and Cabinet Temperatures	
Room Air (°C)	32.2
Lower Compartment Section (°C)	3.3
Upper Compartment Section (°C)	3.4
Air Under Cabinet (°C)	33.0
Compressor Compartment (˚C)	33.0
Air Entering Condenser (°C)	32.2
Defrost and Controls Energy	
Defrost Type (Automatic, Manual)	Manual
Other Cycle-Dependent Loads	
Lower Compartment Section (W)	0
Upper Compartment Section (W)	0
Outside Cabinet (W)	0
Constant Electrical Loads	
Lower Compartment Section (W)	0
Upper Compartment Section (W)	0
Outside Cabinet (W)	1.3
Liquid Refrigerant Line Anti-Sweat	
Lower Compartment Door Flange	
Cycle Average Energy (W)	2.9
Fraction Heat Leak (0-1)	0.5
Upper Compartment Door Flange	
Cycle Average Energy (W)	3.0
Fraction Heat Leak (0-1)	0.5

Built-in All-Refrigerators	21 ft^3 E*
Mullion	
Cycle Average Energy (W)	1.8
Heat Leak to Lower Compartment (0-1)	0.4
Heat Leak to Upper Compartment (0-1)	0.4
Cycle Parameters	
Cycle Type	Dual loop
Cycling Losses	YES
Cycles/hr	1.5
Refrigerant	R-134a
Evaporator Design (Lower Compartment)	
Exit Superheat (°C)	0.8
Fin Type (plain, wavy, herringbone)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC
Fan Power (W)	3.1
Air Flow Rate (Liter/s)	20.2
Tube Characteristics	
Width of Tube Row	48.8
Tube OD (mm)	9.3
Tube Wall Thickness (mm)	0.64
# of Tubes Normal to Airflow	2
Normal Tube Pitch (cm)	1.1
# of Tubes Deep	9
Tube Pitch (cm)	1.9
Fin Characteristics	
Fin Thickness (mm)	0.13
Fin Pitch (mm)	5.1
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.90
Evaporator Design (Upper Compartment)	
Exit Superheat (°C)	0.8
Fin Type (plain, wavy, herringbone)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC
Fan Power (W)	3.1
Air Flow Rate (Liter/s)	13.5
Tube Characteristics	
Width of Tube Row	48.8
Tube OD (mm)	9.3
Tube Wall Thickness (mm)	0.64
# of Tubes Normal to Airflow	2
Normal Tube Pitch (cm)	1.1
# of Tubes Deep	9

Built-in All-Refrigerators	21 ft^3 E*
Tube Pitch (cm)	1.9
Fin Characteristics	
Fin Thickness (mm)	0.13
Fin Pitch (mm)	5.1
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.90
Condenser Design (Lower Compartment)	
Exit Subcooling (°C)	0.7
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC
Fan Power in Fan Energy Calculations (W)	4[1]
Air Flow Rate (Liter/s)	16.4
Tube Characteristics	
Width of Tube Row	34.0
Tube OD (mm)	6.4
Tube Wall Thickness (mm)	0.46
# of Tubes Deep	8
Tube Pitch (cm)	1.3
# of Tubes Normal to Airflow	2
Normal Tube Pitch (cm)	2.2
Faction of Air through Condenser	1
Fin Characteristics	
Fin Thickness (mm)	0.19
Fin Pitch (mm)	3.6
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.86
Condenser Design (Upper Compartment)	
Exit Subcooling (°C)	0.7
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC
Fan Power in Fan Energy Calculations (W)	4[1]
Air Flow Rate (Liter/s)	16.4
Tube Characteristics	
Width of Tube Row	34.0
Tube OD (mm)	6.4

Built-in All-Refrigerators	21 ft^3 E*
Tube Wall Thickness (mm)	0.46
# of Tubes Deep	8
Tube Pitch (cm)	1.3
# of Tubes Normal to Airflow	2
Normal Tube Pitch (cm)	2.2
Faction of Air through Condenser	1
Fin Characteristics	
Fin Thickness (mm)	0.19
Fin Pitch (mm)	3.6
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.86
Compressor Data (Lower Compartment)	
Manufacturer	Embraco
Model	EM20HSC
Capacity Multiplier	1.0
Power Multiplier	1.0
Speed Multiplier	1.0
Compressor Data (Upper Compartment)	
Manufacturer	Embraco
Model	EM20HSC
Capacity Multiplier	1.0
Power Multiplier	1.0
Speed Multiplier	1.0
Interchangers	
Effectiveness (0-1, Lower Compartment)	0.75
Effectiveness (0-1, Upper Compartment)	0.75
Compressor Shell Inlet Temperature (°C)	Calculated

[1]This product has a single condenser with a separate circuit for each of the two refrigeration systems. The single fan operates when one or two of the compressors are operating. The condenser fan power was set to 0W for each of these systems in ERA, and a post-processing spreadsheet was used to calculate fan energy use with consideration of the overlap of the two system on-cycles.

Table 5-A.2.3: ERA Inputs for Bottom-Mount Refrigerator-Freezers (Product Class 5)

Bottom-Mount Refrigerator-Freezers	18.5 ft^3	25 ft^3 E*, #1	25 ft^3 E*, #2
General Data			
Fresh Food Volume (ft^3)	13.1	17.8	17.6
Freezer Volume (ft^3)	5.4	7.3	7.7
Total Volume (ft^3)	18.5	25.1	25.3
Adjusted Volume (ft^3)	21.9	29.6	30.2
Rated Energy Use (kWh/yr)	476	475	478
Calculated Max. Energy Use (kWh/yr)	560	595	598
Rated Energy Use Below Maximum (%)	15.0	20.2	20.0
Cabinet Dimensions			
Category	Bottom-Mount	Bottom-Mount	Bottom-Mount
Cabinet Height (cm)	160.7	168.3	168.0
Cabinet Width (cm)	75.3	90.5	90.8
Depth, from Door Flange (cm)	69.2	72.4	71.3
Depth, from Door Outer Surface (cm)	76.8	79.4	78.3
Liner Properties			
Outer Liner Thickness (mm)	0.5	0.6	0.5
Outer Liner Conductivity (W/m-C)	44.7	43.3	44.7
Inner Liner Thickness (mm)	1.3	1.9	1.4
Liner Conductivity (W/m-C)	0.16	0.16	0.16
Compressor Compartment Dimensions			
Top Depth (cm)	16.5	17.1	12.7
Bottom Depth (cm)	27.0	27.3	25.4
Height (cm)	24.5	24.1	22.9
Wall (vertical) (cm)	7.0	6.9	6.6
Wall (horizontal) (cm)	7.0	6.9	6.6
Freezer Cabinet			
Insulation Thickness			
Side Wall (cm)	6.9	7.5	6.8
Back Wall (cm)	7.9	6.5	7.6
Bottom (cm)	7.0	6.9	6.6
Door (cm)	6.3	6.0	6.9
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.53
Wedge/Flange Dimensions			
Freezer Flange Width (cm)	3.8	3.8	5.4
Freezer Wedge Depth (cm)	5.1	6.4	5.1
Resistivity (m2-C/W-cm)	0.5	0.5	0.5
Heat Paths			
Freezer Gasket Heat Leak (W/m-100C)	9.5	8.0	8.0
Fzr Cabinet Penetration Heat Leak (W)	5	3	0
Fresh Food Cabinet			
Insulation Thickness			

Bottom-Mount Refrigerator-Freezers	18.5 ft^3	25 ft^3 E*, #1	25 ft^3 E*, #2
Top Wall (cm)	5.2	3.9	4.2
Side Wall (cm)	4.2	5.1	3.5
Back Wall (cm)	5.7	6.8	4.1
Door (cm)	4.3	4.9	6.9
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.53
Wedge/Flange Dimensions			
Fresh Food Flange Width (cm)	3.8	3.8	3.4
Fresh Food Wedge Depth (cm)	10.2	11.4	0.0
Resistivity (m2-C/W-cm)	0.5	0.5	0.5
Heat Paths			
FF Gasket Heat Leak (W/m-100C)	9.5	8.0	8.0
FF Cabinet Penetration Heat Leak (W)	0.0	3.0	0.0
Mullion			
Distance to Top (cm)	92.7	100.0	94.3
Thickness w/Liners (cm)	5.4	5.4	7.3
Resistivity w/Liners (m2-C/W-cm)	0.50	0.51	0.5
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Freezer Section (°C)	-15.0	-15.0	-15.0
Fresh Food Section (°C)	7.2	7.2	7.2
Air Under Cabinet (°C)	36.6	35.0	35.0
Compressor Compartment (˚C)	36.6	35.0	35.0
Air Entering Condenser (°C)	32.2	33.0	34.5
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Automatic	Automatic	Automatic
Timer Interval (Hr)	7.5	38.0	38.0
Heater On-Time (Min)	7.0	7.0	24.0
Defrost Power (W)	375	450	440
Other Cycle-Dependent Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	3	0	0
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Freezer Section (W)	0.7	0.0	4.2
Fresh Food Section (W)	0.0	0.4	0.0
Outside Cabinet (W)	0.0	0.0	1.5
Liquid Refrigerant Line Anti-Sweat			
Freezer Door Flange			
Cycle Average Energy (W)	1.0	3.8	3.0
Fraction Heat Leak (0-1)	0.75	0.5	0.75
Fresh Food Door Flange			
Cycle Average Energy (W)	0	0	0

Bottom-Mount Refrigerator-Freezers	**18.5 ft^3**	**25 ft^3 E*, #1**	**25 ft^3 E*, #2**
Mullion			
Cycle Average Energy (W)	2	1.3	1.0
Heat Leak to Freezer (0-1)	0.75	0.5	0.5
Heat Leak to Fresh Food (0-1)	0.15	0.25	0.25
Evaporator Design			
Exit Superheat (°C)	0.8	4.0	1.0
Fin Type (plain, wavy, herringbone)	Plain	Plain	Spine Fin
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole	Shaded Pole	DC-Input BLDC
Fan Power (W)	6.2	6.5	3.8
Air Flow Rate (Liter/s)	20	30	16.6
Tube Characteristics			
Width of Tube Row	48.9[b]	71.1[c]	76.2
Tube OD (mm)	7.9	7.9	9.7
Tube Wall Thickness (mm)	0.5	0.5	1.1
# of Tubes Deep	4.5[b]	4.5[c]	7
Tube Pitch (cm)	3.8	3.6	2.5
# of Tubes Normal to Airflow	4	4	2
Normal Tube Pitch (cm)	1.9	1.9	2.5
Fin Characteristics			
Fin Thickness (mm)	0.13	0.13	0.25
Fin Pitch (mm)	5.1	5.1	9.5
Fin Conductivity (W/m-K)	190	190	190
Fraction Finned (0-1)	0.98	0.89	1.0
Spine Fin Input Data			
Spine Height (mm)	NA	NA	10.5
Spine Width (mm)	NA	NA	0.8
Condenser Design			
Exit Subcooling (°C)	0.7	1.0	1.5
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin	Tube & Fin	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Wire	Wire	Wire
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC	AC-Input BLDC	DC-Input BLDC
Fan Power (W)	3.8	3.7	2.6
Air Flow Rate (Liter/s)	30	30.8	23.7
Tube Characteristics			

[b] Number of tubes in the air flow direction alternate 4 and 5, averaging 4.5. ERA analysis was conducted by selecting 4 rows deep and increasing the tube row width to 55.0 cm to compensate for the missing tubes.

[c] Number of tubes in the air flow direction alternate 4 and 5, averaging 4.5. ERA analysis was conducted by selecting 4 rows deep and increasing the tube row width to 80.0 cm to compensate for the missing tubes.

Bottom-Mount Refrigerator-Freezers	**18.5 ft^3**	**25 ft^3 E*, #1**	**25 ft^3 E*, #2**
Airflow Direction (W, L, H)	L	L	H
Tube OD (mm)	4.8	4.8	5.0
Tube Wall Thickness (mm)	0.5	0.6	0.64
Length of Tube in "L" Direction (cm)	34.9	34.9	52.4
# of Tubes in H Direction	2	2	3
Tube Pitch (cm)	2.2	3.8	0.8
# of Tubes in W Direction	26	30	10
Tube Pitch (cm)	2.2	2.2	2.5
Fraction Air through Exchanger (0-1)	0.8	1.0	1
Fin Characteristics			
Wire OD (mm)	1.3	1.3	1.4
# of Wires on 1-side	55	51	206
Wire Mounting (1-side, 2-sides)	2-sides	2-sides	2-sides
Wire Fin Pitch (mm)	4.8	4.8	2.5
Wire Length (cm)	57.1	66.7	23.5
Wire Conductivity (W/m-K)	44.7	44.7	44.7
Compressor Data			
Manufacturer	Embraco	Tecumseh	Embraco
Model	EMX70HSC	TPG1370YXA	VEGY 8H
Cycles per hour	1.0	1.5	0.45
Interchanger			
Effectiveness (0-1)	NA	0.95	0.98
Compressor Shell Inlet Temperature (°C)	33.3	Unspecified	Unspecified

Table 5-A.2.4: ERA Inputs for Built-In Bottom-Mount Refrigerator-Freezers (Product Class 5-BI)

Built-In Bottom-Mount Refrigerator-Freezer	**21 ft^3 Baseline**
General Data	
Fresh Food Volume (ft^3)	13.3
Freezer Volume (ft^3)	7.1
Total Volume (ft^3)	20.4
Adjusted Volume (ft^3)	24.9
Rated Energy Use (kWh/yr)	562
Calculated Max. Energy Use (kWh/yr)	573
Rated Energy Use Below Maximum (%)	1.9
Cabinet Dimensions	
Category (from ERA selection)	Bottom-Mount
Cabinet Height (cm)	172.9
Cabinet Width (cm)	90.8
Depth, from Door Flange (cm)	57.2
Depth, from Door Outer Surface (cm)	61.0
Liner Properties	
Outer Liner Thickness (mm)	1.5
Outer Liner Conductivity (W/m-C)	44.7
Inner Liner Thickness (mm)	0.9
Liner Conductivity (W/m-C)	190
Freezer Cabinet	
Insulation Thickness	
Side Wall (cm)	4.9
Back Wall (cm)	4.4
Bottom (cm)	4.2
Door (cm)	4.6
Insulation Resistivity	
Side Wall (m2-C/W-cm)	0.50
Back Wall (m2-C/W-cm)	0.50
Bottom (m2-C/W-cm)	0.50
Door (m2-C/W-cm)	0.50
Wedge/Flange Dimensions	
Freezer Width (cm)	3.6
Freezer Wedge Depth (cm)	6.7
Resistivity (m2-C/W-cm)	0.5
Heat Paths	
Freezer Gasket Heat Leak (W/m-100C)	9.0
Freezer Penetration Heat Leak (W)	0.0
Fresh Food Cabinet	
Insulation Thickness	
Top Wall (cm)	3.6
Side Wall (cm)	4.9

Built-In Bottom-Mount Refrigerator-Freezer	21 ft^3 Baseline
Back Wall (cm)	4.4
Door (cm)	4.6
Insulation Resistivity	
Top Wall (m2-C/W-cm)	0.50
Side Wall (m2-C/W-cm)	0.50
Back Wall (m2-C/W-cm)	0.50
Door (m2-C/W-cm)	0.50
Wedge/Flange Dimensions	
Fresh Food Flange Width (cm)	3.6
Fresh Food Wedge Depth (cm)	6.7
Resistivity (m2-C/W-cm)	0.5
Heat Paths	
Fresh Food Gasket Heat Leak (W/m-100C)	9.0
Fresh Food Cabinet Penetration Heat Leak (W)	0.0
Mullion	
Distance to Top (cm)	102.9
Thickness w/Liners (cm)	10.1
Resistivity w/Liners (m2-C/W-cm)	0.50
Air and Cabinet Temperatures	
Room Air (°C)	32.2
Freezer Section (°C)	-15.0
Fresh Food Section (°C)	7.2
Air Under Cabinet (°C)	33.0
Compressor Compartment (˚C)	33.0
Air Entering Condenser (°C)	32.2
Defrost and Controls Energy	
Defrost Type (Automatic, Manual)	Automatic
Timer Interval (hr)	24
Heater On-time (min)	10.0
Defrost Power (W)	484.2
Other Cycle-Dependent Loads	
Freezer Section (W)	0
Fresh Food Section (W)	0
Outside Cabinet (W)	0
Constant Electrical Loads	
Freezer Section (W)	0
Fresh Food Section (W)	0
Outside Cabinet (W)	1.3
Liquid Refrigerant Line Anti-Sweat	
Freezer Door Flange	
Cycle Average Energy (W)	3.7
Fraction Heat Leak (0-1)	0.5
Fresh Food Door Flange	

Built-In Bottom-Mount Refrigerator-Freezer	21 ft^3 Baseline
Cycle Average Energy (W)	2.2
Fraction Heat Leak (0-1)	0.5
Mullion	
Cycle Average Energy (W)	1.7
Heat Leak to Freezer (0-1)	0.5
Heat Leak to Fresh Food (0-1)	0.3
Cycle Parameters	
Cycle Type	Dual loop
Cycling Losses	YES
Cycles/hr	1.5
Refrigerant	R-134a
Evaporator Design (Freezer)	
Exit Superheat (°C)	0.8
Fin Type (plain, wavy, herringbone)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC
Fan Power (W)	4
Air Flow Rate (Liter/s)	16.5
Tube Characteristics	
Width of Tube Row	46.4
Tube OD (mm)	9.5
Tube Wall Thickness (mm)	0.64
# of Tubes Normal to Airflow	2
Normal Tube Pitch (cm)	1.8
# of Tubes Deep	14
Tube Pitch (cm)	1.3
Fin Characteristics	
Fin Thickness (mm)	0.19
Fin Pitch (mm)	4.2
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.88
Evaporator Design (Fresh Food)	
Exit Superheat (°C)	0.8
Fin Type (plain, wavy, herringbone)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC
Fan Power (W)	3.1
Air Flow Rate (Liter/s)	14.2
Tube Characteristics	
Width of Tube Row	50.6
Tube OD (mm)	9.3
Tube Wall Thickness (mm)	0.64
# of Tubes Deep	2

Built-In Bottom-Mount Refrigerator-Freezer	21 ft^3 Baseline
Tube Pitch (cm)	1.1
# of Tubes Normal to Airflow	9
Normal Tube Pitch (cm)	1.9
Fin Characteristics	
Fin Thickness (mm)	0.13
Fin Pitch (mm)	5.1
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.90
Condenser Design (Freezer)	
Exit Subcooling (°C)	0.7
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole
Fan Power in Fan Energy Calculations (W)	6[1]
Air Flow Rate (Liter/s)	18.9
Tube Characteristics	
Width of Tube Row	34.0
Tube OD (mm)	6.4
Tube Wall Thickness (mm)	0.46
# of Tubes Normal to Airflow	8
Normal Tube Pitch (cm)	1.3
# of Tubes along Airflow	2
Along Tube Pitch (cm)	2.2
Fraction Air through Exchanger (0-1)	1
Fin Characteristics	
Fin Thickness (mm)	0.19
Fin Pitch (mm)	3.6
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.86
Condenser Design (Fresh Food)	
Exit Subcooling (°C)	0.7
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole
Fan Power in Fan Energy Calculations (W)	6[1]
Air Flow Rate (Liter/s)	18.9
Tube Characteristics	

Built-In Bottom-Mount Refrigerator-Freezer	21 ft^3 Baseline
Width of Tube Row	34.0
Tube OD (mm)	6.4
Tube Wall Thickness (mm)	0.46
# of Tubes Normal to Airflow	8
Normal Tube Pitch (cm)	1.3
# of Tubes along Airflow	2
Along Tube Pitch (cm)	2.2
Fraction Air through Exchanger (0-1)	1
Fin Characteristics	
Fin Thickness (mm)	0.19
Fin Pitch (mm)	3.6
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.86
Compressor Data (Freezer)	
Manufacturer	Embraco
Model	EGU70HLC
Capacity Multiplier	1.0
Power Multiplier	1.0
Speed Multiplier	1.0
Compressor Data (Fresh Food)	
Manufacturer	Embraco
Model	EMT30HSC
Capacity Multiplier	1.0
Power Multiplier	1.0
Speed Multiplier	1.0
Interchangers	
Effectiveness (0-1, Freezer)	0.95
Effectiveness (0-1, Fresh Food)	0.95
Compressor Shell Inlet Temperature (°C)	Calculated

[1]This product has a single condenser with a separate circuit for each of the two refrigeration systems. The single fan operates when one or two of the compressors are operating. The condenser fan power was set to 0W for each of these systems in ERA, and a post-processing spreadsheet was used to calculate fan energy use with consideration of the overlap of the two system on-cycles.

Table 5-A.2.5: ERA Inputs for Bottom-Mount Refrigerator-Freezers w/TTD Ice (Product Class 5A)

Bottom-Mount Refrigerator-Freezers w/TTD Ice	**25 ft^3**
General Data	
Fresh Food Volume (ft^3)	17.6
Freezer Volume (ft^3)	7.1
Total Volume (ft^3)	24.7
Adjusted Volume (ft^3)	29.2
Rated Energy Use (kWh/yr)	547
Calculated Max. Energy Use (kWh/yr)	685
% Rated Energy Use Below Maximum (%)	20.0
Cabinet Dimensions	
Category	Bottom-Mount
Cabinet Height (cm)	171.1
Cabinet Width (cm)	91.4
Depth, from Door Flange (cm)	68.6
Depth, from Door Outer Surface (cm)	76.2
Liner Properties	
Outer Liner Thickness (mm)	0.5
Outer Liner Conductivity (W/m-C)	44.7
Inner Liner Thickness (mm)	1.4
Liner Conductivity (W/m-C)	0.16
Compressor Compartment Dimensions	
Top Depth (cm)	13.5
Bottom Depth (cm)	26.7
Height (cm)	24.5
Wall (vertical) (cm)	6.8
Wall (horizontal) (cm)	6.8
Freezer Cabinet	
Insulation Thickness	
Side Wall (cm)	6.8
Back Wall (cm)	7.9
Bottom (cm)	6.8
Door (cm)	7.1
Insulation Resistivity	
All Walls (m2-C/W-cm)	0.48[d]
Wedge/Flange Dimensions	
Freezer Flange Width (cm)	4.5
Freezer Wedge Depth (cm)	2.5
Resistivity (m2-C/W-cm)	0.5
Heat Paths	
Freezer Gasket Heat Leak (W/m-100C)	8[e]

[d] Product has insulation using cyclopentane blowing agent.

Bottom-Mount Refrigerator-Freezers w/TTD Ice	**25 ft^3**
Freezer Cabinet Penetration Heat Leak (W)	0
Fresh Food Cabinet	
Insulation Thickness	
Top Wall (cm)	5.2
Side Wall (cm)	5.1
Back Wall (cm)	4.7
Door (cm)	5.1
Insulation Resistivity	
All Walls (m2-C/W-cm)	0.48
Wedge/Flange Dimensions	
Fresh Food Flange Width (cm)	4.8
Fresh Food Wedge Depth (cm)	11.4
Resistivity (m2-C/W-cm)	0.5
Heat Paths	
Fresh Food Gasket Heat Leak (W/m-100C)	8[f]
Fresh Food Cabinet Penetration Heat Leak (W)	3.0
Mullion	
Distance to Top (cm)	102.2
Thickness w/Liners (cm)	5.1
Resistivity w/Liners (m2-C/W-cm)	0.47
Air and Cabinet Temperatures	
Room Air (°C)	32.2
Freezer Section (°C)	-15.0
Fresh Food Section (°C)	7.2
Air Under Cabinet (°C)	35.0
Compressor Compartment (˚C)	35.0
Air Entering Condenser (°C)	32.2
Defrost and Controls Energy	
Defrost Type (Automatic, Manual)	Automatic
Timer Interval (Hr)	38.0
Heater On-Time (Min)	12.7
Defrost Power (W)	396
Other Cycle-Dependent Loads	
Freezer Section (W)	0
Fresh Food Section (W)	0
Outside Cabinet (W)	0
Constant Electrical Loads	
Freezer Section (W)	0
Fresh Food Section (W)	0

[e] The checkbox indicating that the product has two drawers is checked.

[f] The checkbox indicating that the product has French doors is checked.

Bottom-Mount Refrigerator-Freezers w/TTD Ice	25 ft^3
Outside Cabinet (W)	4.0
Liquid Refrigerant Line Anti-Sweat	
Freezer Door Flange	
Cycle Average Energy (W)	3.8
Fraction Heat Leak (0-1)	0.5
Fresh Food Door Flange	
Cycle Average Energy (W)	0
Fraction Heat Leak (0-1)	0
Mullion	
Cycle Average Energy (W)	1.3
Heat Leak to Freezer (0-1)	.5
Heat Leak to Fresh Food (0-1)	.25
Evaporator Design	
Exit Superheat (°C)	0.8
Fin Type (plain, wavy, herringbone)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	DC-Input BLDC
Fan Power (W)	1.5
Air Flow Rate (Liter/s)	16.0
Tube Characteristics	
Width of Tube Row	70.5[g]
Tube OD (mm)	7.9
Tube Wall Thickness (mm)	0.7
# of Tubes Deep	4.5[g]
Tube Pitch (cm)	3.8
# of Tubes Normal to Airflow	4
Normal Tube Pitch (cm)	2.5
Fin Characteristics	
Fin Thickness (mm)	0.15
Fin Pitch (mm)	5.1
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.90
Condenser Design	
Exit Subcooling (°C)	0.7
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Wire
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	DC-Input BLDC
Fan Power (W)	1.56
Air Flow Rate (Liter/s)	24.0
Tube Characteristics	

[g] Number of tubes in the air flow direction alternate 4 and 5, averaging 4.5. ERA analysis was conducted by selecting 4 rows deep and increasing the tube row width to 79.3 cm to compensate for the missing tubes.

Bottom-Mount Refrigerator-Freezers w/TTD Ice	**25 ft^3**
Airflow Direction (W, L, H)	W
Tube OD (mm)	5.0
Tube Wall Thickness (mm)	0.64
Length of Tube in "L" Direction (cm)	15.2
# of Tubes in H Direction	12
Tube Pitch (cm)	2.2
# of Tubes in W Direction	10
Tube Pitch (cm)	2.5
Fraction Air through Exchanger (0-1)	0.9
Fin Characteristics	
Wire OD (mm)	1.4
# of Wires on 1-side	22
Wire Mounting (1-side, 2-sides)	2-sides
Wire Fin Pitch (mm)	6.4
Wire Length (cm)	18.0
Wire Conductivity (W/m-K)	44.7
Compressor Data	
Manufacturer	Embraco
Model #	EGX90HLC_BM25
Cycles per Hour	1.0
Interchanger	
Effectiveness (0-1)	0.95

Table 5-A.2.6: ERA Inputs for Side-Mount Refrigerator-Freezers (Product Classes 4 and 7)

Side-Mount Refrigerator-Freezers	PC7 26 ft^3	PC7 26 ft^3 E*	PC4 22 ft^3
General Data			
Fresh Food Volume (ft^3)	16.5	16.5	14.8
Freezer Volume (ft^3)	9.5	9.5	7.0
Total Volume (ft^3)	26.0	26.0	
Adjusted Volume (ft^3)	32.0	32.0	26.3
Rated Energy Use (ft^3)	728	582	635
Calculated Max. Energy Use (kWh/yr)	729	729	637
% Rated Energy Use Below Maximum (%)	0.2	20.2	0.3
Cabinet Dimensions			
Category	Side-Mount	Side-Mount	Side-Mount
Cabinet Height (cm)	165.9	165.9	162.6
Cabinet Width (cm)	90.2	90.2	85.1
Depth, from Door Flange (cm)	72.0	72.0	69.3
Depth, from Door Outer Surface (cm)	80.3	80.3	77.8
Liner Properties			
Outer Shell Thickness (mm)	0.5	1	0.4
Shell Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	0.5	1	0.4
Liner Conductivity (W/m-C)	0.16	0.16	44.7
Compressor Compartment Dimensions			
Top Depth (cm)	15.9	15.9	24.1
Bottom Depth (cm)	27.9	27.9	30.5
Height (cm)	23.5	23.5	25.1
Wall (vertical) (cm)	8.3	8.3	5.8
Wall (horizontal) (cm)	8.3	8.3	5.8
Freezer Cabinet			
Insulation Thickness – Freezer			
Top Wall (cm)	7.2	7.2	6.2
Side Wall (cm)	5.7	5.7	7.3
Back Wall (cm)	7.8	7.8	5.7
Bottom (cm)	8.3	8.3	5.8
Door (cm)	6.4	6.4	5.7
Insulation Resistivity - Freezer			
All Walls (m2-C/W-cm)	0.50	0.50	0.5
Wedge/Flange Dimensions			
Freezer Wedge Depth (cm)	0.1	0.1	7.0
Freezer Flange Width (cm)	5.7	5.7	3.8
Heat Paths			
Fzr Gasket Heat Leak (W/m-100C)	9.0	9.0	9.0
Fzr Cabinet Penetration Heat Leak (W)	7.0	7.0	8.0

Side-Mount Refrigerator-Freezers	PC7 26 ft^3	PC7 26 ft^3 E*	PC4 22 ft^3
Fresh Food Cabinet			
Insulation Thickness – Fresh Food			
Top Wall (cm)	4.0	4.0	4.0
Side Wall (cm)	3.6	3.6	3.8
Back Wall (cm)	3.6	3.6	4.8
Bottom (cm)	6.2	6.2	4.7
Door (cm)	6.4	6.4	5.7
Insulation Resistivity – Fresh Food			
All Walls (m2-C/W-cm)	0.50	0.50	0.5
Wedge/Flange Dimensions			
Fresh Food Wedge Depth (cm)	0.1	0.1	11.4
Fresh Food Flange Width (cm)	3.6	3.6	3.8
Heat Paths			
FF Gasket Heat Leak (W/m-100C)	9.0	9.0	9.0
FF Cabinet Penetration Heat Leak (W)	4.0	4.0	5.0
Mullion			
Distance to Right Side Wall (cm)	49.2	49.2	49.4
Thickness w/Liners (cm)	3.5	3.5	3.7
Resistivity w/Liners (m2-C/W-cm)	0.53	0.53	0.52
Air and Cabinet Temperatures			
Room Air (°C)	32.3	32.2	32.3
Freezer Section (°C)	-15.0	-15.0	-15.0
Fresh Food Section (°C)	7.2	7.2	7.2
Air Under Cabinet (°C)	35.0	35.0	35.0
Compressor Compartment (˚C)	35.0	35.0	35.0
Air Entering Condenser (°C)	33.0	33.0	33.0
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Automatic	Automatic	Automatic
Timer Interval (Hr)	24.0	24.0	24
Heater On-Time (Min)	5.0	5.0	18.0
Defrost Power (W)	500	500	535
Other Cycle-Dependent Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	0	0	0
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	0.5	0.4	0
Outside Cabinet (W)	0	0	1.3
Electric Anti-Sweat Heat			
Freezer Door Flange			
Cycle Average Energy (W)	2.1	2.1	0
Fraction Heat Leak (0-1)	0.5	0.5	0.5

Side-Mount Refrigerator-Freezers	**PC7 26 ft^3**	**PC7 26 ft^3 E***	**PC4 22 ft^3**
Liquid Refrigerant Line Anti-Sweat			
Freezer Door Flange			
Cycle Average Energy (W)	3.0	3.0	3.8
Fraction Heat Leak (0-1)	0.5	0.5	0.5
Fresh Food Door Flange			
Cycle Average Energy (W)	0	0	0
Fraction Heat Leak (0-1)	0	0	0
Mullion			
Cycle Average Energy (W)	3.0	3.0	1.3
Heat Leak to Freezer (0-1)	0.5	0.5	0.25
Heat Leak to Fresh Food (0-1)	0.25	0.25	0.25
Evaporator Design			
Exit Superheat (°C)	4.0	4.0	2.0
Fin Type (plain, wavy, herringbone)	Plain	Plain	Specify air-side area and heat transfer
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole	Shaded Pole	DC-Input BLDC
Fan Power (W)	5.8	5.8	3.3
Air Flow Rate (Liter/s)	21.3	21.3	21.3
Tube Characteristics			
Width of Tube Row	27.9[h]	27.9[h]	24.1
Tube OD (mm)	7.9	7.9	9.3
Tube Wall Thickness (mm)	0.7	0.7	0.8
# of Tubes Deep	7.5[h]	7.5[h]	16
Tube Pitch (cm)	3.8	3.8	2.9
# of Tubes Normal to Airflow	8	8	2
Normal Tube Pitch (cm)	1.3	1.3	5.1
Fin Characteristics			
Fin Thickness (mm)	0.2	0.2	0.25
Fin Pitch (mm)	5.1	5.1	9.5
Fin Conductivity (W/m-K)	190	190	190
Fraction Finned (0-1)	0.77	0.77	1
Fin Data (for spine fin only)			
Air-side effective area (m^2)	NA	NA	1.52
Air-side U-Value (W/m^2-C)	NA	NA	30
Condenser Design	[i]	[i]	[j]

[h] Number of tubes in the air flow direction alternate 7 and 8, averaging 7.5. ERA analysis was conducted by selecting 8 rows deep and decreasing the tube row width to 26.2 cm to compensate for the added tubes.

[i] Surface areas calculated by the condenser routine were increased by a factor of 2.63 for the 26 ft^3 side-mount refrigerators to calibrate with test data for condensing temperatures.

Side-Mount Refrigerator-Freezers	**PC7 26 ft^3**	**PC7 26 ft^3 E***	**PC4 22 ft^3**
Exit Subcooling (°C)	0.0	0.0	0.0
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin	Tube & Fin	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Wire	Wire	Wire
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole	AC-Input BLDC	Shaded Pole
Fan Power (W)	8.5	3.4	9.1
Air Flow Rate (Liter/s)	26	26	26
Tube Characteristics			
Airflow Direction (W, L, H)	W	W	H
Tube OD (mm)	4.8	4.8	4.7
Tube Wall Thickness (mm)	0.6	0.6	0.63
Length of Tube in "L" Direction	18.2	18.2	58.0
# of Tubes in H Direction	9	9	2
Tube Pitch (cm)	2.3	2.3	2.5
# of Tubes in W Direction	10	10	10
Tube Pitch (cm)	2.5	2.5	2.5
Fin Characteristics			
Wire OD (mm)	1.1	1.1	1.3
# of Wires on 1-side	23	23	111
Wire Mounting (1-side, 2-sides)	2-sides	2-sides	2-sides
Wire Fin Pitch (mm)	5.6	5.6	5.2
Wire Length (cm)	24.1	24.1	23.5
Wire Conductivity (W/m-K)	44.7	44.7	44.7
Fraction Air through Exchanger (0-1)	1	1	1
Compressor Data			
Manufacturer	Tecumseh	Embraco	Matsushita
Model #	TSA1374YAS	EGX70HLC	DC57C84RCU6
Cycles per Hour	1.12	1.16	0.7
Interchanger			
Effectiveness (0-1)	0.95	0.95	0.85
Component Adjustment Factors			
Condenser UA Multiplier	2.63	2.63	1.4

[j] Surface area calculated by the condenser routine was increased by a factor of 1.4 for the 22 ft^3 side-mount refrigerator to calibrate with test data for condensing temperatures.

Table 5-A.2.7: ERA Inputs for Upright Freezers with Automatic Defrost (Product Class 9)

Upright Freezers	**14 ft³ Baseline**	**20 ft³ Baseline**	**20 ft³ E***
General Data			
Freezer Volume (ft³)	13.7	20.1	20.1
Adjusted Volume (ft³)	23.7	34.8	34.8
Rated Energy Use (kWh/yr)	621	745	671
Calculated Max. Energy Use (kWh/yr)	621	758	758
% Rated Energy Use Below Maximum (%)	0.0	1.8	11.5
Cabinet Dimensions			
Category	Upright Freezer	Upright Freezer	Upright Freezer
Cabinet Height (cm)	130.2	156.2	156.2
Cabinet Width (cm)	71.3	83.8	83.8
Depth, from Door Flange (cm)	66.7	64.5	64.5
Depth, from Door Outer Surface (cm)	72.4	71.1	71.1
Liner Properties			
Outer Liner Thickness (mm)	0.4	0.9	0.9
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	0.4	2.2	2.2
Liner Conductivity (W/m-C)	44.7	0.16	0.16
Compressor Compartment			
Compressor Compartment part of cabinet?	NO	NO	NO
Insulation			
Insulation Thickness			
Top Wall (cm)	6.4	4.8	4.8
Side Wall (cm)	6.4	5.7	5.7
Back Wall (cm)	6.4	5.1	5.1
Bottom Wall (cm)	6.2	6.2	6.2
Door Average Thickness (cm)	3.8	7.1	7.1
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.50
Wedge/Flange Dimensions			
Wedge Depth (cm)	9.5	8.9	8.9
Flange Width (cm)	5.9	4.7	4.7
Heat Paths			
Gasket Heat Leak (W/m-100C)	12	9	9
Cabinet Penetration Heat Leak (W)	8	17	17
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Air Under Cabinet (°C)	35.0	35.5	35.5
Air Entering Condenser (°C)	32.2	32.2	32.2
Compressor Compartment (˚C)	35.0	35.5	35.5

Upright Freezers	14 ft^3 Baseline	20 ft^3 Baseline	20 ft^3 E*
Cabinet (°C)	-17.8	-17.8	-17.8
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Automatic	Automatic	Automatic
Timer Interval (Hr)	12.0	9.0	9.0
Heater On-Time (Min)	5.1	18.0	18.0
Defrost Power (W)	425	370	370
Other Cycle-Dependent Loads			
Outside Cabinet (W)	0	0	0
Cabinet (W)	1.6	0.3	0.3
Constant Electrical Loads			
Outside Cabinet (W)	0	0	0
Cabinet (W)	0	0	0
Refrigerant Line Anti-Sweat	None	None	None
Evaporator Design			
Exit Superheat	5.0	0.0	0.0
Fin Type (plain, wavy, herringbone)	Plain	Plain	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole	Shaded Pole	AC-Input BLDC
Fan Power (W)	7.4	11.2	4.5
Air Flow Rate (Liter/s)	26.0	23.7	23.7
Tube Characteristics			
Width of Tube Row	55.9[k]	50.2	50.2
Tube OD (mm)	7.8	8.6	8.6
Tube Wall Thickness (mm)	0.8	0.9	0.9
# of Tubes Deep	4.5[k]	9	9
Tube Pitch (cm)	3.8	3.2	3.2
# of Tubes Normal to Airflow	4	2	2
Normal Tube Pitch (cm)	1.3	2.5	2.5
Fin Characteristics			
Fin Thickness (mm)	0.18	0.24	0.24
Fin Pitch (mm)	4.6	5.1	5.1
Fin Conductivity (W/m-K)	190	190	190
Fraction Finned (0-1)	0.9	0.9	0.9
Condenser Design			
Exit Subcooling (°C)	3	1	1
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Hot-wall	Hot-wall	Hot-wall
Design Data			
Total Area (sides) (m^2)	2.0	2.1	2.1
Width, Side Normal to Tubes (cm)	288	333	333

[k] Number of tubes in the air flow direction alternate 4 and 5, averaging 4.5. ERA analysis was conducted by selecting 4 rows deep and increasing the tube row width to 62.9 cm to compensate for the missing tubes.

Upright Freezers	**14 ft^3 Baseline**	**20 ft^3 Baseline**	**20 ft^3 E***
Number of Legs	26	30	30
Length of Tubing on Wall (m)	20.3	22.0	22.0
Tube OD (mm)	4.7	6.4	6.4
Tube Wall Thickness (mm)	0.8	0.8	0.8
Thickness of Liner (mm)	0.38	0.9	0.9
Thermal Conductivity (W/m-K)	44.7	44.7	44.7
Number of other Hot Walls (0-2)	1	1	1
Second Hotwall (Top)			
Total Area (m^2)	0.47	0.52	0.52
Width, Side Normal to Tubes (cm)	71	84	84
Number of Legs	7	8	8
Length of Tubing on Wall (m)	5.4	5.8	5.8
Compressor Data			
Manufacturer	Embraco	Matsushita	Matsushita
Model #	EMY60HER	DG73C12RAU6	DG73C12RAU6
Cycles per Hour	1.4	1.5	1.5
Interchanger			
Effectiveness (0-1)	0.7	0.98	0.98

Table 5-A.2.8: ERA Inputs for Built-In Upright Freezers (Product Class 9-BI)

Built-In Upright Freezer	**21 ft^3 E***
General Data	
Upper Compartment Volume (ft^3)	13.6
Lower Compartment Volume (ft^3)	7.9
Total Volume (ft^3)	21.5
Adjusted Volume (ft^3)	37.1
Rated Energy Use (kWh/yr)	613
Calculated Max. Energy Use (kWh/yr)	787
Rated Energy Use Below Maximum (%)	22.1
Cabinet Dimensions	
Category (from ERA selection)	Bottom-Mount
Cabinet Height (cm)	172.9
Cabinet Width (cm)	90.8
Depth, from Door Flange (cm)	57.2
Depth, from Door Outer Surface (cm)	61.0
Liner Properties	
Outer Liner Thickness (mm)	1.5
Outer Liner Conductivity (W/m-C)	44.7
Inner Liner Thickness (mm)	0.9
Liner Conductivity (W/m-C)	190
Lower Compartment Cabinet	
Insulation Thickness	
Side Wall (cm)	4.9
Back Wall (cm)	4.4
Bottom (cm)	4.2
Door (cm)	5.2
Insulation Resistivity	
Side Wall (m2-C/W-cm)	0.73
Back Wall (m2-C/W-cm)	0.88
Bottom (m2-C/W-cm)	0.76
Door (m2-C/W-cm)	0.68
Wedge/Flange Dimensions	
Lower Compartment Flange Width (cm)	3.6
Lower Compartment Wedge Depth (cm)	6.7
Resistivity (m2-C/W-cm)	0.5
Heat Paths	
Lower Compartment Gasket Heat Leak (W/m-100C)	9.0
Lower Compartment Penetration Heat Leak (W)	0.0
Upper Compartment Cabinet	
Insulation Thickness	
Top Wall (cm)	3.6
Side Wall (cm)	4.9
Back Wall (cm)	4.4

Built-In Upright Freezer	$21\ ft^3$ E*
Door (cm)	3.6
Insulation Resistivity	
Top Wall (m2-C/W-cm)	0.50
Side Wall (m2-C/W-cm)	0.50
Back Wall (m2-C/W-cm)	0.50
Door (m2-C/W-cm)	0.87
Wedge/Flange Dimensions	
Upper Compartment Flange Width (cm)	3.6
Upper Compartment Wedge Depth (cm)	6.7
Resistivity (m2-C/W-cm)	0.5
Heat Paths	
Upper Gasket Heat Leak (W/m-100C)	9.0
Upper Cabinet Penetration Heat Leak (W)	0.0
Mullion	
Distance to Top (cm)	102.9
Thickness w/Liners (cm)	10.1
Resistivity w/Liners (m2-C/W-cm)	0.001
Air and Cabinet Temperatures	
Room Air (°C)	32.2
Lower Compartment Section (°C)	-17.7
Upper Compartment Section (°C)	-17.8
Air Under Cabinet (°C)	33.0
Compressor Compartment (˚C)	33.0
Air Entering Condenser (°C)	32.2
Defrost and Controls Energy	
Defrost Type (Automatic, Manual)	Automatic
Timer Interval (hr)	24
Heater On-time (min)	10.0
Defrost Power (W)	762
Other Cycle-Dependent Loads	
Lower Compartment Section (W)	0
Upper Compartment Section (W)	0
Outside Cabinet (W)	0
Constant Electrical Loads	
Lower Compartment Section (W)	0
Upper Compartment Section (W)	0
Outside Cabinet (W)	1.3
Liquid Refrigerant Line Anti-Sweat	
Lower Compartment Door Flange	
Cycle Average Energy (W)	3.7
Fraction Heat Leak (0-1)	0.5
Upper Compartment Door Flange	
Cycle Average Energy (W)	3.7

Built-In Upright Freezer	21 ft^3 E*
Fraction Heat Leak (0-1)	0.5
Mullion	
Cycle Average Energy (W)	2.2
Heat Leak to Lower Compartment (0-1)	0.4
Heat Leak to Upper Compartment (0-1)	0.4
Cycle Parameters	
Cycle Type	Single Evaporator
Cycling Losses	YES
Cycles/hr	1.5
Refrigerant	R-134a
Evaporator Design	
Exit Superheat (°C)	0.8
Fin Type (plain, wavy, herringbone)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC
Fan Power (W)	3.1
Air Flow Rate (Liter/s)	21.2
Tube Characteristics	
Width of Tube Row	65.1
Tube OD (mm)	9.5
Tube Wall Thickness (mm)	0.31
# of Tubes Normal to Airflow	1
Normal Tube Pitch (cm)	2.5
# of Tubes Deep	20
Tube Pitch (cm)	2.5
Fin Characteristics	
Fin Thickness (mm)	0.19
Fin Pitch (mm)	4.2
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.92
Condenser Design	
Exit Subcooling (°C)	0.7
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Plain
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC
Fan Power (W)	4
Air Flow Rate (Liter/s)	37.8
Tube Characteristics	
Width of Tube Row	46.2

Built-In Upright Freezer	21 ft^3 E*
Tube OD (mm)	6.4
Tube Wall Thickness (mm)	0.46
# of Tubes Normal to Airflow	8
Normal Tube Pitch (cm)	1.3
# of Tubes along Airflow	2
Along Tube Pitch (cm)	2.2
Fraction Air through Exchanger (0-1)	1
Fin Characteristics	
Fin Thickness (mm)	0.19
Fin Pitch (mm)	3.6
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.87
Compressor Data	
Manufacturer	Embraco
Model	EGX90HLC
Capacity Multiplier	1.0
Power Multiplier	1.0
Speed Multiplier	1.0
Interchangers	
Effectiveness (0-1)	0.95
Compressor Shell Inlet Temperature (°C)	Calculated

Table 5-A.2.9: ERA Inputs for Chest Freezers with Manual Defrost (Product Class 10)

Chest Freezers	15 ft^3 Baseline	15ft^3 E*	20 ft^3 Baseline
General Data			
Freezer Volume (ft^3)	14.8	14.8	19.9
Adjusted Volume (ft^3)	25.6	25.6	34.4
Rated Energy Use (kWh/yr)	394	354	480
Calculated Max. Energy Use (kWh/yr)	397	397	484
Rated Energy Use Below Maximum (%)	0.7	10.8	0.8
Cabinet Dimensions			
Category (from ERA selection)	Chest Freezer	Chest Freezer	Chest Freezer
Cabinet Height (cm)	116.8	116.8	155.9
Cabinet Width (cm)	68.6	68.6	69.9
Depth, from Door Flange (cm)	81.1	81.1	81.6
Depth, from Door Outer Surface (cm)	86.8	86.8	87.0
Liner Properties			
Outer Liner Thickness (mm)	0.5	0.5	0.5
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	1.3	1.3	0.4
Liner Conductivity (W/m-C)	44.7	44.7	44.7
Compressor Compartment Dimensions[1]			
Height (cm)	27.9	27.9	22.9
Depth (cm)	9.1	9.1	22.2
Fractional width of compartment (cm)	1	1	1
Top Wall Insulation Thickness (cm)	6.9	6.9	7.7
Front Wall Insulation Thickness (cm)	5.1	5.1	7.7
Insulation Thickness			
Side Wall (cm)	6.6	6.6	6.7
Bottom (cm)	6.4	6.4	7.0
Door (cm)	4.8	4.8	5.1
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.5	0.5	0.5
Door (m2-C/W-cm)	0.5	0.5	0.33
Wedge/Flange Dimensions			
Wedge Depth (cm)	1.3	1.3	1.0
Flange Width (cm)	4.6	4.6	5.4
Wedge Depth (cm)	1.3	1.3	1.0
Resistivity (m2-C/W-cm)	0.5	0.5	0.5
Heat Paths			
Gasket Heat Leak (W/m-100C)	9	9	9
Cabinet Penetration Heat Leak (W)	0.0	0.0	6.5
Air and Cabinet Temperatures			

[1] Windows ERA allows incorporation of the compressor compartment either into the long or the short wall. DOS ERA allowed incorporation only into the short wall, so the short wall option should be entered for Windows ERA.

Chest Freezers	15 ft^3 Baseline	15ft^3 E*	20 ft^3 Baseline
Room Air (°C)	32.2	32.2	32.2
Air Under Cabinet (°C)	38.0	38.0	36.0
Air Entering Condenser (°C)	32.2	32.2	33.0
Compressor Compartment (°C)	38.0	38.0	36.0
Cabinet (°C)	-17.8	-17.8	-17.8
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Manual	Manual	Manual
Other Cycle-Dependent Loads			
Outside Cabinet (W)	0	0	0
Inside Cabinet (W)	0	0	0
Constant Electrical Loads			
Outside Cabinet (W)	0.4	0.4	0.1
Inside Cabinet (W)	0	0	0
Refrigerant Line Anti-Sweat	None	None	None
Evaporator Design (Cold Wall)			
Exit Superheat	0.5	0.5	0.5
Tube OD (mm)	6.4	6.4	7.9
Tube Wall Thickness (mm)	0.8	0.8	0.8
Side Walls (perimeter)			
Total Area of Side Walls (m^2)	1.57	1.57	2.73
Number of Tube Legs	9	9	9
Width Normal to Tubes	49.1	49.1	73
Liner Thickness (mm)	1.3	1.3	0.4
Liner Conductivity (W/mK)	44.7	44.7	44.7
Bottom Surface			
Area of Bottom Surface (m^2)	0.17	0.17	0.3
Number of Tube Legs	3	3	2
Width Normal to Tubes	16.4	16.4	15
Condenser Design			
Exit Subcooling (°C)	0.5	0.5	0.5
Configuration	Hot-wall	Hot-wall	Hot-wall
Total Area (m^2)	2.0	2.0	2.6
Width of Side Normal to Tubes (cm)	53.3	53.3	50.6
Number of Legs	6	6	6
Length of Tubing on Wall (m)	22.3	22.3	32.2
Tube OD (mm)	4.8	4.8	4.8
Tube Wall Thickness (mm)	0.8	0.8	0.8
Thickness of Liner (mm)	0.5	0.5	0.5
Thermal Conductivity (W/m-K)	44.7	44.7	44.7
Number of other Hot Walls (0-2)	0	0	0
Second Hotwall	None	None	None
Compressor Data			
Manufacturer	Matsushita	Matsushita	Matsushita

Chest Freezers	15 ft^3 Baseline	15ft^3 E*	20 ft^3 Baseline
Model #	SF51C97RAU6	DG57C84RAU6	DGH66C94RAU
Cycles per Hour	1.0	1.0	1.0
Interchanger			
Effectiveness (0-1)	0.9	0.9	0.7

Table 5-A.2.10: ERA Inputs for Compact Refrigerators (Product Class 11)

Compact Refrigerators	4 ft^3 Baseline	4 ft^3 E*	1.7 ft^3
General Data			
Fresh Food Volume (ft^3)	3.3	3.65	1.5
Freezer Volume (ft^3)	0.7[m]	0.44	0.2
Total Volume (ft^3)	4.0	4.1	1.7
Adjusted Volume (ft^3)	4.3	4.3	1.7[n]
Rated Energy Use (kWh/yr)	340	270	296
Calculated Max. Energy Use (kWh/yr)	345	345	317
Rated Energy Use Below Maximum (%)	1.5	22	6.8
Cabinet Dimensions			
Category	Single Door w/ Ice Box	Single Door w/ Ice Box	Single Door w/ Ice Box
Cabinet Height (cm)	83.5	83.8	47.0
Cabinet Width (cm)	47.3	49.5	44.5
Depth, from Door Flange (cm)	40.4	45.6	40.6
Depth, from Door Outer Surface (cm)	44.5	50.2	44.8
Liner Properties			
Outer Liner Thickness (mm)	0.8	0.5	0.4
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	1.3	1.1	1.3
Liner Conductivity (W/m-C)	0.16	0.16	0.16
Compressor Compartment Dimensions			
Height (cm)	21.6	20.3	19.1
Horizontal Wall Thickness (cm)	3.4	4.3	3.8
Top Depth (cm)	16.2	12.7	13.0
Vertical Wall Thickness (cm)	3.3	3.0	2.8
Bottom Depth (cm)	16.2	12.7	13.0
Insulation Thickness – Fresh Food			
Top Wall (cm)	2.5	4.1	3.4
Side Wall (cm)	2.7	4.1	3.4
Back Wall (cm)	3.3	5.8	3.5
Bottom (cm)	2.5	4.8	3.1
Door (cm)	2.8	4.3	3.3
Insulation Resistivity – Fresh Food			
All Walls (m2-C/W-cm)	0.50	0.50	0.50
Wedge/Flange Dimensions			
Fresh Food Flange Width (cm)	2.3	3.3	2.5
Fresh Food Wedge Depth (cm)	0	0	0.6

[m] The rated freezer volume is 0.7 ft^3 as indicated, but the volume based on observed freezer dimensions is 0.4 ft^3

[n] This product is classified as an all-refrigerator for testing and rating purposes, since its freezer compartment is less than 0.5 ft^3 in volume. It is not clear wheter the 4 ft^3 E* product was also rated as an all-refrigerator based on available data. DOE analyzed both 4 ft^3 products as basic refrigerators and the 1.7 ft^3 product as an all-refrigerator.

Compact Refrigerators	4 ft^3 Baseline	4 ft^3 E*	1.7 ft^3
Resistivity (m2-C/W-cm)	0.5	0.5	0.5
Heat Paths			
Gasket Heat Leak (W/m-100C)	12.0	9.0	12.0
Cabinet Penetration Heat Leak (W)	0	0	2.5
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Freezer Section (°C)	-9.4	-9.4	-3.9
Fresh Food Section (°C)	7.2	7.2	3.3
Air Under Cabinet (°C)	35.0	36.6	35.0
Compressor Compartment (°C)	35.0	36.6	35.0
Air Entering Condenser (°C)	32.2	32.2	32.2
Defrost and Controls Energy			
Defrost Type (Manual, Cycle)	Manual	Manual	Manual
Cycle-Dependent Loads			
Inside Cabinet (W)	0	0	0
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Inside Cabinet (W)	0	0	0
Outside Cabinet (W)	0	0	0
Anti-Sweat Heat	None	None	None
Evaporator Design			
Exit Superheat (°C)	0.5	0.1	2.0
Tube Height (mm) Width (mm) Hydraulic Diameter (mm)	4.4 9.5 6.1	4.7 9.5 6.3	4.3 9.5 5.9
Refrigerant Tube Length (m)	6.7	6.1	3.1
Number of Legs	11	10	8
Freezer Surfaces: Present (Y/N), Spacing to Cabinet Wall (cm)			
Top	N	N	N
Left	Y 1.4	Y 1.6	Y 15
Right	Y 1.4	Y 1.6	Y 1.3
Freezer Box Dimensions			
Width (cm)	38.7	38.4	21.0
Height (cm)	11.4	12.7	8.9
Depth (cm)	25.4	24.8	21.0
Inner Door (Y or N)	Y	Y	Y
Condenser Design			
Exit Subcooling (°C)	1.0	1.0	0.5
Heat Transfer Type (Static, Hot-wall, Tube & Fin, Microchannel)	Static	Static	Hot-wall
Static Condenser Details			
Fin Type	Wire	Wire	NA

Compact Refrigerators	4 ft^3 Baseline	4 ft^3 E*	1.7 ft^3
Tube OD (mm)	4.8	4.8	NA
Tube Wall Thickness (mm)	0.6	0.6	NA
Number of Tube Rows	9	9	NA
Tube Pitch (mm)	6.0	6.0	NA
Width of Tube Row (cm)	43.2	43.2	NA
Wire OD (mm)	1.5	1.5	NA
Wire Length (cm)	60.3	60.3	NA
# of Wires	98	98	NA
Wire Conductivity (W/m-K)	44.7	44.7	NA
Hot Wall Condenser Details			
First Hot Wall (sides)			
Total Area of Side Panels (m2)	NA	NA	0.33
Width of Side Normal to Tubes (cm)	NA	NA	94.0
Number of Legs	NA	NA	16
Length of Tubing on Wall (m)	NA	NA	6.0
Tube OD (cm)	NA	NA	3.9
Tube Wall (mm)	NA	NA	0.76
Liner Thickness (mm)	NA	NA	0.38
Thermal Conductivity (W/mK)	NA	NA	44.7
Second Hot Wall (top)			
Total Area (m2)	NA	NA	0.10
Width Normal to Tubes (cm)	NA	NA	23.5
Number of Legs	NA	NA	4
Length of Tubing on Wall (m)	NA	NA	1.7
Compressor Data			
Manufacturer	ZEL	LG	Huayi
Model #	GVT44AD	NSA36LACG	AES25DS
Cycles per Hour	4.0	5.0	3.0
Interchanger			
Effectiveness (0-1)	0.8	0.98	0.7

Table 5-A.2.11: ERA Inputs for Compact Chest Freezers (Product Class 18)

Compact Chest Freezers	3.4 ft^3	7.0 ft^3, #1	7.0 ft^3, #2
General Data			
Freezer Volume (ft^3)	3.4	7.0	7.0
Adjusted Volume (ft^3)	5.9	12.1	12.1
Rated Energy Use (kWh/yr)	213	277	276
Calculated Max. Energy Use (kWh/yr)	213	279	279
Rated Energy Use Below Maximum (%)	0	0.6	0.9
Cabinet Dimensions			
Category	Chest Freezer	Chest Freezer	Chest Freezer
Cabinet Length (cm)	53.3	92.7	94.0
Cabinet Width (cm)	58.4	51.8	58.4
Depth, from Door Flange (cm)	76.2	74.6	73.3
Depth, from Door Outer Surface (cm)	81.3	80.0	78.7
Liner Properties			
Outer Liner Thickness (mm)	0.5	0.6	0.9
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	0.4	0.4	1.0
Liner Conductivity (W/m-C)	190	190	190
Compressor Compartment Dimensions[o]			
Height (cm)	21.0	28.6	22.9
Depth (cm)	19.7	18.1	22.9
Fractional width of compartment (0-1)	1	1	1
Top Wall Insulation Thickness (cm)	6.6	7.0	6.4
Front Wall Insulation Thickness (cm)	6.4	7.0	7.3
Location	Short Wall	Short Wall	Short Wall
Insulation Thickness – Freezer			
Side Wall (cm)	6.7	6.0	6.4
Bottom Wall (cm)	6.3	5.1	7.3
Door (cm)	5.8	6.4	5.5
Insulation Resistivity – Freezer			
All Walls (m2-C/W-cm)	0.5	0.5	0.53
Wedge/Flange Dimensions			
Wedge Depth (cm)	1.0	1.0	1.9
Flange Width (cm)	3.8	4.0	4.4
Heat Paths			
Gasket Heat Leak (W/m-100C)	7.5	7.5	7.5
Cabinet Penetration Heat Leak (W)	0	0	0
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Air Under Cabinet (°C)	35.0	35.0	35.0

[o] Windows ERA allows incorporation of the compressor compartment either into the long or the short wall. DOS ERA allowed incorporation only into the short wall, so the short wall option should be entered for Windows ERA.

Compact Chest Freezers	**3.4 ft³**	**7.0 ft³, #1**	**7.0 ft³, #2**
Air Entering Condenser (°C)	32.2	32.2	32.2
Compressor Compartment (°C)	35.0	35.0	35.0
Cabinet Setpoint (°C)	-17.8	-17.8	-17.8
Defrost and Controls Energy			
Defrost Type (Manual, Auto)	Manual	Manual	Manual
Cycle-Dependent Loads			
Inside Cabinet (W)	0	0	0
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Inside Cabinet (W)	0	0	0
Outside Cabinet (W)	0.4	0.2	0.1
Anti-Sweat Heat	None	None	None
Evaporator Design			
Exit Superheat (°C)	0.5	0.5	0.0
Tube OD (mm)	8.0	7.6	6.4
Tube Wall Thickness (mm)	0.6	0.6	0.6
Liner Thickness (mm)	0.4	0.4	1.0
Liner Conductivity (W/m-K)	190	190	190
Total Area of Side Walls (m2)	1.1	1.43	1.5
Number of Legs	10	9	12
Width Normal to Tubes (cm)	68.3	72	64.8
Condenser Design			
Exit Subcooling (°C)	0.5	0.5	0.0
Heat Transfer Type (Static, Hot-wall, Tube & Fin, Microchannel)	Static	Hot-wall	Hot-wall
Static Condenser Details			
Fin Type	Wire	NA	NA
Tube OD (mm)	6.0	NA	NA
Tube Wall Thickness (mm)	0.64	NA	NA
Number of Tube Rows	14	NA	NA
Tube Pitch (mm)	4.6	NA	NA
Width of Tube Row (cm)	47.0	NA	NA
Wire OD (mm)	1.4	NA	NA
Wire Length (cm)	64.5	NA	NA
# of Wires	110	NA	NA
Wire Conductivity (W/m-K)	44.7	NA	NA
Hot Wall Condenser Details			
Total Area of Side Panels (m2)	NA	1.5	1.72
Width of Side Normal to Tubes (cm)	NA	53.3	241
Number of Legs	NA	7	32
Length of Tubing on Wall (m)	NA	20.2	19.6
Tube OD (mm)	NA	4.6	3.9
Tube Wall Thickness (mm)	NA	0.6	0.5

Compact Chest Freezers	3.4 ft^3	7.0 ft^3, #1	7.0 ft^3, #2
Liner Thickness (mm)	NA	0.64	0.9
Thermal Conductivity (W/mK)	NA	44.7	44.7
Compressor Data			
Manufacturer	Jiangsu Baixue[p]	Danfoss	ZEL
Model #	QDH3511G	TTE4.6GFK	GVY44AD
Cycles per Hour	2.25	1.3	2.0
Interchanger			
Effectiveness (0-1)	0.95	0.95	0.95

[p] Jiangsu Baixue Electric Appliances Co. Ltd.

5-A.3 INCREMENTAL COST DETAIL

The tables in this section identify the groups of design options and their associated costs for all analyzed efficiency levels for the reverse-engineering units for which the full incremental cost analysis was conducted.

Table 5-A.3.1: Incremental Cost Detail for 16 ft^3 Top-Mount Refrigerator-Freezer (Product Class 3)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Condenser Size by 100%	$8.46	$0.00	$0.00	$0.00	$2.20	$10.66	$20.44	$20.44
	Increase Compressor EER from 5.55 to 6.1	$7.76	$0.00	$0.00	$0.00	$2.02	$9.78		
15%	Increase Compressor EER from 6.1 to 6.26	$3.00	$0.00	$0.00	$0.00	$0.78	$3.78	$9.20	$29.64
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
20%	Increase Evaporator Size by 14%	$0.84	$0.00	$0.00	$0.00	$0.22	$1.06	$95.85	$125.50
	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08		
	Variable Speed Compressor	$67.23	$0.00	$0.00	$0.00	$17.48	$84.71		
25%	12.2 sqft VIP in FZR Cabinet	$39.92	$4.17	$5.16		$12.80	$62.05	$62.05	$187.54
30%	2.9 sqft VIP in FZR Door	$9.50	$0.42	$1.16		$2.88	$13.96	$82.58	$270.12
	7.1 sqft VIP in FF Door	$23.08	$0.42	$2.75		$6.82	$33.07		
	6.7 sqft VIP in FF Cabinet	$22.00	$3.25	$2.96		$7.34	$35.55		
30.6%	1.9 sqft more VIP in FF Cabinet	$6.19	$0.91	$0.83		$2.06	$9.99	$9.99	$280.12

Table 5-A.3.2: Incremental Cost Detail for 21 ft³ Top-Mount Refrigerator-Freezer (Product Class 3)

<table>
<tr><th rowspan="2">Efficiency Level</th><th rowspan="2">Design Options Added</th><th colspan="6">Design Option Costs</th><th colspan="2">Incremental Costs</th></tr>
<tr><th>Material</th><th>Labor</th><th>Overhead</th><th>Depreciation</th><th>G&A, Profit</th><th>Total</th><th>Added</th><th>Cumulative</th></tr>
<tr><td>10%</td><td>Increase Compressor EER from 4.92 to 5.57</td><td>$2.52</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$0.66</td><td>$3.18</td><td>$3.18</td><td>$3.18</td></tr>
<tr><td>15%</td><td>Increase Compressor EER from 5.57 to 5.96</td><td>$5.27</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$1.37</td><td>$6.63</td><td>$6.63</td><td>$9.81</td></tr>
<tr><td rowspan="3">20%</td><td>Increase Compressor EER from 5.94 to 6.08</td><td>$2.38</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$0.62</td><td>$3.00</td><td rowspan="3">$10.95</td><td rowspan="3">$20.76</td></tr>
<tr><td>Increase Evaporator Size by 25%</td><td>$2.01</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$0.52</td><td>$2.53</td></tr>
<tr><td>Brushless DC Condenser Fan Motor</td><td>$4.30</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$1.12</td><td>$5.42</td></tr>
<tr><td>25%</td><td>Brushless DC Evaporator Fan Motor</td><td>$4.10</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$1.07</td><td>$5.17</td><td>$5.17</td><td>$25.92</td></tr>
<tr><td rowspan="3">30%</td><td>Adaptive Defrost</td><td>$8.00</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$2.08</td><td>$10.08</td><td rowspan="3">$64.87</td><td rowspan="3">$90.80</td></tr>
<tr><td>3.6 sqft VIP in FZR Door</td><td>$11.73</td><td>$0.42</td><td colspan="2">$1.42</td><td>$3.53</td><td>$17.09</td></tr>
<tr><td>7.6 sqft VIP in FZR Cabinet</td><td>$24.82</td><td>$1.97</td><td colspan="2">$3.13</td><td>$7.78</td><td>$37.70</td></tr>
<tr><td rowspan="2">35.5%</td><td>Remove 0.9 sqft VIP FZR Cabinet</td><td>-$2.79</td><td>-$0.22</td><td colspan="2">-$0.35</td><td>-$0.87</td><td>-$4.23</td><td rowspan="2">$81.24</td><td rowspan="2">$172.03</td></tr>
<tr><td>Variable Speed Compressor</td><td>$67.84</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$17.64</td><td>$85.47</td></tr>
<tr><td rowspan="3">40.5%</td><td>7.6 sqft VIP in FZR Cabinet</td><td>$18.73</td><td>$1.49</td><td colspan="2">$2.37</td><td>$5.87</td><td>$28.45</td><td rowspan="3">$120.24</td><td rowspan="3">$292.27</td></tr>
<tr><td>8.5 sqft VIP in FF Door</td><td>$27.76</td><td>$0.42</td><td colspan="2">$3.30</td><td>$8.18</td><td>$39.65</td></tr>
<tr><td>10.9 sqft VIP in FF Cabinet</td><td>$35.56</td><td>$1.48</td><td colspan="2">$4.33</td><td>$10.76</td><td>$52.13</td></tr>
</table>

Table 5-A.3.3: Incremental Cost Detail for 21 ft^3 Built-in All-Refrigerator (Product Class 3A-BI)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Decrease Both Compressor Capacities (same EER)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$7.14	$7.14
	10% Increase to Condenser Area	$1.00	$0.00	$0.00	$0.00	$0.40	$1.40		
	BLDC Evaporator Fan Upper Evaporator	$4.10	$0.00	$0.00	$0.00	$1.64	$5.74		
15%	BLDC Evaporator Fan Lower Evaporator	$4.10	$0.00	$0.00	$0.00	$1.64	$5.74	$11.76	$18.90
	BLDC Condenser Fan	$4.30	$0.00	$0.00	$0.00	$1.72	$ 6.02		
20%	VIP--Upper Door	$30.80	$0.42	$3.65		$13.95	$48.82	$108.20	$127.10
	VIP--Lower Cabinet	$35.49	$2.48	$4.44		$16.97	$59.38		
25%	VIP--Lower Cabinet	$24.20	$1.69	$3.03		$11.57	$40.48	$144.99	$272.09
	VIP--Upper Cabinet	$12.53	$4.17	$1.95		$7.46	$26.11		
	Upper SystemVSC	$56.00	$0.00	$0.00	$0.00	$22.40	$78.40		
29%	VIP--Lower Doors	$19.54	$0.42	$2.33		$8.92	$31.20	$109.60	$381.70
	Lower System VSC	$56.00	$0.00	$0.00	$0.00	$22.40	$78.40		

Table 5-A.3.4: Incremental Cost Detail for 18.5 ft^3 Bottom-Mount Refrigerator-Freezer (Product Class 5)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 5.61 to 6.26	$9.98	$0.00	$0.00	$0.00	$2.60	$12.58	$20.89	$20.89
	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17		
	Increase Evaporator Size by 25%	$2.50	$0.00	$0.00	$0.00	$0.65	$3.15		
15%	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08	$12.35	$33.24
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
	Remove Evaporator Size Increase	-$2.50	$0.00	$0.00	$0.00	-$0.65	-$3.15		
20%	Variable Antisweat Heat Control	$17.48	$0.00	$0.00	$0.00	$4.54	$22.02	$25.17	$58.42
	Increase Evaporator Size by 25%	$2.50	$0.00	$0.00	$0.00	$0.65	$3.15		
25%	Variable Speed Compressor	$60.02	$0.00	$0.00	$0.00	$15.60	$75.62	$86.84	$145.26
	2.4 sqft VIP in FZR Door	$7.76	$0.21	$0.93		$2.31	$11.22		
30%	6.8 sqft VIP in FF Door	$22.09	$0.42	$2.63		$6.54	$31.68	$111.75	$257.01
	2.4 sqft more VIP in FZR Door	$7.76	$0.21	$0.93		$2.31	$11.22		
	13.7 sqft VIP in FZR Cabinet	$44.76	$4.17	$5.72		$14.21	$68.86		
32%	7.2 sqft VIP in FF Cabinet	$23.49	$4.17	$3.24		$8.03	$38.93	$38.93	$295.94

Table 5-A.3.5: Incremental Cost Detail for 25 ft^3 Bottom-Mount Refrigerator-Freezer (Product Class 5)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 5.00 to 5.67	$4.04	$0.00	$0.00	$0.00	$1.05	$5.08	$5.08	$5.08
15%	Increase Compressor EER from 5.67 to 5.97	$3.93	$0.00	$0.00	$0.00	$1.02	$4.95	$4.95	$10.03
20%	Increase Compressor EER from 5.97 to 6.26	$5.27	$0.00	$0.00	$0.00	$1.37	$6.64	$6.64	$16.67
25%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$17.11	$33.78
	Variable Anti-Sweat Heater Control	$9.48	$0.00	$0.00	$0.00	$2.46	$11.94		
30%	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42	$59.30	$93.09
	Variable Speed Compressor	$42.77	$0.00	$0.00	$0.00	$11.12	$53.89		
40.5%	9.2 sqft VIP in FF Door	$30.12	$0.42	$3.57		$8.87	$42.98	$197.92	$291.01
	5.9 sqft VIP in FZR Door	$19.34	$0.42	$2.31		$5.74	$27.81		
	14.8 sqft VIP in FZR Cabinet	$48.43	$4.17	$6.15		$15.28	$74.03		
	10.3sqft VIP in FF Cabinet	$33.57	$4.17	$4.41		$10.96	$53.10		

Table 5-A.3.6: Incremental Cost Detail for 21 ft^3 Built-In Bottom-Mount Refrigerator-Freezer (Product Class 5-BI)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Decrease FF Compressor Capacity (same EER)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$21.47	$21.47
	10% Increase to Condenser Area	$1.00	$0.00	$0.00	$0.00	$0.40	$1.40		
	Increase Freezer Compressor EER to 6.26	$10.71	$0.00	$0.00	$0.00	$4.28	$14.99		
	1.0 sqft VIP--FZR Door	$3.18	$0.07	$0.38		$1.45	$5.09		
15%	Remove 1.0 sqft VIP--FZR Door	-$3.18	-$0.07	-$0.38		-$1.45	-$5.09	$64.35	$85.82
	FZR System VSC	$49.60	$0.00	$0.00	$0.00	$19.84	$69.43		
20%	14.6 sqft VIP--FZR Compartment	$47.86	$3.34	$5.99		$22.88	$80.07	$80.07	$165.89
25%	Add 3.6 sqft VIP -- FZR Compartment	$11.83	$0.83	$1.48		$5.65	$19.79	$129.39	$295.28
	6.0 sqft VIP--FZR Door	$19.54	$0.42	$2.33		$8.92	$31.20		
	FF System VSC	$56.00	$0.00	$0.00	$0.00	$22.40	$78.40		
27%	9.4 sqft VIP -- FF Door	$30.80	$0.42	$3.65		$13.95	$48.82	$74.93	$370.22
	3.8 sqft VIP -- FF Cabinet	$12.53	$4.17	$1.95		$7.46	$26.11		

Table 5-A.3.7: Incremental Cost Detail for 22 ft^3 Side-Mount Refrigerator-Freezer with TTD Ice (Product Class 7)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 5.51 to 5.85	$4.45	$0.00	$0.00	$0.00	$1.16	$5.60	$12.54	$12.54
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
	Increase Evaporator Area 19%	$1.21	$0.00	$0.00	$0.00	$0.31	$1.52		
15%	Increase Compressor EER from 5.85 to 6.22	$6.09	$0.00	$0.00	$0.00	$1.58	$7.68	$7.68	$20.22
20%	Increase Compressor EER from 6.22 to 6.26	$0.75	$0.00	$0.00	$0.00	$0.20	$0.95	$41.92	$62.14
	Increase Condenser Size by 27%	$3.91	$0.00	$0.00	$0.00	$1.02	$4.92		
	Variable Anti-Sweat Heater Control for Ice Dispenser	$9.48	$0.00	$0.00	$0.00	$2.46	$11.94		
	5.1 sqft VIP in FZR Door	$16.71	$0.42	$2.00		$4.98	$24.11		
25%	Remove 5.1 sqft VIP FZR Door	-$16.71	-$0.42	-$2.00		-$4.98	-$24.11	$47.49	$109.64
	Variable Speed Compressor	$44.71	$0.00	$0.00	$0.00	$11.62	$56.34		
	3.0 sqft VIP in FZR Cabinet	$9.66	$1.19	$1.27		$3.15	$15.27		
30%	7.4 sqft more VIP in FZR Cabinet	$24.15	$2.98	$3.17		$7.88	$38.17	$139.49	$249.13
	5.1 sqft VIP in FZR Door	$16.71	$0.42	$2.00		$4.98	$24.11		
	8 sqft VIP in FF Door	$26.28	$0.42	$3.12		$7.75	$37.57		
	7.8 sqft VIP in FF Cabinet	$25.60	$2.56	$3.30		$8.18	$39.64		
31%	4.9 sqft more VIP in FF Cabinet	$16.08	$1.61	$2.07		$5.14	$24.89	$24.89	$274.02

Table 5-A.3.8: Incremental Cost Detail for 26 ft³ Side-Mount Refrigerator-Freezer with TTD Ice (Product Class 7)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 5.21 to 5.86	$5.76	$0.00	$0.00	$0.00	$1.50	$7.26	$7.26	$7.26
15%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$10.58	$17.84
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
20%	Increase Compressor EER from 5.86 to 6.11	$3.90	$0.00	$0.00	$0.00	$1.01	$4.91	$4.91	$22.75
25%	Increase Compressor EER from 6.11 to 6.26	$2.82	$0.00	$0.00	$0.00	$0.73	$3.55	$56.03	$78.78
	Variable Anti-Sweat Heater Control for Ice Dispenser	$17.48	$0.00	$0.00	$0.00	$4.54	$22.02		
	Increase Condenser Size by 10%	$1.21	$0.00	$0.00	$0.00	$0.31	$1.53		
	6.2 sqft VIP in FZR Door	$20.14	$0.42	$2.41		$5.97	$28.93		
30%	Variable Speed Compressor	$57.55	$0.00	$0.00	$0.00	$14.96	$72.51	$85.79	$164.57
	2.6 sqft VIP in FZR Cabinet	$8.51	$0.93	$1.10		$2.74	$13.29		
35%	9.1 sqft more VIP in FZR Cabinet	$29.71	$3.24	$3.86		$9.57	$46.38	$151.83	$316.41
	8.2 sqft VIP in FF Door	$26.65	$0.42	$3.17		$7.86	$38.09		
	13.4 sqft VIP in FF Cabinet	$43.70	$4.17	$5.60		$13.90	$67.36		

Table 5-A.3.9: Incremental Cost Detail for 28 ft^3 Built-In Side-Mount Refrigerator-Freezer with TTD ice service (Product Class 7-BI)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	High Efficiency Compressor	$7.31	$0.00	$0.00	$0.00	$2.92	$10.23	$51.45	$51.45
	Heat Exchanger Improvement	$2.00	$0.00	$0.00	$0.00	$0.80	$2.80		
	Variable Anti-sweat	$9.50	$0.00	$0.00	$0.00	$3.80	$13.30		
	Partial VIP to Freezer Door	$15.81	$0.25	$1.88		$7.18	$25.12		
15%	Eliminate VIP to Freezer Door	-$15.81	-$0.25	-$1.88		-$7.18	-$25.12	$72.02	$123.47
	Variable Speed Compressor	$69.38	$0.00	$0.00	$0.00	$27.75	$97.14		
20%	VIP to Freezer Door	$26.36	$0.42	$3.13		$11.96	$41.86	$158.06	$281.53
	VIP to Freezer Cabinet	$70.14	$4.17	$8.69		$33.20	$116.20		
22%	VIP to Fresh Food Cabinet	$11.59	$4.17	$1.84		$7.04	$24.64	$89.74	$371.27
	VIP to Fresh Food Door	$41.22	$0.42	$4.87		$18.60	$65.10		

Table 5-A.3.10: Incremental Cost Detail for 14 ft^3 Upright Freezer with Auto Defrost (Product Class 9)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$10.40	$10.40
	Increase compressor efficiency from 5.04 to 5.69	$4.15	$0.00	$0.00	$0.00	$1.08	$5.23		
15%	Increase compressor efficiency from 5.69 to 6.08	$9.03	$0.00	$0.00	$0.00	$2.35	$11.38	$21.14	$31.54
	Door Insulation Thickness Increase of 0.21 inches	$0.75	$0.00	$0.00	$7.00	$2.02	$9.77		
20%	Door Insulation Thickness Increase of 0.79 inches	$2.83	$0.00	$0.00	$0.00	$0.74	$3.56	$13.64	$45.18
	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08		
25%	Add 0.22" Insulation to Walls	$2.59	$0.00	$0.00	$23.00	$6.65	$32.24	$32.24	$77.43
30%	Add 0.34" more Insulation to Walls	$3.92	$0.00	$0.00	$0.00	$1.02	$4.94	$4.94	$82.37
35%	Remove 0.06" Wall Insulation	-$0.68	$0.00	$0.00	$0.00	-$0.18	-$0.86	$85.18	$167.56
	Variable Speed Compressor	$68.29	$0.00	$0.00	$0.00	$17.76	$86.05		
40%	Add 0.5" Wall Insulation	$5.76	$0.00	$0.00	$0.00	$1.50	$7.26	$34.16	$201.71
	5.7 sqft VIP in Door	$18.46	$0.23	$2.65		$5.55	$26.90		
43%	4.6 sqft more VIP in Door	$14.94	$0.19	$2.15		$4.49	$21.76	$113.38	$315.09
	18.9 sqft VIP in Cabinet	$61.59	$2.08	$9.04		$18.90	$91.61		

Table 5-A.3.11: Incremental Cost Detail for 20 ft^3 Upright Freezer with Auto Defrost (Product Class 9)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$11.98	$11.98
	Increase Compressor EER from 5.73 to 6.1	$5.41	$0.00	$0.00	$0.00	$1.41	$6.82		
15%	Increase Compressor EER from 6.1 to 6.24	$2.63	$0.00	$0.00	$0.00	$0.68	$3.31	$13.39	$25.37
	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08		
20%	Increase Evaporator Size by 22%	$1.47	$0.00	$0.00	$0.00	$0.38	$1.86	$16.98	$42.35
	Forced Convection Condenser with Brushless DC Condenser Fan	$12.00	$0.00	$0.00	$0.00	$3.12	$15.12		
25%	Add 0.9 inch Insulation to Door	$4.28	$0.00	$0.00	$7.00	$2.93	$14.22	$14.22	$56.57
30%	Remove 0.2 inch Insulation from Door	-$0.95	$0.00	$0.00	$0.00	-$0.25	-$1.20	$37.50	$94.06
	Add 0.5 inch Insulation to Cabinet	$7.71	$0.00	$0.00	$23.00	$7.98	$38.69		
35%	Add 0.5 inch Insulation to Cabinet	$7.76	$0.00	$0.00	$0.00	$2.02	$9.78	$9.78	$103.84
40%	Variable Speed Compressor	$78.00	$0.00	$0.00	$0.00	$20.28	$98.28	$98.28	$202.12
44.0%	14.4 sqft VIP in Door	$46.97	$0.42	$6.73		$14.07	$68.18	$180.00	$382.12
	23.1 sqft VIP in Cabinet	$75.63	$2.08	$11.03		$23.07	$111.82		

Table 5-A.3.12: Incremental Cost Detail for 22 ft^3 Built-In Upright Freezer (Product Class 9-BI)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER to 6.29	$11.20	$0.00	$0.00	$0.00	$4.48	$15.68	$15.68	$15.68
15%	BLDC Fan for Evaporator	$4.10	$0.00	$0.00	$0.00	$1.64	$5.74	$11.76	$27.44
	BLDC Fan for Condenser	$4.30	$0.00	$0.00	$0.00	$1.72	$6.02		
20%	10% Increase to Condenser Area	$1.00	$0.00	$0.00	$0.00	$0.40	$1.40	$71.80	$99.23
	Variable Speed Compressor	$44.80	$0.00	$0.00	$0.00	$17.92	$62.72		
	1.5 sqft VIP Upper Door	$4.84	$0.07	$0.57		$2.19	$7.67		
25%	VIP Upper Door (Full Coverage)	$25.96	$0.35	$3.08		$11.76	$41.15	$112.50	$211.74
	13.1 sqft VIP Lower Cabinet	$42.65	$2.98	$5.34		$20.39	$71.36		
27%	VIP Lower Cabinet (Full Coverage)	$17.04	$1.19	$2.13		$8.14	$28.50	$85.82	$297.56
	VIP--Lower Door	$19.54	$0.42	$2.33		$8.92	$31.20		
	VIP--Upper Cabinet	$12.53	$4.17	$1.95		$7.46	$26.11		

Table 5-A.3.13: Incremental Cost Detail for 15 ft^3 Chest Freezer (Product Class 10)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 4.92 to 5.48	$1.74	$0.00	$0.00	$0.00	$0.45	$2.19	$2.19	$2.19
15%	Increase Compressor EER from 5.48 to 5.81	$4.39	$0.00	$0.00	$0.00	$1.14	$5.53	$5.53	$7.72
20%	Increase Compressor EER from 5.81 to 6.08	$3.99	$0.00	$0.00	$0.00	$1.04	$5.02	$14.66	$22.39
	Add 0.24 inch Insulation to Door	$0.65	$0.00	$0.00	$7.00	$1.99	$9.64		
25%	Add 0.76 inch Insulation to Door	$2.11	$0.00	$0.00	$0.00	$0.55	$2.66	$37.50	$59.89
	Add 0.15 inch Insulation to Cabinet	$1.66	$0.00	$0.00	$26.00	$7.19	$34.85		
30%	Add 0.35 inch Insulation to Cabinet	$3.78	$0.00	$0.00	$0.00	$0.98	$4.77	$4.77	$64.66
35%	Variable Speed Compressor	$46.15	$0.00	$0.00	$0.00	$12.00	$58.14	$58.14	$122.80
44%	Add 0.25 inch Insulation to Cabinet	$2.65	$0.00	$0.00	$0.00	$0.69	$3.33	$85.87	$208.67
	8.2 sqft VIP on bottom	$26.66	$1.39	$3.98		$8.33	$40.36		
	8.8 sqft VIP on door	$28.89	$0.42	$4.16		$8.70	$42.17		

Table 5-A.3.14: Incremental Cost Detail for 20 ft³ Chest Freezer (Product Class 10)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Condenser Size by 24%	$1.68	$0.00	$0.00	$0.00	$0.44	$2.12	$10.68	$10.68
	Increase Compressor EER from 5.71 to 6.16	$6.80	$0.00	$0.00	$0.00	$1.77	$8.56		
15%	Increase Compressor EER from 6.16 to 6.25	$1.69	$0.00	$0.00	$0.00	$0.44	$2.13	$10.95	$21.63
	Convert Door Insulation to PU Foam	$0.00	$0.00	$0.00	$7.00	$1.82	$8.82		
20%	Add 1 inch Insulation to Door	$3.47	$0.00	$0.00	$0.00	$0.90	$4.37	$4.37	$26.00
25%	Add 0.35 inch Insulation to Cabinet	$4.77	$0.00	$0.00	$26.00	$8.00	$38.78	$38.78	$64.78
30%	Add 0.4 inch Insulation to Cabinet	$5.32	$0.00	$0.00	$0.00	$1.38	$6.70	$28.91	$93.69
	4.5 sqft VIP in Bottom Wall	$14.82	$0.62	$2.19		$4.58	$22.21		
35%	Remove 4.5 sqft VIP Bottom Wall	-$14.82	-$0.62	-$2.19		-$4.58	-$22.21	$37.65	$131.34
	Variable Speed Compressor	$47.51	$0.00	$0.00	$0.00	$12.35	$59.87		
39%	10.2 sqft VIP in Bottom Wall	$33.46	$1.39	$4.95		$10.35	$50.14	$107.09	$238.43
	12 sqft VIP in Door	$39.16	$0.42	$5.62		$11.75	$56.95		

Table 5-A.3.15: Incremental Cost Detail for 1.7 ft^3 Compact Refrigerator (Product Class 11)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Evaporator Size by 20%	$0.27	$0.00	$0.00	$0.00	$0.07	$0.34	$2.61	$2.61
	Increase Compressor EER from 3.02 to 3.20	$1.80	$0.00	$0.00	$0.00	$0.47	$2.27		
15%	Increase Compressor EER from 3.20 to 3.47	$2.70	$0.00	$0.00	$0.00	$0.70	$3.40	$3.40	$6.01
20%	Increase Condenser Size by 19%	$0.39	$0.00	$0.00	$0.00	$0.10	$0.49	$5.12	$11.13
	Add 3/4 inch Insulation in Door	$0.67	$0.00	$0.00	$3.00	$0.95	$4.62		
25%	Add 0.18 inch Insulation in Cabinet	$0.60	$0.00	$0.00	$10.00	$2.76	$13.36	$13.36	$24.49
30%	Add 0.57 inch Insulation in Cabinet	$2.00	$0.00	$0.00	$0.00	$0.52	$2.51	$2.51	$27.00
35%	Eliminate all previous Design Options	-$8.43	$0.00	$0.00	-$13.00	-$5.57	-$27.00	$43.56	$70.56
	Variable Speed Compressor	$56.00	$0.00	$0.00	$0.00	$14.56	$70.56		
40%	Convert to Isobutane Refrigerant	$8.00	$0.00	$0.00	$1.00	$2.34	$11.34	$11.34	$81.90
45%	Increase Evaporator Size by 20%	$0.27	$0.00	$0.00	$0.00	$0.07	$0.34	$5.46	$87.36
	Increase Condenser Size by 19%	$0.39	$0.00	$0.00	$0.00	$0.10	$0.49		
	Add 3/4 inch Insulation in Door	$0.67	$0.00	$0.00	$3.00	$0.95	$4.62		
50%	Add 3/4 inch Insulation in Cabinet	$2.60	$0.00	$0.00	$10.00	$3.28	$15.88	$15.88	$103.23
55%	Add 4.7 sqft VIP in Cabinet	$15.38	$4.17	$3.83		$6.08	$29.45	$41.06	$144.29
	Add 2.2 sqft VIP in Door	$7.29	$0.42	$1.51		$2.39	$11.61		

Table 5-A.3.16: Incremental Cost Detail for 4.0 ft^3 Compact Refrigerator (Product Class 11)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 4.57 to 5.1	$5.30	$0.00	$0.00	$0.00	$1.38	$6.68	$6.68	$6.68
15%	Increase Compressor EER from 5.1 to 5.3	$2.30	$0.00	$0.00	$0.00	$0.60	$2.90	$3.65	$10.32
	Increase Condenser Size by 22%	$0.59	$0.00	$0.00	$0.00	$0.15	$0.75		
20%	Add 3/4 inch Insulation to Door	$0.92	$0.00	$0.00	$3.00	$1.02	$4.94	$4.94	$15.26
25%	Convert to Isobutane Refrigerant	$4.00	$0.00	$0.00	$1.00	$1.30	$6.30	$6.69	$21.95
	Add 1/4 inch Insulation to Door	$0.31	$0.00	$0.00	$0.00	$0.08	$0.39	$14.23	
30%	Add 0.22 inch Insulation to Cabinet	$0.98	$0.00	$0.00	$10.00	$2.86	$13.84	$13.45	$35.40
	Remove 1/4 inch Insulation from Door	-$0.31	$0.00	$0.00	$0.00	-$0.08	-$0.39		
35%	Add 0.22 inch Insulation to Cabinet	$0.99	$0.00	$0.00	$0.00	$0.26	$1.25	$1.25	$36.66
40%	Add 0.31 inch Insulation to Cabinet	$1.37	$0.00	$0.00	$0.00	$0.36	$1.73	$1.73	$38.38
45%	Variable Speed Compressor	$52.40	$0.00	$0.00	$0.00	$13.62	$66.02	$49.20	$87.59
	Remove 3/4 inch Cabinet Insulation	-$3.35	$0.00	$0.00	-$10.00	-$3.47	- $16.82		
50%	Add 0.23 inch Insulation to Cabinet	$1.02	$0.00	$0.00	$10.00	$2.87	$13.89	$13.89	$101.47
62%	Add 0.32 inch Insulation to Cabinet	$2.33	$0.00	$0.00	$0.00	$0.61	$2.93	$66.16	$167.63
	7.2 sqft VIP Cabinet	$23.57	$4.17	$5.44		$8.62	$41.79		
	4.2 sqft VIP Door	$13.81	$0.42	$2.79		$4.42	$21.43		

Table 5-A.3.17: Incremental Cost Detail for 3.4 ft^3 Compact Chest Freezer (Product Class 18)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 3.74 to 4.17	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42	$5.42	$5.42
15%	Increase Compressor EER from 4.17 to 4.29	$1.20	$0.00	$0.00	$0.00	$0.31	$1.51	$10.45	$15.87
	Add 1 inch Insulation to Door	$1.09	$0.00	$0.00	$6.00	$1.84	$8.94		
20%	Remove 1/4 inch Insulation from Door	-$0.27	$0.00	$0.00	$0.00	-$0.07	-$0.34	$35.22	$51.09
	Add 0.48 inch Insulation to Cabinet	$2.23	$0.00	$0.00	$26.00	$7.34	$35.57		
25%	Add 0.27 inch Insulation to Cabinet	$1.22	$0.00	$0.00	$0.00	$0.32	$1.54	$13.96	$65.05
	Add 2.1 sqft VIP in Bottom Wall	$6.85	$1.39	$1.62		$2.56	$12.42		
30%	Remove all design options through 25% Level	-$16.62	-$1.39	-$33.62		-$13.42	-$65.05	$5.51	$70.56
	Variable Speed Compressor	$56.00	$0.00	$0.00	$0.00	$14.56	$70.56		
35%	Add 0.75 inch Insulation to Door	$0.82	$0.00	$0.00	$6.00	$1.77	$8.59	$8.59	$79.15
43.3%	Add 0.75 inch Insulation to Cabinet	$3.45	$0.00	$0.00	$26.00	$7.66	$37.11	$66.56	$145.71
	Add 2.1 sqft VIP in Bottom Wall	$6.85	$1.39	$1.62		$2.56	$12.42		
	Add 3.3 sqft VIP in Door	$10.89	$0.42	$2.22		$3.51	$17.03		

Table 5-A.3.18: Incremental Cost Detail for 7.0 ft^3 Compact Chest Freezer (Product Class 18)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 4.50 to 5.02	$5.20	$0.00	$0.00	$0.00	$1.35	$6.55	$6.55	$6.55
15%	Increase Compressor EER from 5.02 to 5.27	$2.50	$0.00	$0.00	$0.00	$0.65	$3.15	$10.98	$17.53
	Add 0.12 inch Insulation to Door	$0.22	$0.00	$0.00	$6.00	$1.62	$7.83		
20%	Add 0.63 inch Insulation to Door	$1.14	$0.00	$0.00	$0.00	$0.30	$1.44	$36.84	$54.37
	Add 0.26 inch Insulation to Cabinet	$2.09	$0.00	$0.00	$26.00	$7.30	$35.39		
25%	Add 0.36 inch Insulation to Cabinet	$2.91	$0.00	$0.00	$0.00	$0.76	$3.66	$3.66	$58.03
30%	Remove all design options through 25% Level	-$14.06	$0.00	$0.00	-$32.00	-$11.97	-$58.03	$47.08	$105.11
	Variable Speed Compressor	$56.00	$0.00	$0.00	$0.00	$14.56	$70.56		
	Add 0.18 inch Insulation to Cabinet	$1.42	$0.00	$0.00	$26.00	$7.13	$34.55		
35%	Add 0.47 inch Insulation to Cabinet	$3.71	$0.00	$0.00	$0.00	$0.96	$4.67	$4.67	$109.79
40%	Add 0.11 inch Insulation to Cabinet	$0.85	$0.00	$0.00	$0.00	$0.22	$1.07	$58.69	$168.47
	Add 3/4 inch Insulation to Door	$1.36	$0.00	$0.00	$6.00	$1.91	$9.27		
	Add 4.1 sqft VIP to Cabinet Bottom	$13.50	$1.39	$2.92		$4.63	$22.43		
	Add 5.1 sqft VIP to Door	$16.78	$0.42	$3.37		$5.35	$25.91		

5-A.4 PRELIMINARY ANALYSIS ENGINEERING QUESTIONNAIRE

DOE used the preliminary analysis engineering questionnaire as a guide for engineering discussions during manufacturer interviews. Some of the information provided in the questionnaire has been redacted to protect vendor information.

DESIGN FOR ENERGY IMPROVEMENT INFORMATION REQUEST

DOE would like to confirm information on the incremental costs of increasing product efficiency by understanding the design options involved in the efficiency improvement.

1. **Market Share of products you sell**

To help DOE discover manufacturer sub-groups and the relative importance of various product classes to specific manufacturers, please disaggregate your annual unit shipments for each product category as shown below. Please also indicate whether you purchase these products from other manufacturers (i.e. private label), and whether the factory that supplies the product is located in the USA.

Product Class (response for PC1 through PC20 not including built-in products)	% Private Label?	% Made in USA?	Yearly Unit Shipments
1. Refrigerators and refrigerator-freezers with manual defrost.			
2. Refrigerator-freezer—partial automatic defrost.			
3a. Refrigerator-freezer—automatic defrost with top-mounted freezer without through-the-door ice service			
3b. All-refrigerator—automatic defrost.			
4. Refrigerator-freezers—automatic defrost with side-mounted freezer without through-the-door ice service.			
5. Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service.			
6. Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service.			
7. Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service.			
8. Upright freezers with manual defrost.			
9. Upright freezers with automatic defrost.			
10. Chest freezers and all other freezers except compact freezers.			
11. Compact refrigerators and refrigerator-freezers with manual defrost.			
12. Compact refrigerator-freezer—partial automatic defrost.			
13a. Compact refrigerator-freezers—automatic defrost with top-mounted freezer compact all-refrigerator—automatic defrost.			
13b. Compact all-refrigerator—automatic defrost.			

14. Compact refrigerator-freezers—automatic defrost with side-mounted freezer.			
15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.			
16. Compact upright freezers with manual defrost.			
17. Compact upright freezers with automatic defrost.			
18. Compact chest freezers.			
19. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service.			
20. Chest freezers with automatic defrost.			
21. Wine Coolers			
22. Built-in Refrigerators, Refrigerator-Freezers, and Freezers (please provide percentage breakdown by Product Class for units presenting at least 5% of unit sales)			

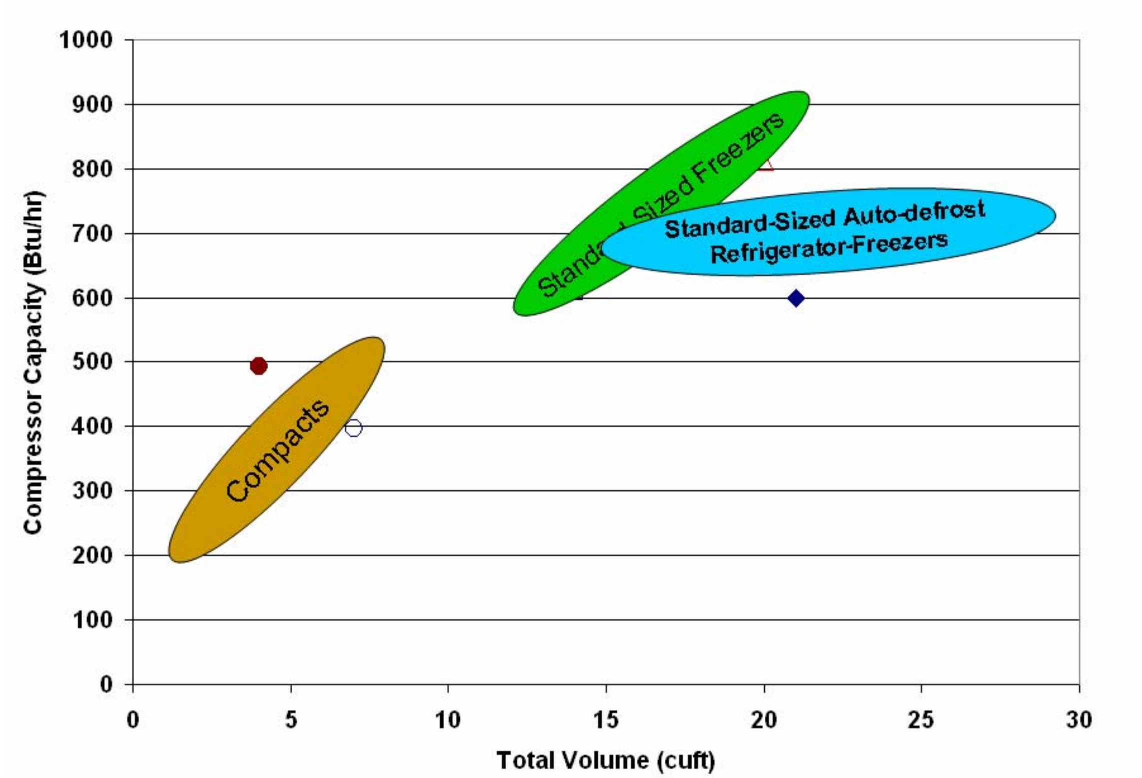
a. What percentage of products classified as product class 4 or 7 (side-by-sides) have convertible bottom drawers?
b. What percentage of product class 5 and what percentage of product class 19 products are French-door?

2. Product Technical Descriptions

The following series of exhibits and questions address technical characteristics of key refrigerator and freezer components for both baseline and improved-efficiency products.

Compressors

Please comment on the typical capacities of compressors used in the indicated products.



- Should there be differences in capacity levels for auto-defrost and manual defrost freezers?
- What capacity/volume relationship is representative for standard-sized manual-defrost refrigerators?

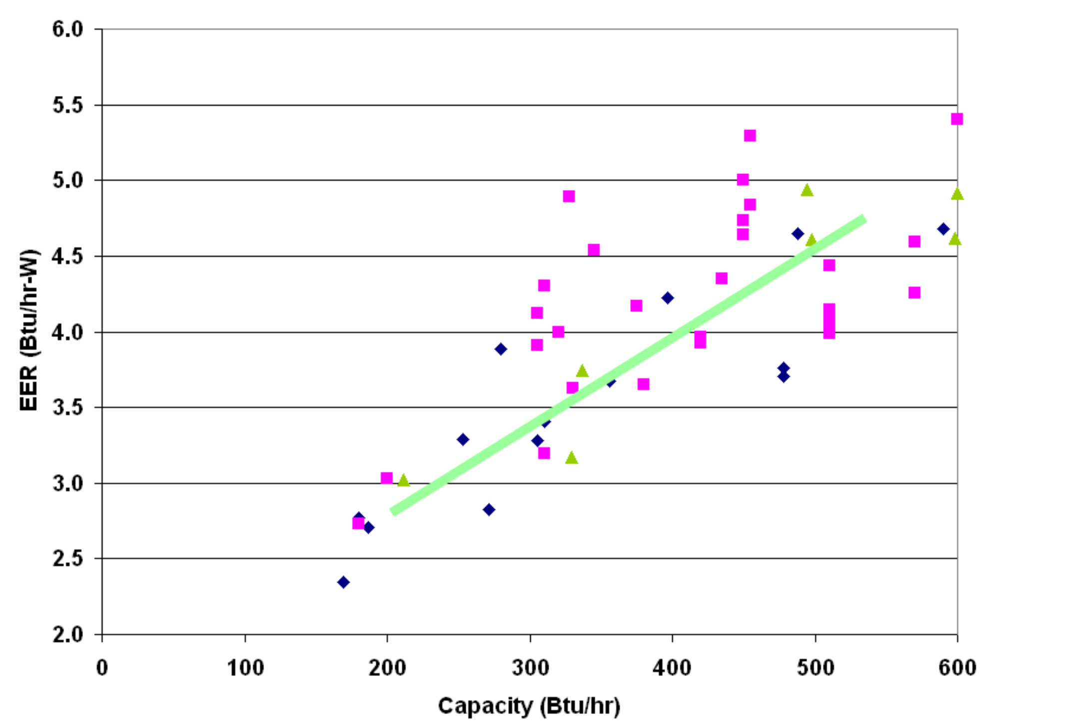
Please comment on the indicated typical EER of compressors used in standard and Energy Star products.

	Typical Nominal Compressor EER	
Products	Std-Efficiency	E*
Standard-Sized Refrigerator-Freezer Auto-Defrost	5.4	5.9
Standard-Sized Freezers	5.0	5.7

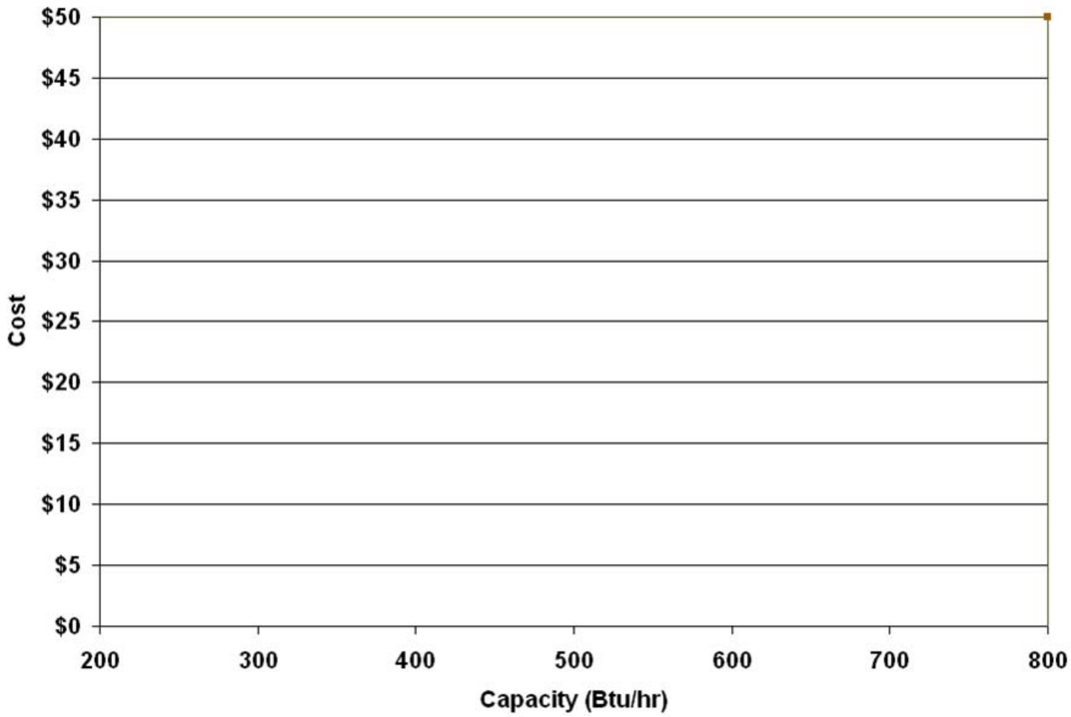
- Should there be differences between compressor EER used in auto-defrost and manual defrost freezers?

Typical EER trend for compressors used in compact refrigerators and freezers:

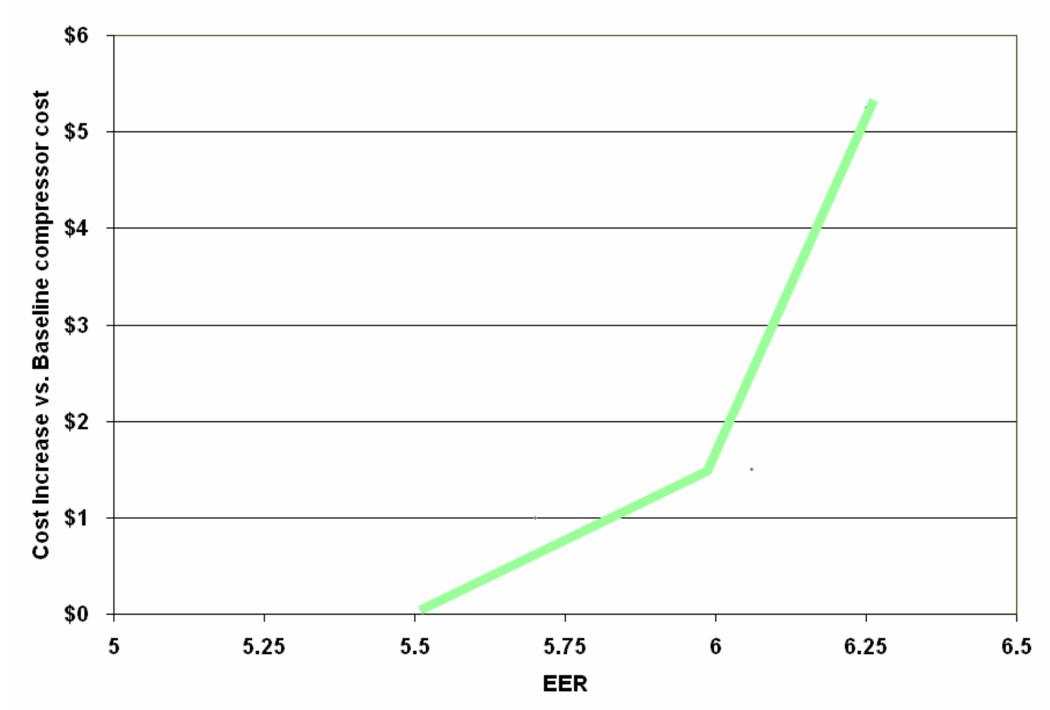
- Is variation in compressor EER in compact products dependent primarily on capacity, as illustrated in the line in the plot below?
- Note that while a range of EER is offered by compressor vendors, it is not clear that the range of EER's actually being used in products is as broad--Is this driven by cost pressures for compact products?



Is the Illustrated Typical Cost vs. Capacity for Baseline Product compressors accurate?



Is the Illustrated Curve for incremental cost for higher EER compressors for standard-sized refrigerator-freezers accurate?



- What percentage of your baseline unit shipments use variable-speed compressors, and what percentage of Energy Star-rated products do?
- If you use variable-speed compressors in your products, do you run them at two or three speeds, or do you modulate the speed based on demand?
- Is $30 an appropriate cost increase for a variable-speed compressor as compared to a baseline efficiency single-speed compressor purchased from the vendor for standard-sized refrigerator-freezers? What other costs need to be considered?

Evaporator Heat Exchanger Characteristics
In the following table, please comment on the typical key details of evaporator heat exchangers.

Product Type	**Type**	**Core Volume (cuft)**	**Tube Outer Dia (inch)**	**Tube Length (ft)**	**Fin Surface or cold plate surface (sqft)**
Standard-Sized Refrigerator-Freezers	Forced Convection	0.21	0.33 (0.008 wall)	37	18
Standard-Sized Upright Freezers	Forced Convection	0.18	0.33 (0.008 wall)	32	18
Product Type	**Type**	**Tube Outer Dia (inch)**	**Specific Tube Length (inch per Btu/hr compressor capacity)**	**Fin Surface (sqin per Btu/hr compressor capacity)**	
Standard-Sized Chest Freezers	Cold Wall	0.3	1.7		
Compact Basic Refrigerators	Roll Bond	Channels 0.18 high x 0.38 wide	0.55	0.6	
Compact Chest Freezers	Cold Wall	0.3	2.0		

- All forced-convention evaporators use aluminum tubes?
- Typical forced-convection evaporator fin style is flat aluminum with oval gaps to slide over tube serpentine?
- Any use of internally-enhanced tubes?
- Any use of enhanced fins?
- What percentage of refrigerator/freezers use more than one evaporator?
- What percentage of refrigerator/freezers use other than forced-convection evaporators?
- Do you employ wide fin spacing and lack of fin surface enhancements for frost tolerance and quick melt runoff?

- Is there a typical evaporator air flow rate vs. compressor capacity relationship? If so, can you detail it?
- Are you aware of any further significant system improvements that may be possible through evaporator heat exchanger changes? (for example, via eggcrate evaporators, spine-fin?)
- If you use spine-fin heat exchangers, is their performance for volume/fan power better than for flat-fin heat exchangers? Or was your decision driven by cost? What about frost tolerance and internal enhancements?

Condenser Heat Exchanger Characteristics

In the following table, please comment on the typical key details of evaporator heat exchangers.

Product Type	**Type**	**Tube Outer Dia (inch)**	**Tube Length (ft)**	**Wire Fin Diameter (inch)**	**Wire Fin Total Length (ft)**
Standard-Sized Refrigerator-Freezers	Forced Convection Steel Tube Wire Fin	0.19 (0.025 wall)	50	0.05	300
Product Type	**Type**	**Tube Outer Dia (inch)**	**Tube Wall (inch)**	**Specific Tube Length (inch per Btu/hr compressor capacity)**	**Specific Wire Fin Length (foot per Btu/hr compressor capacity)**
Standard-Sized Upright Freezers	Hot Wall	0.19	0.03	1.0	N/A
Standard-Sized Chest Freezers	Hot Wall	0.19	0.03	1.3	N/A
Compact Basic Refrigerators	Static or Hot Wall	0.19	0.025	Hot Wall 1.5 Static 0.4	0.4
Compact Chest Freezers	Hot Wall or Static	0.19	0.025	Hot Wall 1.7 Static 0.9	0.7

- Any use of internally-enhanced tubes?
- Most external condenser heat exchangers designs appear to be based on steel wire fins. What are the key drivers leading to this design choice?
  - Is in-field dust-covered performance a consideration?
  - Are enhanced-surface designs too expensive?
  - Or perhaps not worthwhile because there is enough space for lower-cost wire fin design?
  - Performance degradation when dirty?
  - Or can't do better than wire fin for a given volume and the typically low fan power?
- Is there a relationship between typical condenser air flow rate vs. the compressor capacity? If so, can you detail it?

- During teardowns we noted that some manufacturers use "rolled up" heat exchangers vs. the typical flat external condenser heat exchangers. What are the benefits and drawbacks of such heat exchangers?

Evaporator and Condenser Fans

- Are the indicated characteristics for fan motors typical for refrigerator-freezers?

Shaded Pole Evaporator Fan Typical Wattage	6 W
Shaded Pole Condenser Fan Typical Wattage	9 W
Percent Wattage Reduction with Brushless DC	65%
Cost impact Evaporator Fan switch to BLDC	$3.00
Cost impact Condenser Fan switch to BLDC	$2.50

- Is there any room for further, significant energy efficiency improvement via fan blade/air flow path design improvements (i.e. PAX fan)?
- Do you consider PSC fan motors a viable intermediary step between SP and BLDC fan motors?
- Do any of your fans run at multiple speeds, for example to match the output of a variable-speed compressor?
- What are the benefits or drawbacks associated with using BLDC motors that are based on DC-power input vs. AC-power input? What is the cost difference between such motors?

Cabinet Insulation Characteristics (as applicable)

In the following table, please comment on the typical average insulation thicknesses.

Product Type	**Insulation Thickess (inches)**
Standard-Sized Refrigerator-Freezers with Automatic Defrost—Fresh Food Compartment	1.9
Standard-Sized Refrigerator-Freezers with Automatic Defrost—Freezer Compartment	2.7
Standard-Sized Upright Freezers	2.3
Standard-Sized Chest Freezers	2.5
Compact Basic Refrigerators	1.2
Compact Chest Freezers	2.5

What typical insulation thickness would be used for the following product types?

- Standard-sized refrigerator with manual or partial automatic defrost?
- Compact refrigerator-freezers?

- Standard-sized all-refrigerators?
- Compact all-refrigerators?
- Differences in typical average insulation thicknesses for built-in products?

- Is the state-of-the-art current insulation system based on HFC-245fa blowing agent with cabinet preheating and high pressure injection? Is the conductivity typically achieved for this system 0.13 Btu-in/hr-ft^2-ºF at room temperature? Do you use any other insulation systems?

- Is there any significant further cabinet load reduction possible through lower conductivity foam?
- Have you considered switching to low Global-Warming-Potential (GWP) blowing agents? If so, what are the drivers for these changes? What are the conductivity, cost impacts?
- Are you using any vacuum-insulated panels (VIPs) in any products?
- If you have or were considering the adoption of VIPs can you detail how you would incorporate them into your products, what the capital costs, and what the marginal product costs of such a step would be?
- Have you considered gas-filled panels? If so, what drove you to adopt, or not to adopt them?

Door Frame:

- What are the key aspects of good state-of-the-art door frame/gasket area design? To what extent does a typical product adhere to this? What is the range of load impact of poor door frame region designs (i.e. in Btu/hr-ft)?
- Is there any value to using double-gaskets?
- Some refrigerators have extra-strong magnets requiring special handle designs to assist with door-opening. How much load reduction is possible with such an approach?

Through-the-Door Dispensers:

- Today's TTD systems don't appear to represent thermal loads as high as suggested by the energy allowance associated with this feature, based for example on max energy difference between product classes 7 and 4. Is there more to the energy impact than the thermal load difference? How much anti-sweat heating wattage is typically used around your TTDs?

Anti-sweat Heaters:

- Most anti-sweat heaters appear to use hot liquid. Is this correct? Is there any continued use of hot gas anti-sweat systems?
- Is there data available indicating average duty cycle of such heaters for typical in-home installation? Does this depend on use of anti-sweat heater for freezer door frame, mullion door frame, ducts, etc.?
- For example, do your products use resistance heaters within the fresh food return air duct to prevent frost accumulation? If so, is it always on or controlled based on humidity?

Defrost:

- What are your thoughts about benefits and drawbacks of precool prior to the defrost cycle?

- The DOE energy test energy impact of defrost is small, particularly with variable defrost. Is this a good reflection of in-field defrost impacts?
- Are dedicated controllers available to allow variable defrost to be used in products which otherwise use non-electronic controls?

Expansion Devices:

- Is there any performance improvement potential with expansion devices other than capillary tube? What about for variable-speed compressor systems?
- Do you use any expansion device besides capillary tubes?

Energy Efficiency Conversion Costs

- What design changes are typically associated with converting baseline products mentioned above in Question 1 to Energy Star?
- What are the marginal costs of the individual design options selected?
- When considering energy efficiency improvements to achieve or exceed Energy Star, do different product classes take different pathways or are pathways similar?
- Are the cost increments higher for some classes than others for a given performance improvement over baseline? (think 10%, 15%, 20%, 25%, 30%, 35%, 35+ improvement over today's baseline)

Thoughts/feedback on alternative refrigeration cycles/implementations:

- Dual-evaporator systems attempting to cool fresh food compartment at higher evaporator temperatures.
- Ejector system.
- Stirling.
- Thermoacoustic.
- Thermoelectric.

APPENDIX 5-B. ERA MODEL DEVELOPMENT AND WINERA USERS MANUAL

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APPENDIX 5-B. ERA MODEL DEVELOPMENT AND WINERA USERS MANUAL

5-B.1 INTRODUCTION

The Energy-efficient Refrigerator Analysis Program (ERA), formerly called the EPA Refrigerator Analysis Program, serves as an important tool in the engineering analysis, described in Chapter 5 of the TSD. This appendix provides background description of the evolution of the program since its creation in the late 1980s, provides details regarding changes made to the program as part of this rulemaking, and provides program operation guidance for the user. ERA has undergone extensive analytical upgrades and has also been converted to a Window-based program. The program has its own internal help utility to provide additional assistance to the user beyond the information provided in this appendix.

5-B.2 HISTORY OF ERA MODEL

ERA has seen several major improvements since its creation. This section describes the characteristics of the initial version of ERA and the subsequent modifications to the model prior to the current DOE rulemaking, including involvement in the Thailand refrigeration appliance efficiency standards analysis and in refrigerator energy use analysis training workshops in China in the 1990s.

5-B.2.1 DOE Refrigeration Appliance Efficiency Standards

Preparation of the current DOS version of ERA (EPA Refrigerator Analysis Program) was initiated under EPA-sponsorship during the late 1980s. This was undertaken by the EPA as part its involvement in the establishment of energy standards for refrigerators, refrigerator-freezers, and freezers under the National Appliance Energy Conservation Act of 1987 (NAECA). A developmental version of the program was used by the DOE (Lawrence Berkeley Laboratory) as a partial basis for the energy standard established in 1989 (effective in 1993). The LBL work also involved an extensive testing of the model against manufacturer-supplied refrigeration appliance design and test data. Based on these comparisons and manufacturer review comments through its industry organization (AHAM), development of the model continued until its release in 1997 [1].

ERA combined an analysis of the refrigeration load requirements of the cabinet with a simulation of the capacity and efficiency of the refrigeration cycle. The cabinet loads module was a modest enhancement of a program developed for the DOE during the late 1970s [2], including the consideration of door-opening effects on the load and an ability to deal with complex insulation systems. The cycle module was a derivative of the NIST CYCLE 7 program [3] which used the CSD equation of state to represent the thermodynamic properties of pure and mixed refrigerants [4], adapting routines for calculating refrigerant properties from REFPROP3 [5]. Using this new program, EPA carried out an extensive investigation of the potential for energy efficiency improvements [6].

The program, and its User's Manual, were first released to the public in 1993, and for a few years were downloadable from the EPA website [7].

Subsequent to the 1993 final rule, DOE published updated standards for refrigerators, refrigerator-freezers and freezers in 1997, becoming effective in 2001. This involved use of the final released EPA version of ERA [1].

5-B.2.2 Thailand Refrigeration Appliance Efficiency Standards

Under three separate contracts from the Thai National Energy Policy Office, a modified version of the program was used by the program author[a] to establish minimum efficiency performance standards (MEPS) for residential refrigerators and refrigerator-freezers used in Thailand [8, 9, 10]. The first study established goals for two categories of appliances: a one-door manual defrost refrigerator, and a two-door automatic-defrost refrigerator-freezer. Three levels of MEPS were proposed, a "long-term goal" (assumed to be achievable within 10 years, and tier1 and tier 2 standards which allowed 30% and 15% energy use over the long-term goal.

As in the earlier DOE work, the local manufacturing industry was involved in the review and assessment of the proposed standard.

In response to highly negative comments on the achievability of any of the proposed efficiency levels, a second contract was awarded to prepare and test refrigerators that would meet or exceed the long-term energy target. Working with Sano Electric Company of Thailand, four prototype units were designed and tested: 31-liter and 41.5-liter one-door refrigerators, and 78.5-liter and 126.5-liter two-door refrigerator-freezers. Using available technology, the achieved energy reductions were over 20% for the one-door units, and over 34% for the two-door units, meeting the long-term target levels. Within several years, the proposed standards became law.

5-B.2.3 ERA Training Workshop in China

In response to a request from China's State Bureau of Technical Supervision (SBTS), LBNL hosted a training seminar on the use of ERA for three research engineers. The results of this training provided an increased understanding of approaches to achieve improved standards, leading to a more substantial series of cost-effective cooperative efforts towards creating China's standards program [11].

As part of a subsequent large program sponsored by the UN Global Environmental Fund (GEF), ThermoSoft carried out a one-week training workshop in Beijing [12]. The participants included 40 engineers from 20 manufacturers located throughout China. Although focused on the use of ERA as a design tool, the workshop covered the then-current component technologies available

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[a] A consultant, established under the name ThermoSoft. This work was subcontracted through ERM-Siam.

worldwide, providing an opportunity for a lively exchange of ideas. Each of the participants utilized ERA to perform analyses of their proprietary appliance models.

5-B.3 CHARACTERISTICS OF THE DOS VERSION OF ERA

ERA was developed employing then-current computer technology of the 1980s. The cabinet loads module was a minor upgrade of an earlier program used for efficiency standards, and an existing simplified heat pump cycle model was adapted to represent the refrigerator cycle. Written in FORTRAN, with a very extensive set of assembly language routines to provide a smooth user-interface, the program was hosted in DOS.

Because of the complexities of the program, and the limitations of DOS, it was broken into three modules, linked by data files and a batch file that managed the information and program execution flow. Both the MENU module (which provided the user-input interface) and the cycle execution module used nearly all of the available 600+ Kbytes of DOS accessible memory.[b] This memory limitation, inherent in DOS (which can address only 655,360 bytes of conventional memory, 10×2^{16}), imposed a fundamental limitation on the design of the program and the details that could be considered in any analysis.

ERA was constructed to take maximum advantage of the available capabilities provided by DOS, leading to somewhat complicated coding and sharing of memory spaces for certain functions. Because of the limitations imposed by DOS, ERA was designed to fit within the capabilities of a specific compiler, Microsoft FORTRAN 5.0, which was discontinued in the early 1990s. As a result, ERA is not compliable with any other version FORTRAN compiler. Further, the program requires access to the specially-developed assembly language user-interface module. As a consequence, although the source code has been made available upon request, no entity other than ThermoSoft has been able to compile it.

Because of these restrictions, the thermophysical property routines within the DOS version cannot be upgraded beyond Refprop 4.0, nor can additional fluids be considered.[c] Hence, no changes to the refrigerant properties capabilities of ERA have been made since the mid-1990s.

5-B.3.1 Modifications to ERA Since its Public Release

Given the DOS-imposed restrictions, options for upgrades to the model have been limited within this environment. However, during on the work in Thailand, several minor enhancements were made:

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[b] Of course, the program executable object had to load within this space, limiting the available memory space for data objects.

[c] Later versions of Refprop use a different structure.

- Calculation of the hot-wall effective heat transfer area. This involved specification of the tubing routing and additional details about the wall area. The outer shell, to which the tubing is pressed by the expanded foam, was treated as a thermal fin to estimate the effective heat transfer area. This capability was used during the development of the prototype models in Thailand while investigating the effects of improved hot wall design of the energy use.

- Addition of a similar analysis sub-model to calculate the effective heat transfer area for a cold-wall evaporator.

- Added multiple-speed capability to the compressor model. The efficiency-based model, which was valid only for R-12, was removed to provide this capability.

- Improved evaporator analysis in the single-door refrigerator to more correctly incorporate the radiative heat transfer effects. This led to an improvement between the model predictions and test results for the compact-refrigerator category.

Although no changes to the model were made in the model's use of compressor maps, experience working with Thai manufacturers highlighted the importance of high-quality calorimeter data.[d] As a result, each of the manufacturer-supplied maps was analyzed for consistency by examining the corresponding volumetric and isentropic efficiencies. An ability to qualify a compressor map on the basis of the underlying volumetric and isentropic efficiencies is built into the current revision of the model (see below).

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[d] Similar experience with poorly constructed manufacturer-supplied compressor maps was encountered during the EPA Multiple Pathways project [6].

5-B.4 OBJECTIVES OF THE CURRENT PROJECT

A thorough revision of the ERA program, now entitled the "**E**nergy-Efficient **R**efrigerator **A**nalysis" program, is being undertaken for the current rulemaking to meet the following objectives:

- Enhancement of the user-interface to a Windows environment
- Employment of the most current refrigerant property routines
- Incorporation of a broad range of evaporator and condenser algorithms that correspond to the technologies now found in modern refrigerators
- Improved compressor modeling, with built-in procedures for validating supplied compressor maps
- Improvements where desirable in the cabinet loads analysis and cycle performance algorithms.
- Preparation of internal documentation of the program through extensive context-sensitive Help files.

In addition to these objectives, support has been provided in the use of the DOS-version of ERA for the current standards development work. To assist this effort, a small suite of stand-alone programs has been prepared to calculate the required input values to ERA. This suite consists of:

ERAEVAP – for the calculation of the net heat transfer capabilities of a variety of evaporator designs;

ERACOND – for the calculation of the net heat transfer capabilities of a variety of condenser designs; and

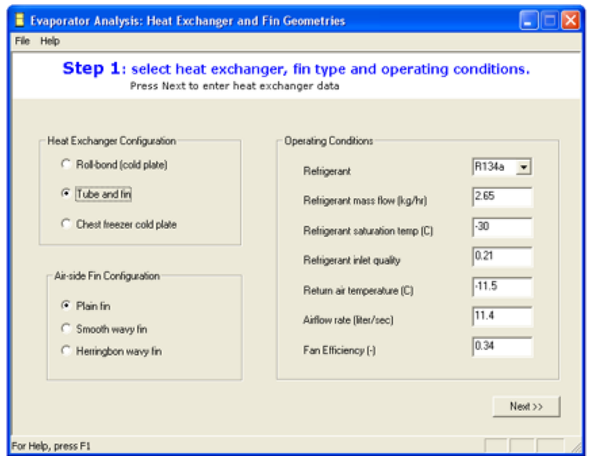
COMPMAP – a program to validate compressor maps by the calculation and display of isentropic and volumetric efficiencies, and the construction of new maps based on methods for smoothing the efficiencies as a function of compression ratio.

Each of these models contains algorithms that will be incorporated into the final Windows version of ERA, including the refrigerant algorithms. They are stand-alone programs, designed only for interim use. However, since they provide a technical basis for the new version of ERA and have been used in the ongoing engineering analyses, they are described next.

5-B.4.1 Evaluator Analysis Program – ERAEVAP

User Interface

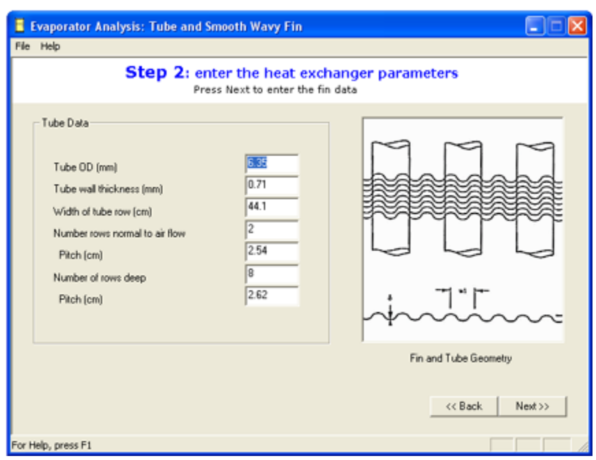
ERAEVAP is a data-wizard based Windows program that guides the user through several steps in the specification of the evaporator design parameters.



Step1 requires selection of the heat exchanger type (roll-bond freezer compartment, tube and fin fan-forced evaporator, or a chest freezer cold-wall). Three options are represented for a tube and fin configuration: plain fin, smooth wavy fin, and herringbone fin.

Refrigerant choices are: R134a, R152a, R290 (propane), R404A, R507A, R600a (isobutane), and R744 (carbon dioxide). Refrigerant properties are calculated using the NIST Refprop 8.0 routines, supplied as a linkable dll.

Other typical value operating parameters are user-specified: refrigerant mass-flow, refrigerant saturation temperature, refrigerant inlet quality, return or cabinet air temperature, and the airflow rate and corresponding fan efficiency (fan-forced analyses only).[e]



Step 2 depends on the heat exchanger configuration selected above. The illustration shows the input dialog for a tube and wavy fin design. In this instance, the tube dimensions, vertical pitch (normal to the air flow) and horizontal pitch (along the direction of the air flow) are specified.

Each data dialog contains a simple illustration of the component under consideration.

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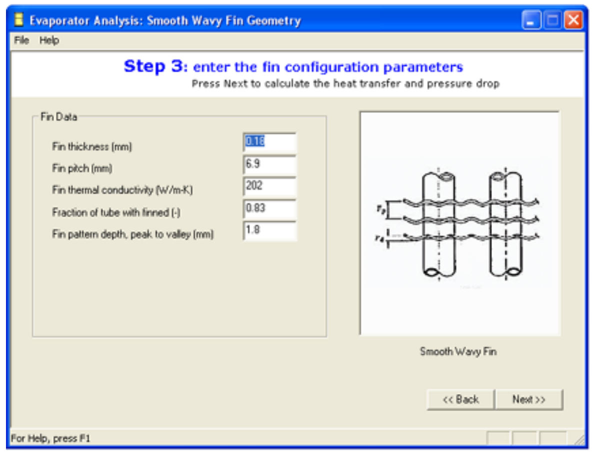
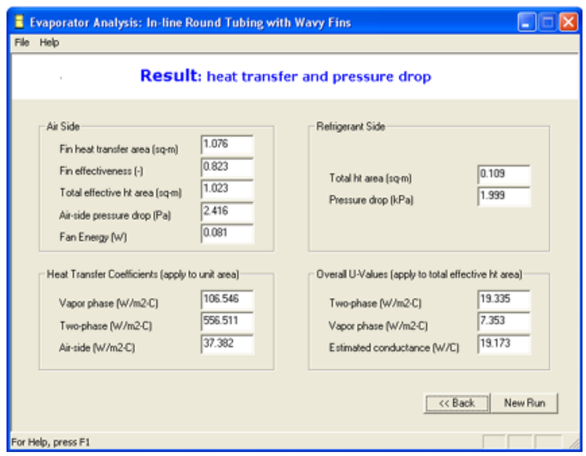
[e] These data must be user-defined since the program is not integrated into an overall cycle analysis.

Step 3, in this example, presents a dialog that requests information on the design of the fin. For the example of a wavy fin, the requested data are: fin thickness and pitch, fin thermal conductivity, fraction of the tube row that is finned, and fin pattern depth.



The number of steps required to define the evaporator depends on the design. For example, roll-bond and chest freezer evaporators only require two steps.

Results displayed depend on the type of evaporator modeled. In the case of a tube and fin design, the output includes the fin heat transfer area and effectiveness, the total effective heat transfer area, air-side pressure drop and fan energy, and the refrigerant-side pressure drop. In addition, the display lists the overall U-values that are to be used as input to ERA. These are shown specific to the input requirements of the DOS version of ERA.[f]



Roll-bond Evaporator

ERAEVAP uses the Dittus-Bolter equation [13] to determine the heat transfer coefficients for the air and the vapor phase of the refrigerant. A radiative component is added on the air-side. Liquid phase heat transfer is calculated using the Bo Pierre correlation [14]. The overall heat transfer rate is dominated by the air-side resistance. Heat transfer resistance across the roll-bond surface is assumed to be negligible.

The pressure drop in the evaporating heat transfer regime is calculated by marching stepwise downstream, calculating the local pressure gradient, and summing the local pressure drops to determine the total pressure drop. The local pressure drop is calculated using the Lockhart-Martinelli correlation [15].

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[f] As noted earlier, the stand-alone programs are intended only as an assist towards preparing input values needed by DOS ERA. Hence, they are considered an interim step in the development of the final Windows version of the updated ERA program.

Chest Freezer Cold Wall

Both air-side and refrigerant-side heat transfer rates are determined in the same manner as with a roll-bond. Calculation of the refrigerant pressure drop also uses the Lockhart-Martinelli correlation.

The refrigerant tubes are pressed on the inside surface of the chest freezer liner, which because of its small thickness acts like a thermal fin. With adjustment made for the end tubes, each parallel tube is represented as having a fin of width:

$$W_f = \text{Width of plate normal to the tube} / (2 * \text{number of tubes}),$$

The effectiveness for this equivalent fin is:

$$\eta = (k\,\delta / h)^{0.5} \tanh [W_f * (h / k\,\delta)^{0.5}] / W_f$$

For typical designs the effectiveness should be close to unity.

Tube and Fin Evaporator

Three fin options are modeled for the tube and fin design: plain fin, wavy fin, and herringbone fin. Refrigerant-side heat transfer and pressure drop are calculated in the same manner as described above. The air-side heat transfer rate depends on the type of fin and its design.

Equations for representing plain fin and herringbone fin designs were based on studies by Wang [16]. The wavy fin configuration was represented by correlations published by Mirth and Ramadhyani [17].[g] Because the correlations are quite complex, they are not reproduced here. However, both references are readily available.

The modeling and calculation approaches used in ERAEVAP will be employed in the final Windows version of ERA where analyses of the heat transfer and pressure drop characteristics of the evaporator will be built into the program. ERAEVAP will not be part of the Windows ERA package.

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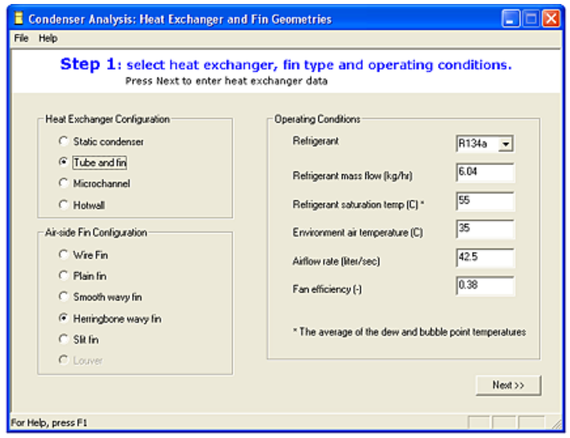
[g] Reference [16] is a summary of many studies performed and published by Wang and his colleagues for a wide variety of fin configurations, including louver fins, and slit-fins. It includes a summary of the work done on wavy fins by Mirth and Ramadhyani, but incorrectly reproduces their correlation.

5-B.4.2 Condenser Analysis Program – ERACOND

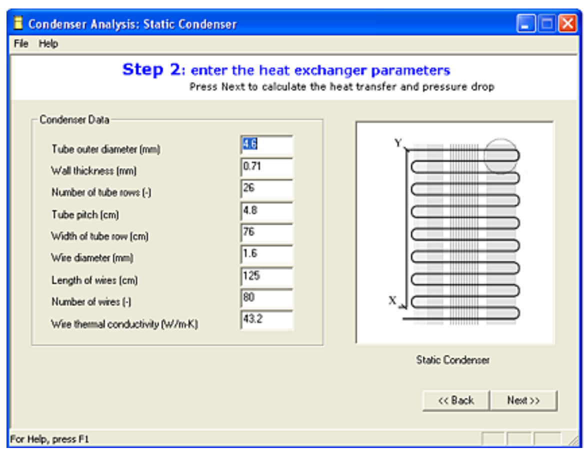
Condenser Design Options

Four generic classes of condensers are modeled: 1) static condenser, 2) various tube and fin designs, 3) microchannel design, and 4) a hot wall condenser. For each of these, the user defines the refrigerant mass flow rate, the saturation temperature, and the temperature of the environment (room or under-cabinet). The air flow rate and fan efficiency are also specified for the fan-forced designs.



Static Condenser

The static condenser model uses correlations developed by Bansal and Chin [18], who relied heavily on the work by Tagliafico and Tamda [19]. Design data include tube spacing and length, wire diameter, conductivity, and length, and the number of wires on both sides of the tubing. Heat transfer from the connecting bare tube is included in the analysis.



Refrigerant-side heat transfer is calculated according to the Shah correlation [20, 21]. Pressure drop is calculated according to the Lockhart-Martinelli correlation, assuming for the purposes of analysis that 15% of the tube is in the superheated vapor phase regime, 80% in two-phase condensation, and 5% in the subcooled regime.[h]

All of the condenser models to be described use the same approach to determining refrigerant-side heat transfer and pressure drop.

Wire Fin Condensers

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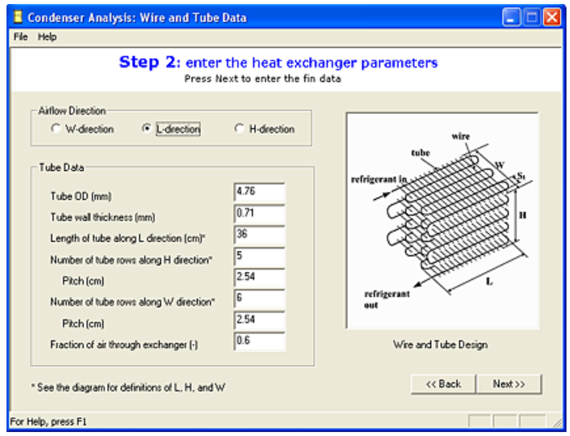
[h] This assumption will be replaced by the cycle model for the condenser in the Windows version of ERA, which will model the entire cycle system.

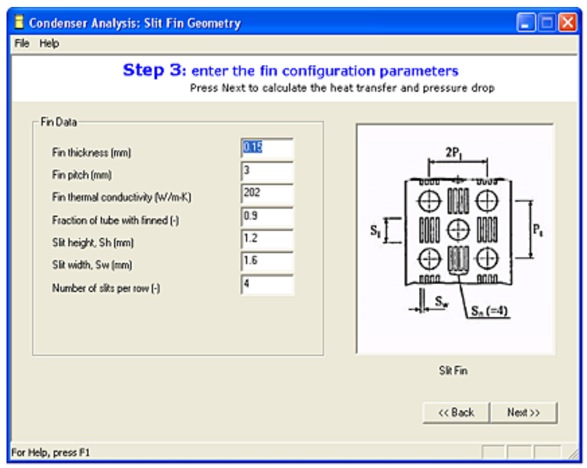
Wire fin condensers are found in many domestic refrigerators. ERACOND provides three options for air flow across the unit, listed in the data dialog as along the W-, L- or H-directions. Since the heat exchanger is normally located under the cabinet in the compressor space, not all of the air flow will cross the unit. Hence, a required input is the fraction of the total air flow through the condenser.



Calculation of the air-side heat transfer rate employs the Lee, et al correlation [22], which accounts for the orientation of the heat exchanger relative to the air flow.

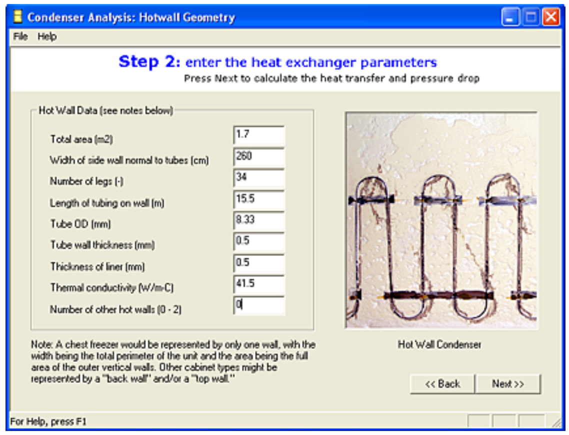
Tube and Extended Fins

Calculation of the fin heat transfer uses the Wang correlations [16] for the plain fin, the herringbone fin, and the slit fin configurations. Representation of a wavy fin heat transfer uses the Mirth and Ramadhyani correlation [17].



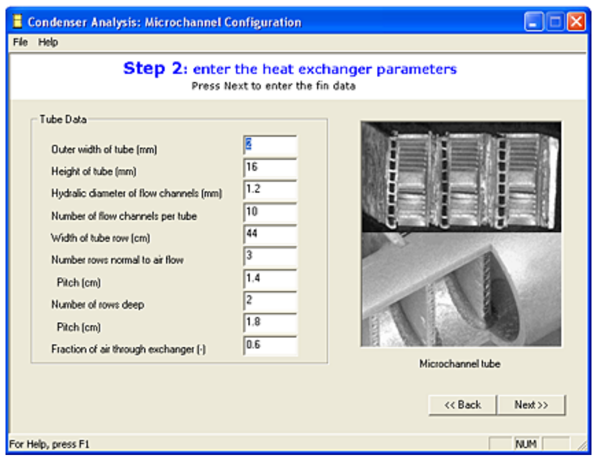
Both sets of correlations also estimate the air flow pressure drop thought the fins. Although calculated and displayed in the output, they do not consider other air flow restrictions, and therefore represent low values for the fan energy.

Hotwall Condenser



A hotwall condenser can be modeled as a single wall, as in a chest freezer, or by multiple walls, as in an upright freezer or refrigerator. The heat transfer effectiveness of each wall is determined. As with the evaporator cold wall, the major heat flow resistance is on the air-side. An overall pressure drop is calculated for the connected tubing using the Lockhart-Martinelli algorithm, with the Shah correlation used for the refrigerant condensing regime.

Microchannel and Louver Design



A microchannel condenser is assumed to use a louver-type fin. The refrigerant-side design determines the refrigerant flow rates and corresponding heat transfer coefficients and pressure drop. Design parameters for the louver determine the air-side heat transfer and air flow pressure drop. They are calculated using correlations developed by Wang [16].

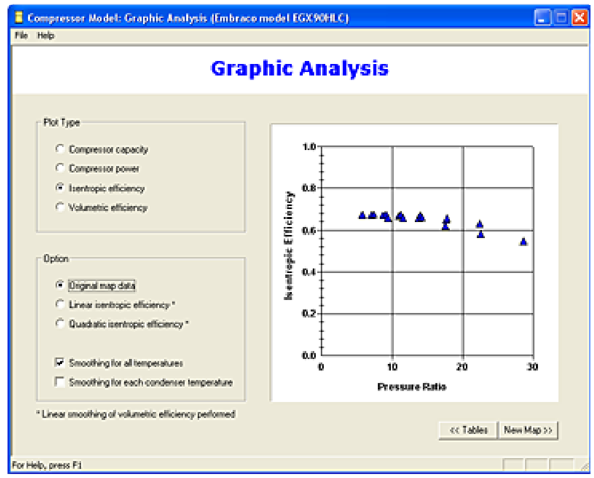
These same correlations, adopted by ERA, are used in the current (Mark VI) on-line version of the Oak Ridge heat pump model [23].

Compressor Model – COMPMAP

COMPMAP is an auxiliary program to the Windows version of ERA. The program graphically displays the isentropic and volumetric efficiencies implied by a compressor map, as a function of pressure ratio, providing a visual indication of whether the map is well formed. If desired, the map can be rebuilt based on various options for smoothing these underlying efficiencies.

COMPMAP may also be used to scale an existing map to a different COP and/or capacity. The program can import maps previously used with the DOS version of ERA or prepare new maps for use with the DOS version

COMPMAP can be used in stand-alone mode or can be directly called by ERA. This provides a built-in tool to validate and prepare maps for use in a simulation.



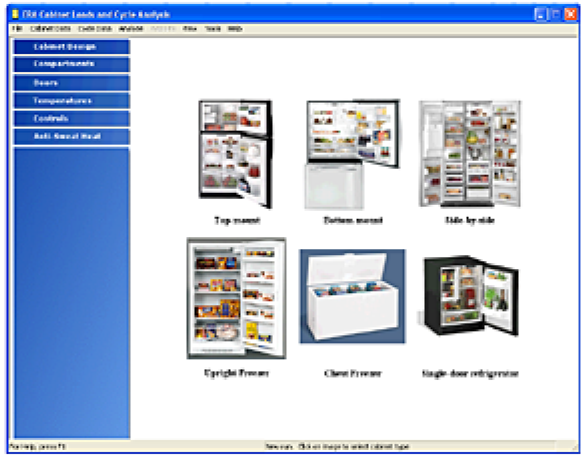
No assumption is made about the specific dependence of isentropic or volumetric efficiency on pressure ratio, other than that some correlation should exit. Using the efficiency values calculated for the particular map, the user is offered a choice of using the map as-is, or using a linear or quadratic smoothing of the efficiencies against the pressure ratio. This can be done for individual condenser temperatures if desired, preserving much of the original map while removing apparent randomness of performance as a function of the evaporator temperature.

5-B.4.3 Windows Version of ERA

User Interface

ERA uses a highly-graphical interface, providing multiple options for selecting from the various cabinet and component choices. It is designed to guide the user carefully through the data input and editing process to ensure data consistency. Prior to an actual simulation of the refrigeration appliance performance, the user is presented a summary of the selected design variables.

Cabinet Mode

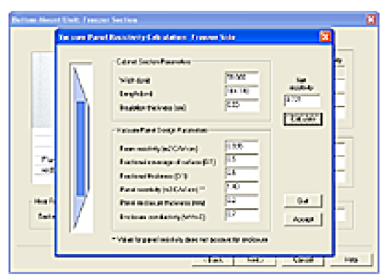


ERA operates in one of four view modes: 1) cabinet design mode (shown in the image), 2) cycle design mode, 3) simulation mode, and 4) reports mode. Each is characterized by its own sidebar, containing hotspots for selecting component or report options. The color of the sidebar provides an additional visual clue to highlight the particular mode that is current.

To define a new analysis, the user may either begin with a default set of design parameters and proceed through the editing process, or may read in an existing data file to be used as-is or edited.

Each analysis must begin with a selection of the basic cabinet design parameters: cabinet category (shown on the desktop) and the overall dimensions of the unit. Once these basic choices have been made, the remaining categories of cabinet design data may be specified in any order. Data wizards, similar to those illustrated above for the stand-alone programs, guide the user at each stage.

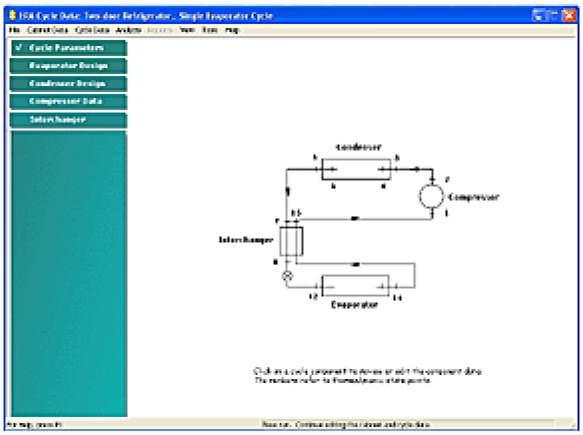
As each category of data is processed, a check mark is drawn on the sidebar to indicate the completeness of the editing progress.



In some instances, special-function dialogs may be summoned to assist in the preparation of an input value. For example, the image to the right shows a dialog used to calculate the effective resistivity of a cabinet wall that contains a vacuum panel or some equivalent high thermal resistance element.

Cycle Mode

Once the basic cabinet type has been selected, the user may specify the cycle parameters. This would begin with a selection of the basic cycle type (single evaporator, dual loop, dual evaporator, or Lorenz cycle). Once this choice has been made, a simple schematic of the chosen cycle category is displayed on the desktop. The user may then continue to define the cycle parameters by clicking on the desktop to select the component of interest, or may use the sidebar or the the drop-down menu to select the next component to be defined.

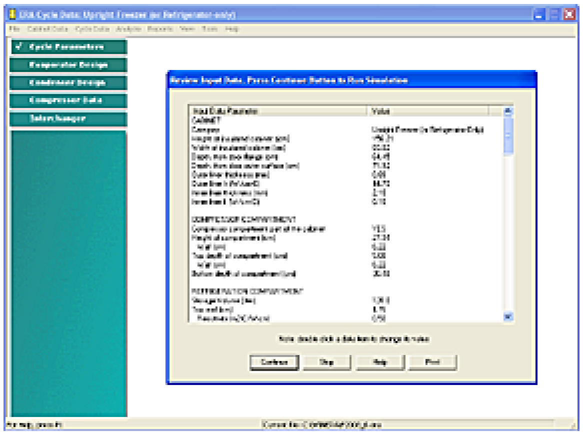


The displayed desktop image and its associated hotspots depend on the specific cycle category selected.

Simulation Mode

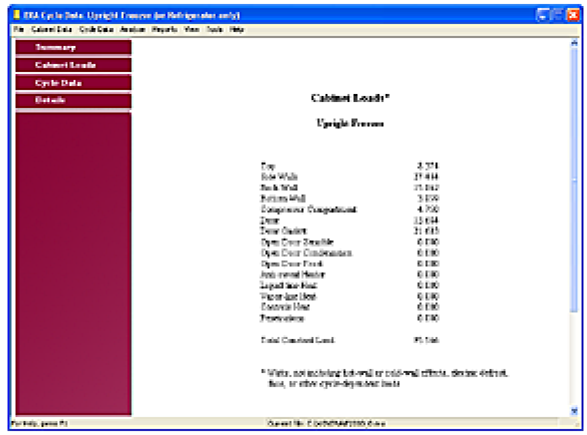
Prior to simulation of the cabinet loads and cycle behavior, the user is presented with a summary of the defined input. A data item can be selected for further editing by double-clicking on the summary line displaying the item in the data review dialog.

Once the data has been reviewed and accepted, the user selects the Continue button to start the simulation.



Reports Mode

At the completion of the simulation (which is instantaneous for the cabinet loads), the program automatically switches to reports mode and displays the results on the desktop. The example here shows the calculated cabinet loads. Results for the cycle analysis, overall performance parameters, or a more detailed summary, can be selected using the side-bar or the drop-down menu for reports.



Cabinet Loads

As of this preliminary documentation, only the cabinet loads have been modeled.

Each of the cabinet walls has at least one beveled edge where it joins another wall. Hence, some adjustment needs to be made for the difference between the inside and outside surfaces of the wall – that is, the conduction is not strictly one-dimensional. Detailed finite difference calculations carried out for a flat wall with adiabatic beveled edges (where the walls connect) show that a very good approximation can be obtained by representing the beveled wall as an equivalent wall of one dimensional heat transfer, where the equivalent wall area is:

$$\text{Area}_{\text{equiv}} = 0.25 \ \text{Area}_{\text{outside}} + 0.75 \ \text{Area}_{\text{inside}}$$

This is nearly identical to the method adopted in the DOS version of ERA, which also made adjustments for corner effects where three walls join. Hence, the previous methodology was retained, with minor corrections made as needed.

The loads analysis does not yet consider cycle-dependent interactions such as hot- or cold-walls, fan energies, defrost, or other cycle-dependent heat terms. These will be incorporated during the cycle portion of the simulation.

Refrigerant Properties

The fluid choices for the refrigeration cycle are: R134a, R152a, R290, R404A, R507A, or R600a. Thermodynamic properties are based on Refprop 8.0 [24]. To speed the computations, an approach to using the Helmholtz equation of state outlined by one of the authors of Refprop [25] has been adopted as the primary simulation option for ERA. This reference contains required property data for R-404A and R-507A. Data for the other refrigerants represented by ERA have been obtained from the Refprop fluid database.

A secondary option to use the full set of the more comprehensive, but considerably slower,[i] Refprop routines will be offered for those instances when the user might wish to confirm the simulated performance.

Because Refprop does not supply a complete set of thermophysical properties for all of the refrigerants over the full set of temperatures and pressures, correlations for the thermal conductivity and viscosity were developed from refrigerant manufacturer literature. In general, uncertainties in these properties are less important than uncertainties in the thermodynamic properties since the net heat transfer resistance is normally dominated by the air-side.

Cycle Analysis

The cycle model, currently under development, will adopt the general approach employed in the DOS version of ERA. An iterative solution procedure will be required to simultaneously satisfy the heat transfer and mass flow equations throughout the loop. Where the cycle components affect the cabinet loads, adjustments to the loads will be calculated.

Several major differences will appear between the Windows and DOS versions of ERA:

- Only a map-based compressor model will be used. This decision is based on experience gained using ERA with actual equipment, where compressor information for the actual unit was needed to accurately reflect the energy consumption. The accompanying compressor module, COMPMAP, can be employed to create or modify map data.

- The heat exchanger performance routines will be integrated into the overall cycle simulation. Hence, the effects of parameters such as refrigerant mass flow, and entering temperature and pressure on the heat exchanger performance will be automatically taken into account at each stage of the simulation.

- An improved iteration approach will be used to ensure rapid and proper convergence. The solution method used in the ORNL Mark series heat pump looks promising [26].

Tools

The new version of ERA provides several tools to assist in preparing the program inputs and in interpreting the results:

Compressor Map program. COMPMAP may be run directly from ERA by selecting this option from the Tools menu. It provides a means of viewing and/or adjusting a map that is to be used in

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[i] Both Lemmon [25] and ThermoSoft experience obtained with a heat pump model confirm that the Helmholtz method can result in computation time reductions of a factor of 30 to 40 over the full set of Refprop routines.

the cycle simulation. When selected, ERA is minimized until the compressor map program is dismissed,

Refrigerant Properties. A calculation of the refrigerant properties for the selected refrigerant can be made given certain specified state points. The calculations are carried out using the Helmholtz method.

Unit Conversion. This tool can be used to convert to different units values of length, flow rate, temperature, thermal conductivity, volume, energy, or power.

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APPENDIX 7-A. LITERATURE SURVEY OF ENERGY CONSUMPTION BY RESIDENTIAL REFRIGERATOR-FREEZERS

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APPENDIX 7-A. LITERATURE SURVEY OF ENERGY CONSUMPTION BY RESIDENTIAL REFRIGERATOR-FREEZERS

7-A.1 INTRODUCTION

Efficient refrigerator-freezers reduce peak energy consumption as well as total household energy use. As a result, electric utilities regard replacement programs for these appliances as an attractive and effective way to reduce residential energy consumption. To estimate the amount of electricity savings attributable to an energy-efficient refrigerator-freezer program, utilities must evaluate the difference between the pre- and post-program energy consumption of the appliance stock. The challenge to accurately estimate the electricity savings of a refrigerator-freezer replacement program lies in estimating the real-life consumption of the original and replacement units.

Estimation of appliance energy consumption may be undertaken in three ways, all of which are represented in the literature:

A) The labeled energy consumption on a new appliance, based on the U.S. Department of Energy (DOE) test procedure undertaken on a sample of several identical appliances, and reported by the appliance manufacturer
B) The DOE test procedure applied to a particular appliance (often not a new appliance), and
C) Measurement for some period of time *in situ* in a household.

Most studies compare two of these measurements in order to evaluate energy use. For example, a study might compare the results of the DOE test procedure on an old refrigerator with the labeled energy consumption when new to isolate the effect of appliance age, while eliminating possible effects due to user behavior. This appendix refers to such a study as comparing (B) to (A).

Researchers have conducted studies that measure the field consumption of refrigerator-freezers to compare *in situ* measurements to the DOE test results, represented either by the labeled results ((C) to (A)), or through direct testing under DOE conditions ((C) to (B)). When such field studies are evaluated, the lack of consistency among study conditions (such as geographic location, housing type, and the number and type of units), limited time of direct measurements, and the degradation of efficiency throughout the lifetime of a refrigerator-freezer contribute to the challenge of estimating potential energy consumption savings from new units.

This appendix summarizes available literature regarding the comparison of different measurement methods for refrigerator-freezers in order to evaluate reasonable possible values for the ‘usage adjustment factor’ (UAF), which is an estimate of the ratio of (C) to (A). There are very few published measurements of freezers or compact appliances, so DOE addresses only refrigerator-freezers in this summary. Section 2 summarizes the DOE test procedure and lists and characterizes the field studies which DOE used in its analyses. Section 3 discusses these studies and their implications for the UAF parameter used in Chapter 6, particularly regarding variation with season and climate, and efficiency degradation with unit age.

7-A.2 TEST PROCEDURE AND FIELD STUDIES

This section describes the DOE test procedure, then lists field studies of energy consumption by refrigerator-freezers and distills their results.

7-A.2.1 DOE Test Procedure

"The DOE test is a compromise between realism and minimizing the costs of performing a reliable, repeatable laboratory test" (Meier, 1993). The DOE procedure for evaluating the annual energy consumption of refrigerator-freezers comprises the following features (10 CFR, Chapter II, Part 430, Appendix A1).

- The standard test temperature for the fresh food compartment is 45°F.
- The standard test temperature for the freezer compartment is 5°F.
- The test is performed in a chamber that is maintained at an ambient temperature of 90°F.
- The temperatures of the freezer and fresh food compartments are measured using three independent thermocouples, one for each compartment. Five thermocouples are used when the refrigerator height is over 40".
- The appliance's energy consumption is calculated by interpolating test results that bracket the standard freezer temperature (5°F). Interpolation is done around the 5°F temperature (freezer compartment) and the 45°F temperature (fresh food compartment).
- Ambient relative humidity is not specified.
- Doors are not opened during the test.
- The fresh food and freezer compartments are empty.
- Ice making capability, if present, is not powered on or evaluated by the test.

The DOE test procedure is currently undergoing a rulemaking process which may change some of the above details. In particular, changes have been proposed to the test temperatures for the refrigerator and freezer compartments.

The DOE test procedure does not measure the effects of door opening, cooling warm food, or ice making. However, this test procedure provides standardized results that can serve as the basis for comparing the performance of appliances. Although the DOE test does not precisely mirror any single unit's performance *in situ*, it serves as a foundation to which field measurements may be compared to develop estimates that account for a range of real-life circumstances (KEMA, 2004).

A summary of new refrigerator-freezer unit energy consumption values provided by manufacturers by year shows the annual variation of shipment-weighted refrigerator energy consumption from 1960s to the year 2006 (Table 2.1). These data are based on "nameplate" values. For the model years before the DOE energy standards (1989 and earlier), the test conditions are unknown in which energy consumption quantities were measured, although it is likely that manufacturers used the American Home Appliance Manufacturers (AHAM) test procedure or the test procedure prescribed by California state energy conservation standards.

Table 7-A.2.1 Refrigerator Energy Consumption Data by Year

Model Year	Shipment Weighted Average Use (kWh/yr)	Model Year	Shipment Weighted Average Use (kWh/yr)
2006	564	1990	988
2005	550	1989	1006
2004	559	1988	1049
2003	589	1987	1052
2002	576	1986	1165
2001	611	1985	1147
2000	779	1984	1139
1999	762	1983	1160
1998	738	1982	1191
1997	728	1981	1190
1996	708	1980	1278
1995	693	1975 – 1979	1530†
1994	693	1970 – 1974	1730†
1993	699	1965 – 1969	1540†
1992	877	1961 – 1964	1150†
1991	918		

Source: AHAM Fact Books
†: Approximate

7-A.2.2 Field Studies

In situ conditions account for several important factors including: ambient air temperature; the number and duration of door openings; the temperature of food loaded into the unit; the placement of the unit in relation to walls, ovens, and stoves; the temperature setting in the field; and the ice maker setting in the field.

Since the early 1980s, utilities and government agencies have collected data on field-measured refrigerator-freezer energy consumption in order to evaluate the effects of refrigerator "early replacement" programs. The collected data varies tremendously by sample size, the type of refrigerator-freezer studied, the length of time each appliance was monitored, and their operating conditions. The studies summarized in Table 2.2 describe the performance of refrigerator-freezers as measured in various ways.

7-A.2.2.1 KEMA-Xenergy Findings

The private consulting firm KEMA-Xenergy in 2002 reviewed numerous reports of *in situ* performance studies for Southern California Edison. Several reports were summarized by KEMA-Xenergy but are not available to be reviewed by DOE. These reports are indicated by a "#" in Table 2.2.

Table 7-A.2.2 Literature summary

Authors(s)	Year	Ratio Average[a]	Ratio Range	Comparison Type	Location	Refrigerator Type	Adjusted for climate or season	No. of Refrigerators
Arthur D. Little, Inc. #	1982	>1.2		C to A	Florida	unknown	No	unknown
Topping & Vineyard	1982		0.85 to 1.5[b]	C to A	Norfolk, VA	New	No[a]	47
Meier & Jansky	1993	0.85 is "typical"	0.56 to 1.17	C to A	Cold climates (many in Pacific Northwest)	Relatively new	No	209
Meier et al.	1993	B to A: 0.99, C to A: 0.87	B to A: 0.89 to 1.10	B and C to A	Rochester, NY	New, "energy efficient", frost-free	No	20
Bos #	1993	"considerably" > 1		B to A	Sacramento, CA	At replacement	N/A	79
Quantum Consulting	1994	0.87 for "high-efficiency", 1 for "super-efficiency"	95% between roughly 0.7 and 1.25	C to A	Southern CA (SCE)	1-3 years old	No	98
Proctor Engineering (Dutt et al.)	1994	Between 0.86 and 0.9[c]		C to A	Northern CA (PG&E)	New, "energy efficient"	Yes[d]	256
Goett #	1995	approx. 1		Unknown	CA (PG&E and SCE)	New	No	unknown
Barakat & Chamberlin #	1996	"significantly more" than 1		B to A	Unknown	At replacement	N/A	unknown
Miller & Pratt	1998	1.1	0.72 to 1.2[e]	C to A	New York City (multi-family public housing)	Some new, some older	No	324
Kinney & Belshe	2001	0.96 (new); 1.3 (mixture)		C to A	New York City (multi-family public housing)	220 old, 56 new	No	276
ICF Consulting	2003	approx. 0.5		C to statistical model of C	CA (Bay Area)	At replacement	No	40
Mowris #	2003	1.06	wide variation	C to A	Northern CA (6 cities)	At replacement	unknown	91
KEMA	2004	1.46 (median)	0.85 to > 3	B to A	California	At replacement	N/A	136
Peterson et al.	2007	median 1.4, mean 1.5		B to A	California	At replacement	N/A	193
ADM, Athens, et al.	2008	0.81 to 0.88, depending on weather model		C to B	California	At replacement	Yes	184

[a] A value greater than 1 for this ratio for a C to A comparison implies that energy use in the field (C) was greater than the labeled energy consumption (A).
[#] KEMA-Xenergy (2004) is DOE's only reference for the results of this study.
[b] Seasonal variation for a single model
[c] Ratio of average C to average A over sample
[d] Adjusted for typical meteorological year (TMY) at location
[e] Variation in the mean of various types of refrigerators in various use environments

7-A.3 LITERATURE ANALYSIS

DOE's interest in surveying the refrigerator-freezer energy use literature is to evaluate the range of possible appropriate values for the 'usage adjustment factor', or UAF. The UAF is a "(C) to (A)"-type measurement, relating energy use in situ to the DOE test result for a new appliance.

Studies of new appliances include Meier & Jansky (1993), Meier et al. (1993), Dutt et al. (1994), Quantum (1994), Goett (1995), Miller & Pratt (1998), and Kinney & Belshe (2001). The average (or typical) values of the ratio of (C) to (A) for these studies range from 0.85 to 1.1, and there is significant variation, with ratios ranging from 0.56 to 1.25. The majority of these studies are not adjusted for ambient temperature variations or climate (although several use year-long samples to eliminate seasonal effects). The only of these studies which is adjusted (Dutt et al.) is normalized to the climate of the particular location of the measurements, rather than to a national average climate model. Taken collectively, these studies do not allow DOE to draw conclusions regarding possible national variation in new-refrigerator energy use, particularly due to variations in climate. They do indicate that the labeled energy consumption of a new appliance is likely to be accurate *in situ* to within 40%, as suggested by Meier (1995).

Studies of refrigerators at the time of replacement by utility programs show higher energy use relative to the labeled energy consumption than do new refrigerators. For older refrigerators, studies predominantly take two forms: (B) to (A) or (C) to (A). (B) to (A) studies isolate the effects of age from any other effects (such as behavior or ambient temperature *in situ*), while (C) to (A) studies give a direct indication of the 'UAF' of old appliances. These studies are not necessarily representative of all older refrigerators, because they study only those units and households participating in utility refrigerator recycling programs.

Test-procedure-only comparison studies include Bos (1993), Barakat & Chamberlin (1996), KEMA (2004) and Peterson et al. (2007). All four of these studies show significant energy use increase in the DOE test procedure; KEMA and Peterson both indicate an energy use increase of close to 50%, with wide variation. Only 7% of the refrigerators measured by KEMA used less than their labeled consumption. 25% of the refrigerators measured by Peterson et al. used more than 70% more that their labeled consumption.

Miller & Pratt (1998), Kinney & Belshe (2001), and Mowris (2003) undertook direct evaluation of the ratio of *in situ* to labeled consumption for older refrigerators. The average ratio in all three studies was measured to be larger than one, although smaller than the test-procedure-based comparisons. Mowris indicated wide variation in energy use relative to the label, and Miller & Pratt's sub-categories show a range of energy consumptions from 28% below the label to 20% above.

Only one study reviewed by DOE compared *in situ* energy use to the DOE test on the same appliance (ADM, Athens, et al., 2008), a (C) to (B) comparison. Depending on the weather model used to adjust the *in situ* measurements, they found that on average the DOE test procedure overestimated the *in situ* use by 13 to 23%. This study does not include an indication of how the DOE test consumption compared with the labeled consumption.

Testing has confirmed that age, in combination with other refrigerator characteristics, accounts for the degradation of refrigerator energy efficiency (KEMA, 2004; Peterson, 2007). Therefore, energy efficiency degradation is a factor in calculating the savings between new and replacement units. Energy use increases when barriers to cabinet air and heat leakage degrade. For example, door seals no longer close tightly, damaged walls allow air flow, and wet or degraded insulation no longer performs its function.

Two studies (KEMA, 2004 and Miller & Pratt, 1998) used regression analysis to measure the average effect of annual degradation on appliance energy use. KEMA determined an energy use growth rate of roughly 40 kWh/year, depending on model characteristics. Miller & Pratt's regression model predicts a 1.37% increase in energy use each year. Smit (2006) reports that Athens (1998) calculated a degradation rate of 0.6% per year.

7-A.4 SUMMARY

This appendix summarizes current literature pertaining to the difference between DOE-test based measurements (when new or at retirement) and field-based measurements of refrigerator-freezer energy consumption. *In situ* energy use was found to be close to labeled consumption for new refrigerators, but higher than labeled at the time of replacement. This appendix has examined the mean values and variability from the literature; the variability across a national sample is likely much greater than the range addressed here.

Degradation of the refrigerator unit contributes to the discrepancy between the DOE test and field measured energy consumption data. However, the precise rate of efficiency decrease (and particularly its variability) cannot be determined from the literature.

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APPENDIX 7-B. DATA FOR ESTIMATING DISTRIBUTION OF REFRIGERATOR AND FREEZER SIZE IN THE RECS SAMPLE

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7-B.1 INTRODUCTION

DOE used the California Energy Commission (CEC) appliance database[1] to determine the distribution of refrigerator and freezer volumes in the market. The Energy Information Administration's (EIA) Residential Energy Consumption Surveys (RECS)[2] provides the volumes of household refrigerators only within bins (ranges). In order to estimate the labeled energy consumption of a household's standard-sized appliance, DOE selected a volume from within the appropriate RECS bin. DOE then selected a more precise volume randomly from the distribution of volumes within the RECS bin, basing the probability of selecting each volume on the number of models in the CEC database having that volume. The figures in this appendix show the volume distributions by number of models in the CEC database (narrower, solid bars in figures) and the distributions of refrigerator volumes reported by RECS respondents (wider, empty bars in figures). For each standard-sized refrigeration product DOE first identified the appropriate RECS bin and product class, then chose a more precise volume from the relevant part of the CEC distribution.

For compact products (product classes 11 and 18), for which DOE did not use a household sample, DOE used the distribution of volumes from the CEC database to characterize the distribution of volumes sold in the market and determine the distribution of energy use.

7-B.2 RESULTS

Figures 7-B.2.1 through 7-B.2.7 depict the volume distributions on the number of models in the CEC database and the distribution of refrigerator and freezer volumes reported in RECS.

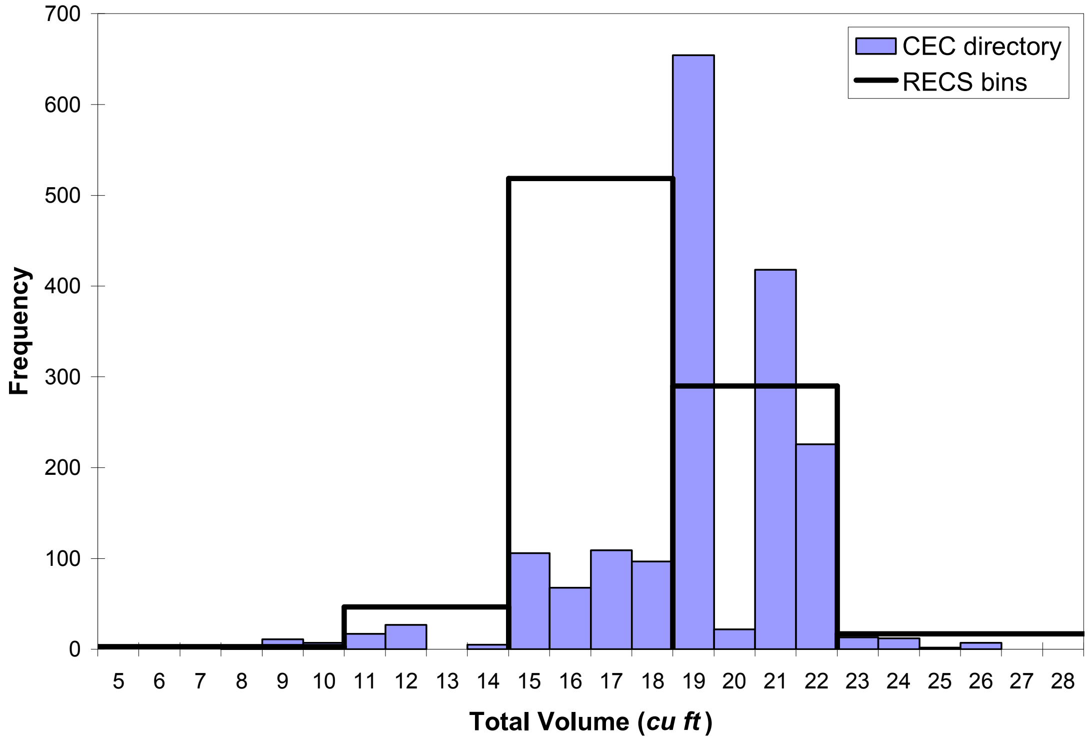

Figure 7-B.2.1 Models of Top Mount Freezer without through-the-door ice (Product Class 3)

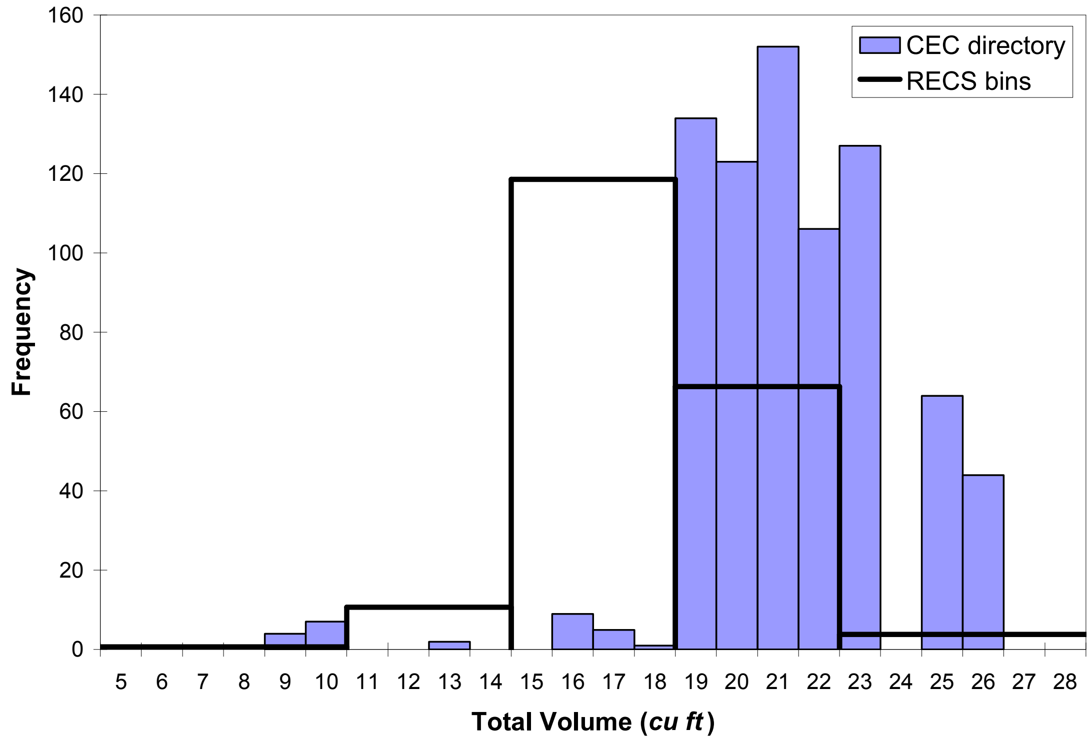

Figure 7-B.2.2 Models of Bottom Mount Freezer without through-the-door ice (Product Class 5)

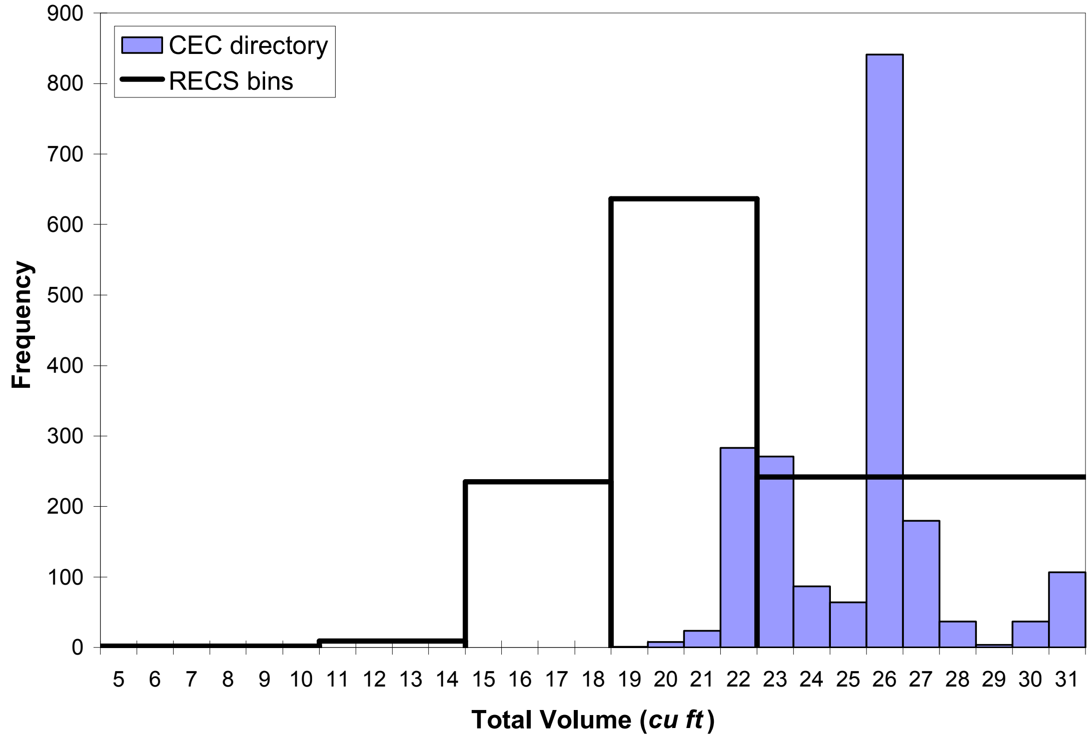

Figure 7-B.2.3 Models of Side Mount Freezer with through-the-door ice (Product Class 7)

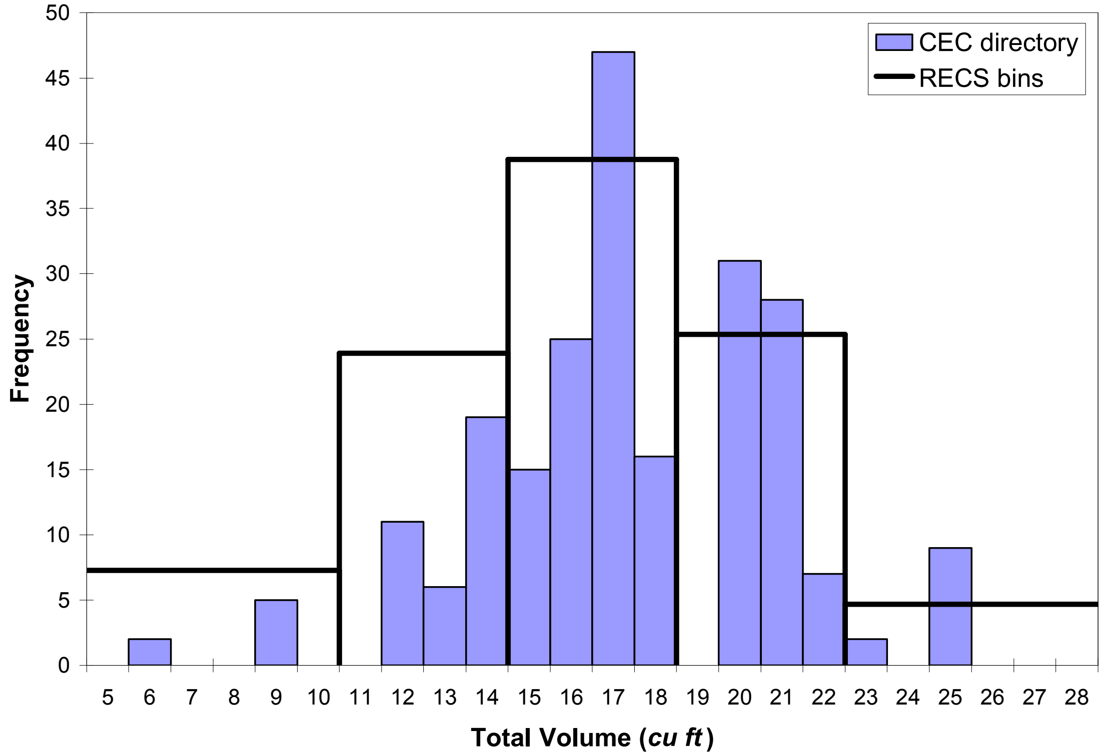

Figure 7-B.2.4 Models of Upright Freezer with automatic defrost (Product Class 9)

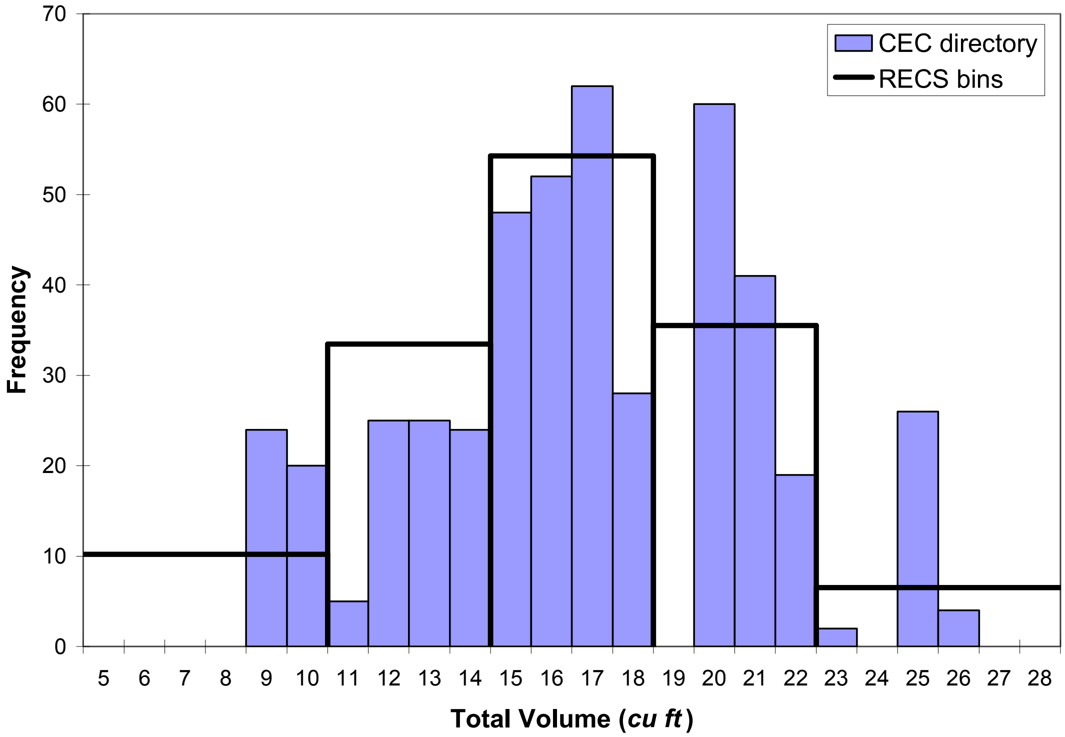

Figure 7-B.2.5 Models of Chest Freezers (Product Class 10)

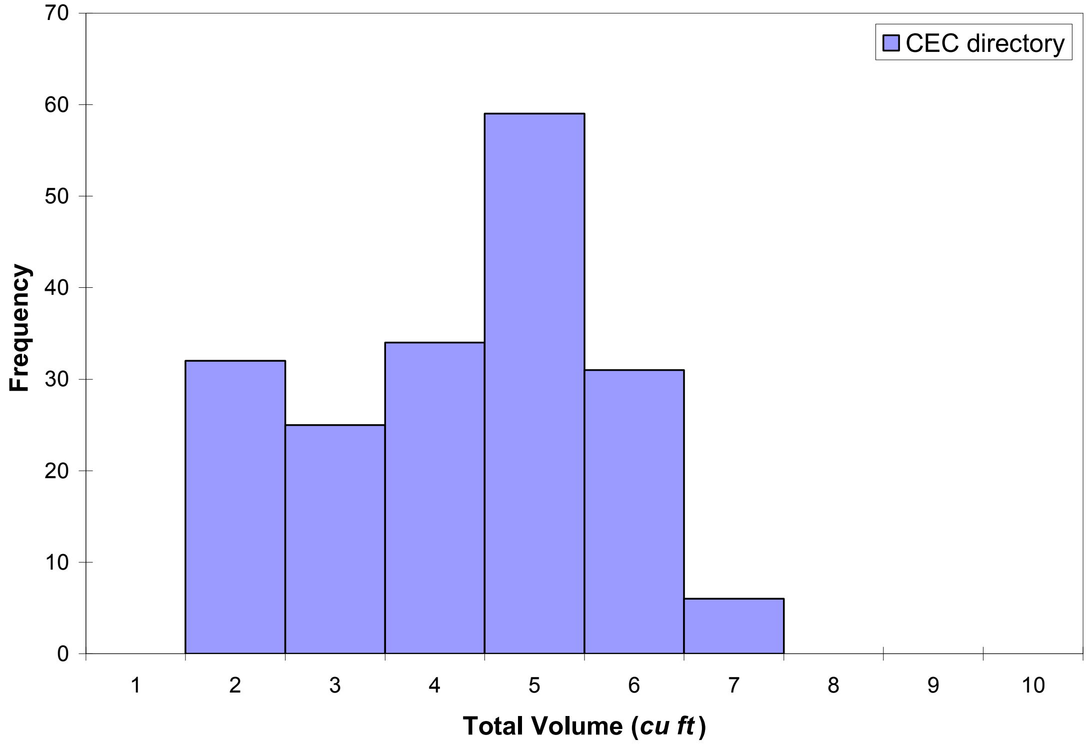

Figure 7-B.2.6 Models of Compact Refrigerator and Refrigerator-Freezer with manual defrost (Product Class 11)

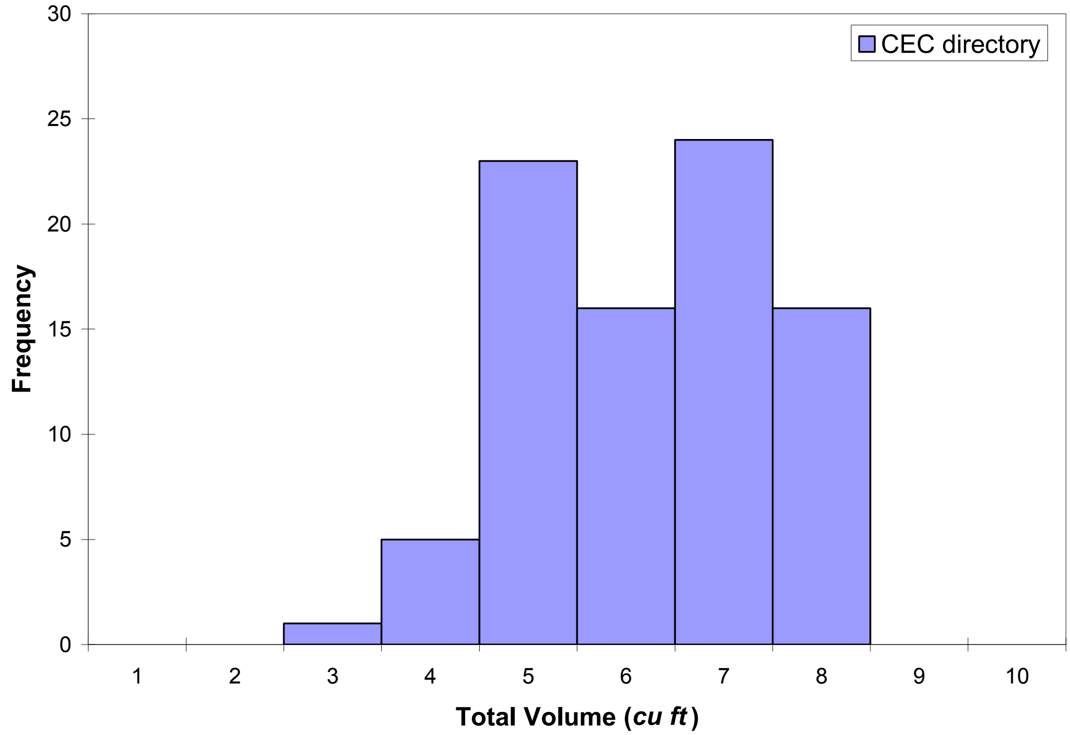

Figure 7-B.2.7 Models of Compact Chest Freezer (Product Class 18)

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[2] U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey, 2005 Public Use Data Files.* 2009. U.S. Department of Energy: Washington, D.C. <www.eia.doe.gov/emeu/recs/recspubuse05/pubuse05.html>

APPENDIX 8-A. USER INSTRUCTIONS FOR LCC AND PBP SPREADSHEETS

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APPENDIX 8-A. USER INSTRUCTIONS FOR LCC AND PBP SPREADSHEETS

8-A.1 INTRODUCTION

It is possible to examine and reproduce the detailed results of the life-cycle cost (LCC) and payback period (PBP) analyses using Microsoft Excel spreadsheets available on the U.S. Department of Energy's website at: http://www.eere.energy.gov/buildings/appliance_standards/. To fully execute the spreadsheets requires both Microsoft Excel and Crystal Ball software. Both applications are commercially available. Crystal Ball is available at: http://www.decisioneering.com.

The seven spreadsheets posted on the DOE website represent the latest versions and have been tested with Microsoft Excel 2003.

8-A.1.1 Standard Size Refrigerator-Freezers and Freezers

The Standard Size Refrigerator-Freezers and Freezers LCC and PBP spreadsheets or workbooks consist of the following worksheets:

LCC Summary Contains the input selections and a summary table of energy use, operating costs, LCC, and Payback. This worksheet also works as an interface between user inputs and the rest of the worksheets — do not modify this sheet.

RECS Households For each RECS household being sampled, contains the equipment usage data, along with product characteristics (i.e., size, volume, product age) and household characteristics (e.g., Census division, income).

RECS UAF Contains the unit adjustment factor calculation which converts tested energy consumption into field energy consumption.

Base Case Eff Dist Contains market efficiency distribution in the year the standard takes effect.

Equipment Price Contains manufacturer price data for the considered design options. Also includes the manufacturer and retail mark-ups, sales tax.

Repair Cost Contains repair cost for every considered design options

Energy Use Contains unit energy use data (tested and field).

Energy Price Contains regional electricity prices for the reference year.

Energy Price Trend	Contains the electricity price trends for the reference, high, and low economic growth scenarios based on AEO 2010.
Discount Rate	Contains data from which an average discount rate and a distribution of discount rates are determined.
Lifetime	Contains the survival function and average lifetime in years.
Standards	Contains past and existing standards by product class along with historical trends of energy consumption prior to first standards.
AV Equations	Contains average relation between volume and adjusted volume by product class.
ESAF	Contains efficiency standard adjustment factor.
EStarModel	Contains Energy Star model assigning energy star to households based on income.

8-A.1.2 Compact Refrigerators and Compact Freezers

The Compact Refrigerators and Compact Freezers LCC and PBP spreadsheet or workbook consists of the following worksheets:

LCC Summary	Contains the input selections and a summary table of energy use, operating costs, LCC, and Payback. This worksheet also works as an interface between user inputs and the rest of the worksheets — do not modify this sheet.
Base Case Eff Dist	Contains market efficiency distribution in the year the standard takes effect.
Division	Contains number of customers for residential and commercial sector by region.
Equipment Price	Contains manufacturer price data for the considered design options. Also includes the manufacturer and retail mark-ups, sales tax.
Repair Cost	Contains repair cost for every considered design options
Energy Use	Contains unit energy use data (tested and field).
Energy Price	Contains regional electricity prices for the reference year.

Energy Price Trend	Contains the electricity price trends for the reference, high, and low economic growth scenarios based on AEO 2010.
Discount Rate	Contains data from which an average discount rate and a distribution of discount rates are determined.
Lifetime	Contains the survival function and average lifetime in years.
AV Equations	Contains average relation between volume and adjusted volume by product class.

8-A.2 BASIC INSTRUCTIONS

Basic instructions for operating the LCC spreadsheets are as follows:

1. Once you have downloaded the LCC file from the Web, open the file using Excel. At the bottom, click on the tab for sheet 'LCC Summary'.

2. Use Excel's "View/Zoom" commands at the top menu bar to change the size of the display to make it fit your monitor.

3. The user interacts with the spreadsheet by clicking choices or entering data using the graphical interface that comes with the spreadsheet. Select choices from the various inputs listed under "User Options" heading.

4. Under the "User Options" heading, select choices from the selection buttons and boxes for the following: (1) type of calculation (Sample or Crystal Ball®), (2) energy price Trend, (3) start year, and (4) efficiency market share scenario. By overwriting the code in the LCC summary sheet, a new discount rate or lifetime can be entered if a value other than the default value is wanted . The Department does not recommend saving the spreadsheet after the code is changed.

5. To change inputs listed under "User Input", select the input you wish to change by either clicking on the appropriate button or selecting the appropriate input from the input box.

6. This spreadsheet gives the user two types of calculation methods:
   a. If the "Sample Calc" is selected, then all calculations are performed for single input values, usually an average. The new results are shown on the same sheet as soon as the new values are entered.

   b. Alternately, if the "CB Calculation" is selected, the spreadsheet generates results that are distributions. Some of the inputs are also distributions. The results from the LCC distribution are shown as single values and refer only to the results from the last

Monte Carlo sample and are therefore not meaningful. To run the distribution version of the spreadsheet, the Microsoft Excel® add-in software called Crystal Ball® must be enabled.

To produce sensitivity results using Crystal Ball, simply select Run from the Run menu (on the menu bar). To make basic changes in the run sequence, including altering the number of trials, select Run Preferences from the Run menu. After each simulation run, the user needs to select Reset (also from the Run menu) before Run can be selected again. Once Crystal Ball has completed its run sequence it will produce a series of distributions. Using the menu bars on the distribution results, it is possible to obtain further statistical information. The time taken to complete a run sequence can be reduced by minimizing the Crystal Ball window in Microsoft Excel. A step-by-step summary of the procedure for running a distribution analysis is outlined below:

1. Find the Crystal Ball toolbar (at top of screen)

2. Click on Run from the menu bar

3. Select Run Preferences and choose from the following choices:
    a. Monte Carlo[a]
    b. Latin Hypercube (recommended)
    c. Initial seed choices and whether you want it to be constant between runs
    d. Select number of Monte Carlo Trials (DOE suggests 10,000).

4. To run the simulation, follow the following sequence (on the Crystal Ball toolbar)

    Run
    Reset
    Run

5. Now wait until the program informs you that the simulation is completed.

The following instructions are provided to view the output generated by Crystal Ball.

1. After the simulation has finished, to see the distribution charts generated, click on the Windows tab bar that is labeled Crystal Ball.

2. The life-cycle cost savings and payback periods are defined as Forecast cells. The frequency charts display the results of the simulations, or trials, performed by Crystal Ball. Click on any chart to bring it into view. The charts show the low and high endpoints of the forecasts. The View selection on the Crystal Ball toolbar can be used to specify whether you want cumulative or frequency plots shown.

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[a] Because of the nature of the program, there is some variation in results due to random sampling when Monte Carlo or Latin Hypercube sampling is used.

3. To calculate the probability that a particular value of LCC savings will occur, either type 0 in the box by the left arrow, or move the arrow key with the cursor to 0 on the scale. The value in the Certainty box shows the likelihood that the LCC savings will occur. To calculate the certainty of payback period being below a certain number of years, choose that value as the high endpoint.
4. To generate a printout report, select Create Report from the Run menu. The toolbar choice of Forecast Windows allows you to select the charts and statistics in which you are interested. For further information on Crystal Ball outputs, please refer to Understanding the Forecast Chart in the Crystal Ball manual.

APPENDIX 8-B. UNCERTAINTY AND VARIABILITY IN LCC ANALYSIS

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APPENDIX 8-B. UNCERTAINTY AND VARIABILITY IN LCC ANALYSIS

8-B.1 INTRODUCTION

Analysis of an energy-efficiency standard involves calculations of impacts, for example, the impact of a standard on consumer life-cycle cost (LCC). In order to perform the calculation, the analyst must first: 1) specify the equation or model that will be used; 2) define the quantities in the equation; and 3) provide numerical values for each quantity. In the simplest case, the equation is unambiguous (contains all relevant quantities and no others), each quantity has a single numerical value, and the calculation results in a single value. However, unambiguity and precision are rarely the case. In almost all cases, the model and/or the numerical values for each quantity in the model are not completely known (i.e., there is uncertainty) or the model and/or the numerical values for each quantity in the model depend upon other conditions (i.e., there is variability).

Thorough analysis involves accounting for uncertainty and variability. While the simplest analysis involves a single numerical value for each quantity in a calculation, arguments can arise about what the appropriate value is for each quantity. Explicit analysis of uncertainty and variability is intended to provide more complete information to the decision-making process.

8-B.2 UNCERTAINTY

When making observations of past events or speculating about the future, imperfect knowledge is the rule rather than the exception. For example, the energy actually consumed by a particular appliance type (such as the average U.S. commercial air conditioner or heat pump) is not directly recorded, but rather estimated based upon available information. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

8-B.3 VARIABILITY

Variability means that different applications or situations produce different numerical values when calculating a quantity. Specifying an exact value for a quantity may be difficult because the value depends on something else. For example, the number of hours an air conditioner is operated by a household depends upon the specific circumstances and behaviors of the occupants (e.g., number of persons, personal habits about how comfortable the person wants to be, etc.). Variability makes specifying an appropriate population value more difficult in as much as any one value may not be representative of the entire population. Surveys can be helpful here, and analysis of surveys can relate the variable of interest (e.g., hours of use) to other variables that are better known or easier to forecast (e.g., persons per household).

8-B.4 APPROACHES TO UNCERTAINTY AND VARIABILITY

This section describes two approaches to uncertainty and variability:

- scenario analysis, and
- probability analysis.

Scenario analysis uses a single numerical value for each quantity in a calculation, then changes one (or more) of the numerical values and repeats the calculation. A number of calculations are done, which provide some indication of the extent to which the result depends upon the assumptions. For example, the life-cycle cost of an appliance could be calculated for energy rates of 2, 8, and 14¢ per kWh.

The advantages of scenario analysis are that each calculation is simple; a range of estimates is used; and crossover points can be identified. (An example of a crossover point is the energy rate above which the life-cycle cost is reduced, holding all other inputs constant. That is, the crossover point is the energy rate at which the consumer achieves savings in operating expense that more than compensate for the increased purchase expense.) The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

Probability analysis considers the probabilities within a range of values. For quantities with variability (e.g., electricity rates in different households), surveys can be used to generate a frequency distribution of numerical values (e.g., the number of households with electricity rates at particular levels) to estimate the probability of each value. For quantities with uncertainty, statistical or subjective measures can be used to provide probabilities (e.g., manufacturing cost to improve energy efficiency to some level may be estimated to be $10 ± $3).

The major disadvantage of the probability approach is that it requires more information, namely information about the shapes and magnitudes of the variability and uncertainty of each quantity. The advantage of the probability approach is that it provides greater information about the outcome of the calculations, that is, it provides the probability that the outcome will be in a particular range.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8-B.5 PROBABILITY ANALYSIS AND THE USE OF CRYSTAL BALL

To quantify the uncertainty and variability that exist in inputs to the engineering, LCC, and payback period (PBP) analyses, the Department used Microsoft Excel spreadsheets combined with Crystal Ball, a commercially available add-in, to conduct probability analyses. The probability analyses used Monte Carlo simulation and probability distributions.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a spreadsheet model will only reveal a single outcome, generally the most likely or average scenario. Spreadsheet risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on outputs of the modeled system. One type of spreadsheet simulation is Monte Carlo simulation, which randomly generates values for uncertain variables again and again to simulate a model. Monte Carlo simulation was named for Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance. Games of chance such as roulette wheels, dice, and slot machines, exhibit random behavior. The random behavior in games of chance is similar to how Monte Carlo simulation selects variable values at random to simulate a model. When you roll a die, you know that either a 1, 2, 3, 4, 5, or 6 will come up, but you do not know which for any particular roll. It's the same with the variables that have a known range of values but an uncertain value for any particular time or event (e.g., equipment lifetime, discount rate, and installation cost).

For each uncertain variable (one that has a range of possible values), possible values are defined with a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include:

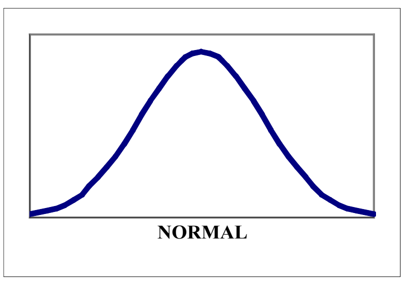

Figure 8-B.5.1 Normal Probability Distribution

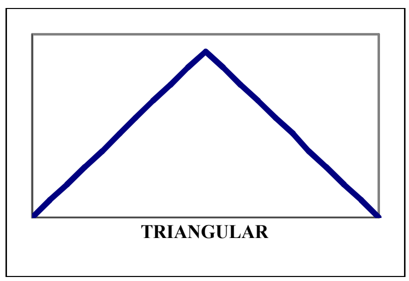

Figure 8-B.5.2 Triangular Probability Distribution

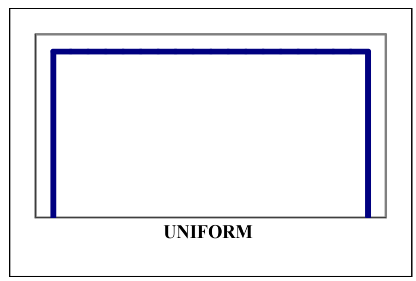

Figure 8-B.5.3 Uniform Probability Distribution

During a simulation, multiple scenarios of a model are calculated by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for the cell. Crystal Ball simulations can consist of as many trials (or scenarios) as desired—hundreds or even thousands. During a single trial, Crystal Ball randomly selects a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable and then recalculates the spreadsheet.

APPENDIX 8-C. CONSUMER RETAIL PRICE DISTRIBUTIONS FOR BASELINE REFRIGERATOR-FREEZERS AND FREEZERS

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APPENDIX 8-C. CONSUMER RETAIL PRICE DISTRIBUTIONS FOR BASELINE REFRIGERATOR-FREEZERS AND FREEZERS

8-C.1 INTRODUCTION

DOE's engineering analysis did not attempt to estimate the manufacturing cost for baseline models. Instead, it developed incremental increases in manufacturer selling price associated with increases in efficiency levels. This approach required DOE to estimate retail prices for the baseline model in each product class.

DOE drew upon proprietary retail price data collected by The NPD Group.[1] These data reflect retail prices and sales at a large number of retail outlets in the United States (including over 50 percent of retail sales), and include information regarding model number, refrigerated volume, configuration of doors and ice-making, and whether the unit is an ENERGY STAR product. The data include enough information to assign each model to the correct product class. Standard-size refrigerators and freezers only contain models with capacity greater than 7.75 cubic feet, whereas compact refrigerators consist of any types of refrigerators with capacity less than 7.75 cubic feet. DOE first converted all the selling prices to 2008 dollar value and then developed a sales-weighted price distribution for non-ENERGY STAR appliances in each product class from this data. For the purpose of developing retail price distribution for baseline products only, DOE excluded the built-in models under product classes 5, 7 and 9.[a] DOE grouped models by selling price in bins of varying width (generally $25 for compact products and $50 to $100 for standard-sized products) in order to balance the accuracy and usability of the distributions. These distributions are shown in the following section.

DOE assumed that prices for non-ENERGY STAR models are a reasonable approximation of prices for the baseline models. These models may be "baseline" in efficiency, but span a wide range of other features and materials, and therefore have a broad distribution of prices. DOE also excluded sales above price threshold that was considered similar to built-in prices for product classes 7 and 11 (at $4,950 and $550 respectively), which removed less than 1 percent of sales in each case. DOE chose not to develop volume-dependent baseline retail prices because the data did not show a strong relationship between volume and retail price. The price distributions within most volume ranges and product classes are almost as broad as the volume-independent distributions DOE chose to use, and regression analysis indicated very weak dependence of average price on volume.

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[a] Based on the guidance from industry experts, built-ins include all models from Subzero, Viking and Thermador. Other manufacturers of built-ins also produce non-built-in products, so those could not be excluded based on brand, and were included in the distributions.

8-C.2 DISTRIBUTION HISTOGRAMS

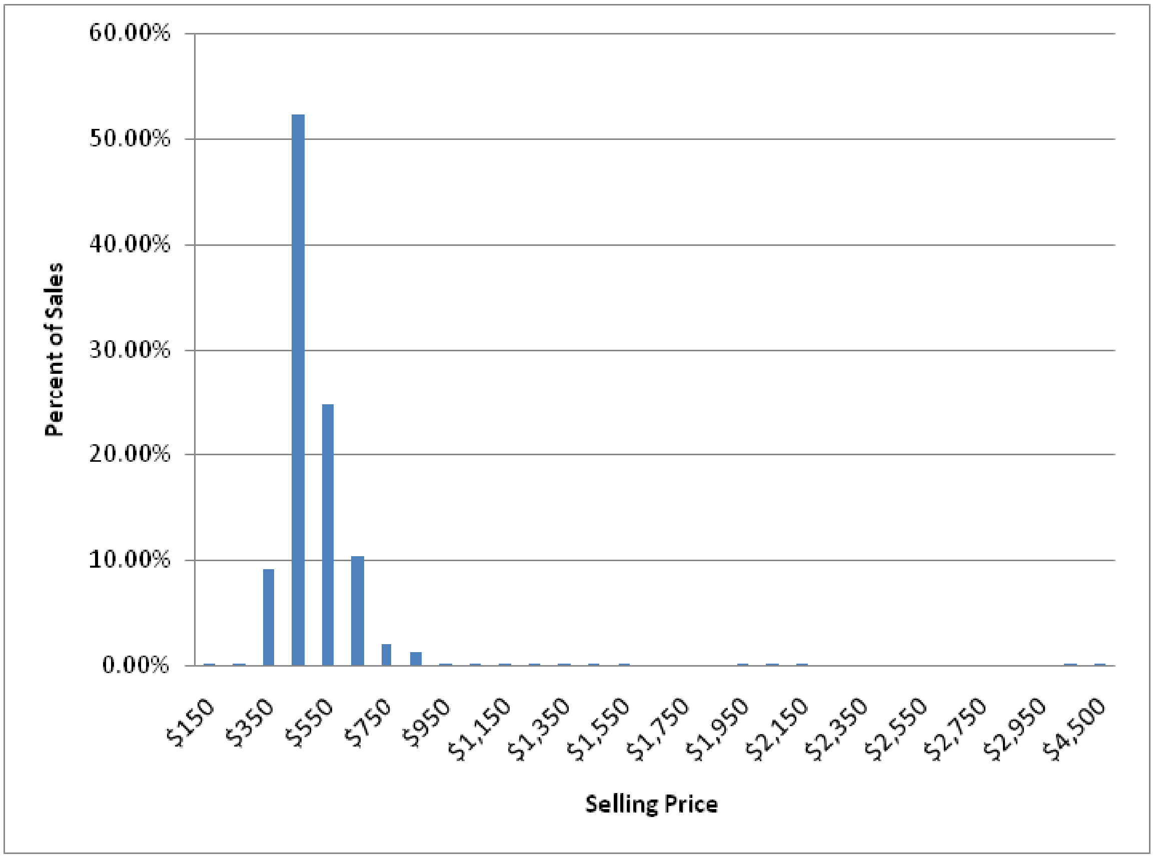

Figure 8-C.2.1 Baseline Retail Price Distribution for Product Class 3 (Standard-sized Top-mount Refrigerator-Freezers without Through-the-door Service)

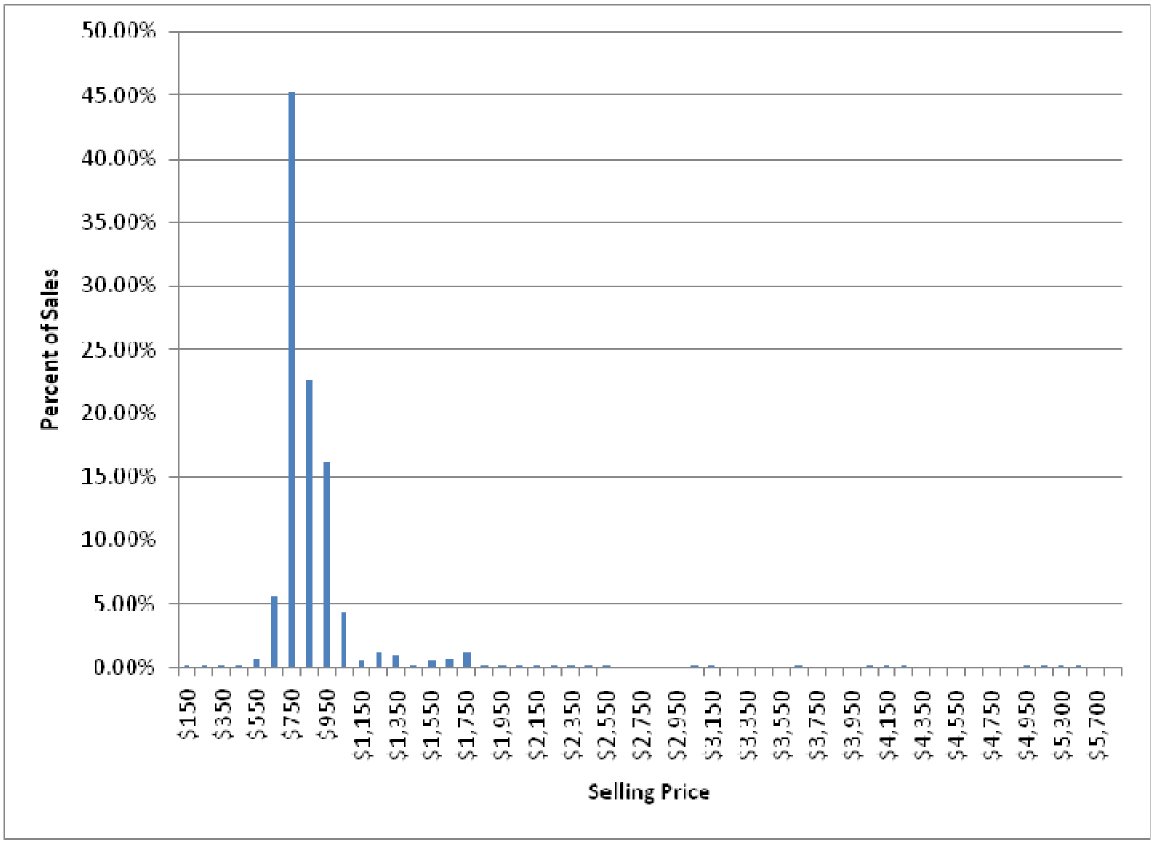

Figure 8-C.2.2 Baseline Retail Price Distribution for Product Class 5 (Standard-sized Bottom-mount Refrigerator-Freezers without Through-the-door Service)

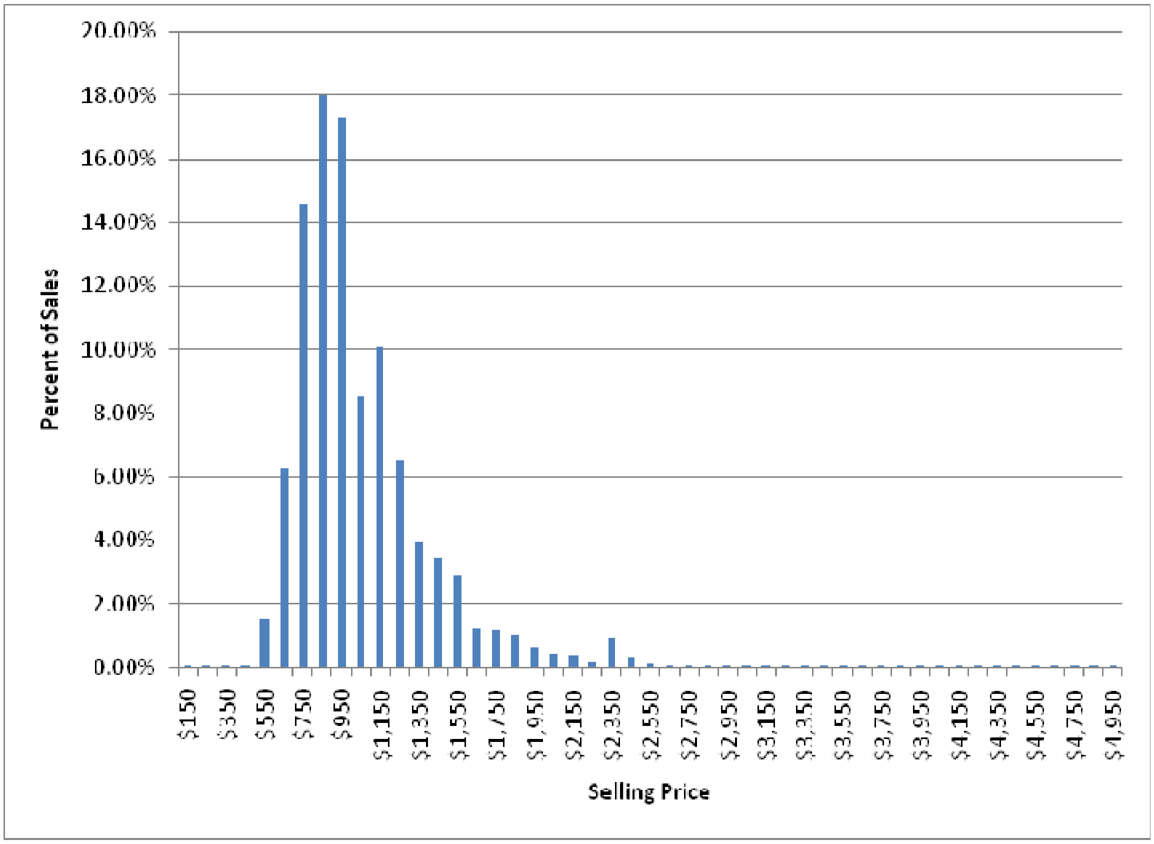

Figure 8-C.2.3 Baseline Retail Price Distribution for Product Class 7 (Standard-sized Side-mount Refrigerator-Freezers with Through-the-door Service)

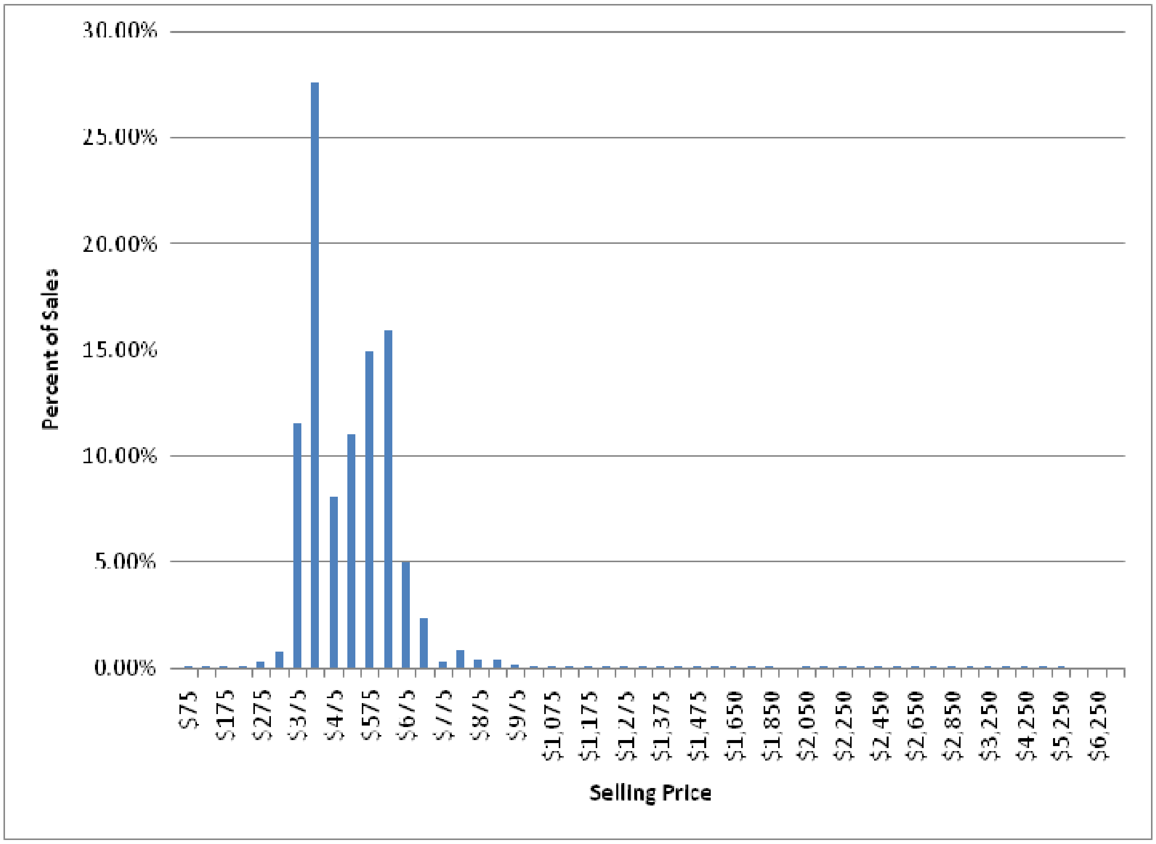

Figure 8-C.2.4 Baseline Retail Price Distribution for Product Class 9 (Standard-sized Upright Freezers)

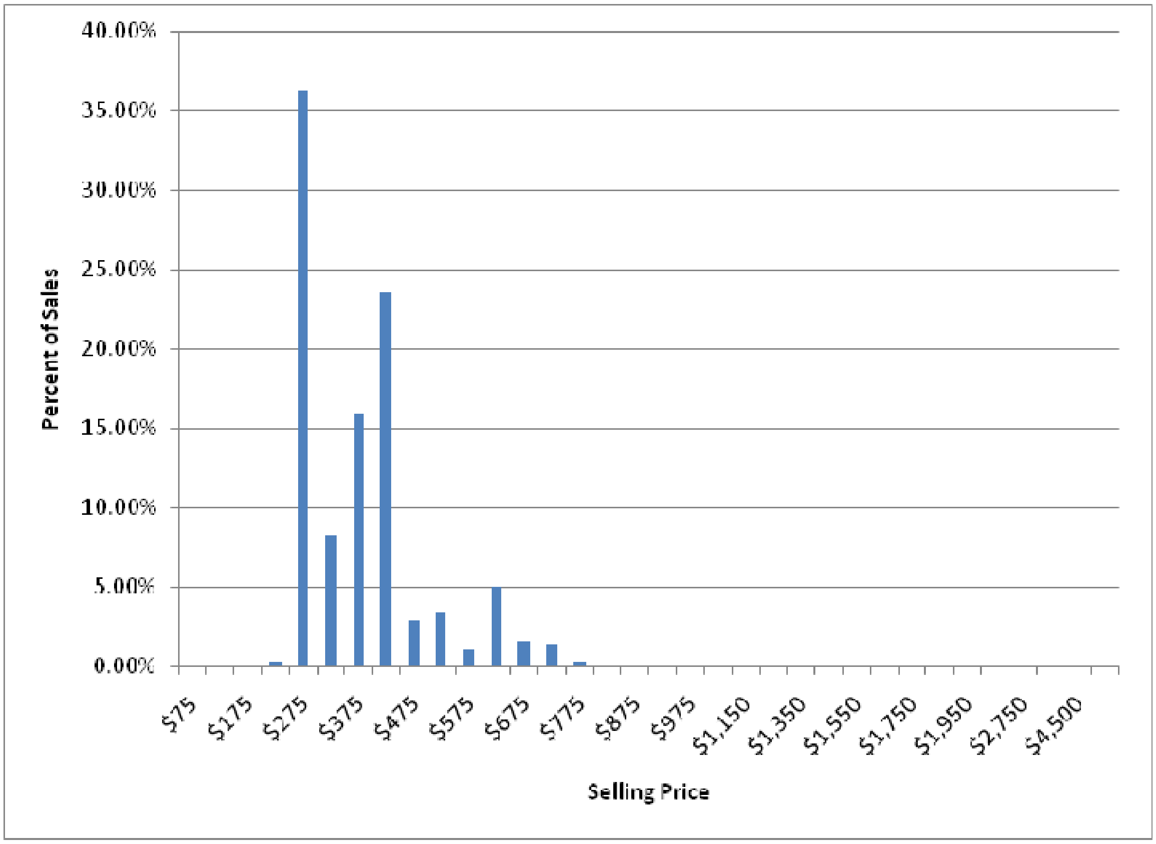

Figure 8-C.2.5 Baseline Retail Price Distribution for Product Class 10 (Standard-sized Chest Freezers)

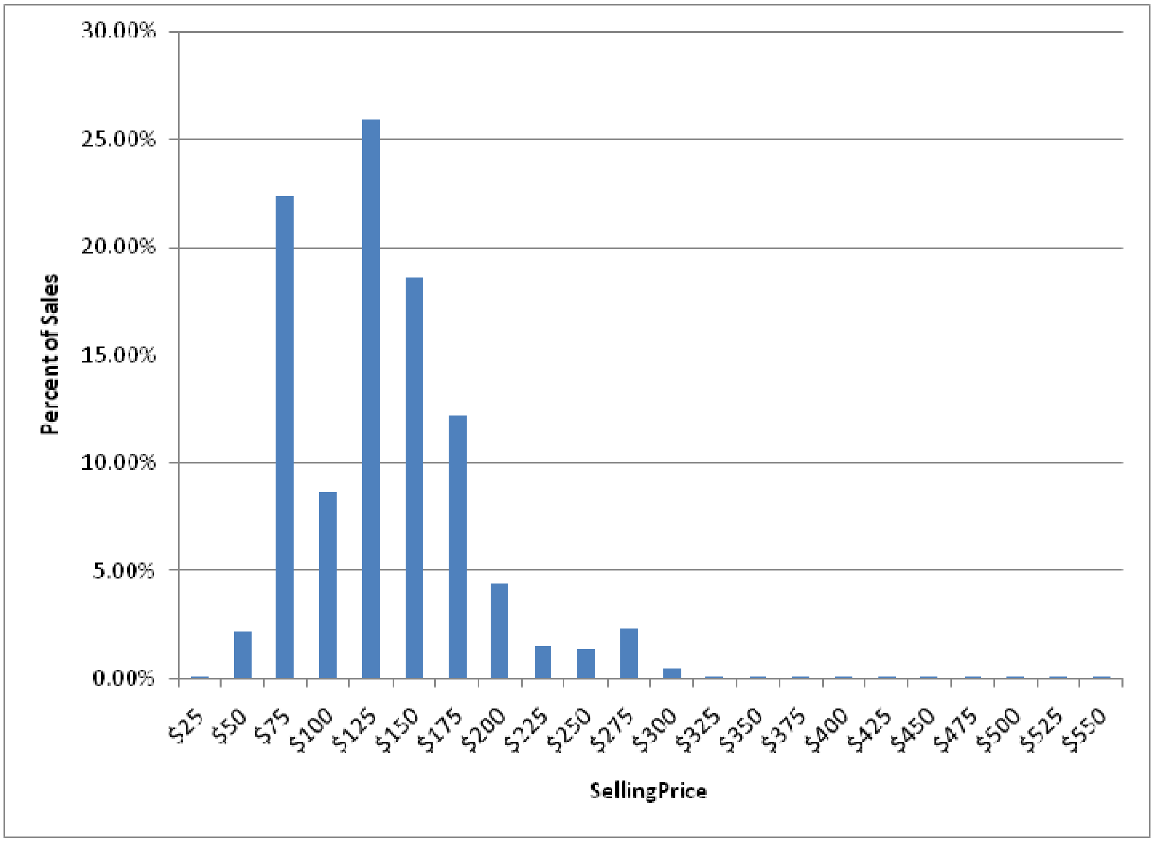

Figure 8-C.2.6 Baseline Retail Price Distribution for Product Class 11 (Compact Refrigerators)

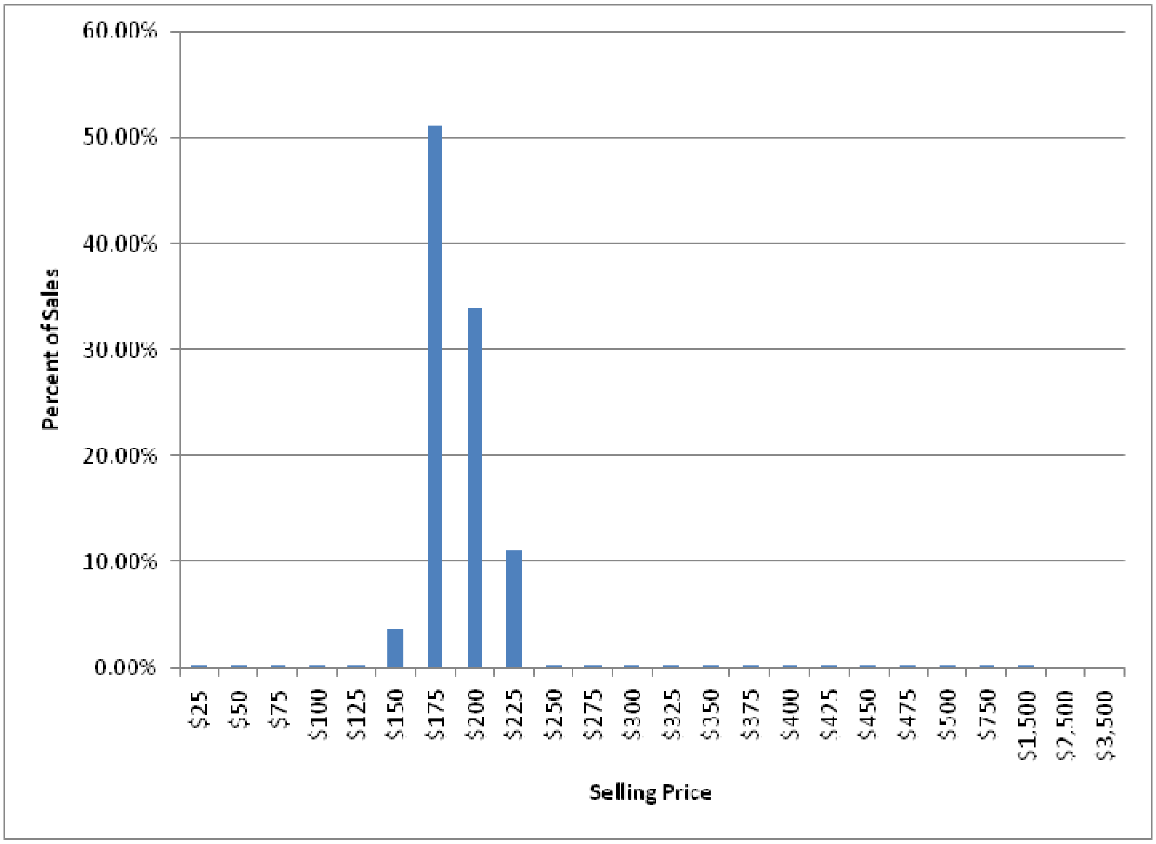

Figure 8-C.2.7 Baseline Retail Price Distribution for Product Class 18 (Compact Freezers)

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1 The NPD Group, Inc., *The NPD Group/NPD Houseworld – POS, Refrigerators, Freezers January – December 2007*, 2008. Port Washington, NY.

APPENDIX 8-D. DISTRIBUTIONS USED FOR DISCOUNT RATES

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APPENDIX 8-D. DISTRIBUTIONS USED FOR DISCOUNT RATES

8-D.1 INTRODUCTION

DOE derived discount rates for the LCC analysis using data on interest or return rates for various types of debt and equity. To account for variation among households in rates for each of the types, DOE sampled a rate for each household from a distribution of rates for each debt and equity type. This appendix describes the distributions used.

8-D.2 DISTRIBUTION OF MORTGAGE INTEREST RATES

Figure 8-D.2.1 shows the distribution of real interest rates for new home mortgages. The data source DOE used for mortgage interest rates is the Federal Reserve Board's *Survey of Consumer Finances (SCF)* in 1989, 1992, 1995, 1998, 2001, 2004, and 2007.[1] Using the appropriate *SCF* data for each year, DOE adjusted the nominal mortgage interest rate for each relevant household in the *SCF* for mortgage tax deduction and inflation. In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero.

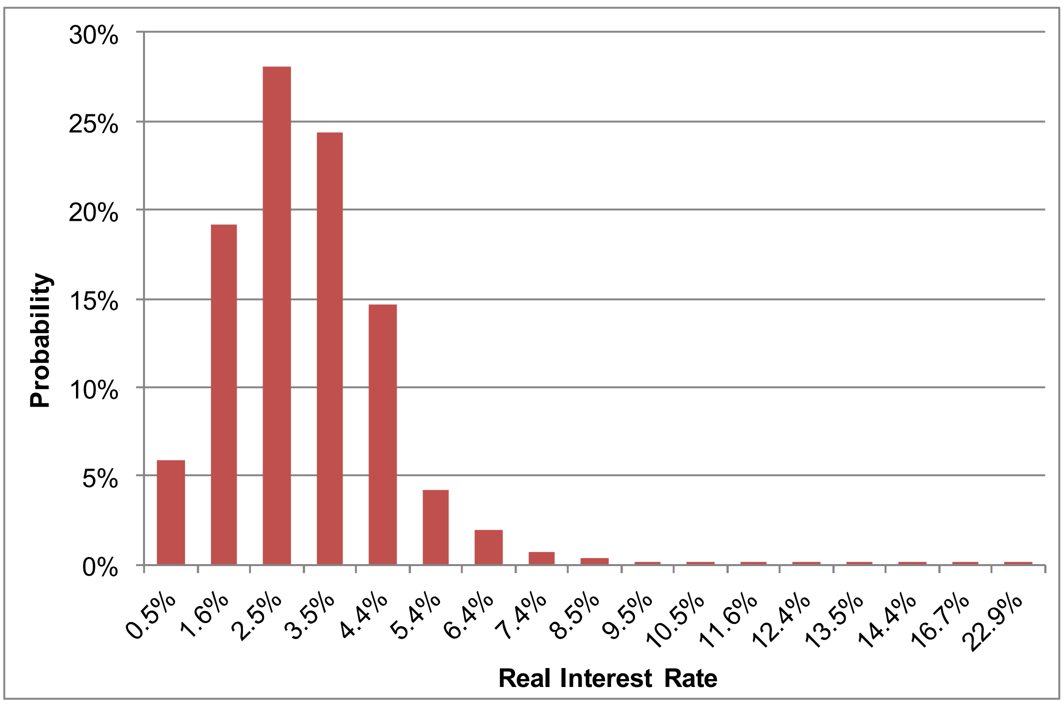

Figure 8-D.2.1 Distribution of New Home Mortgage Interest Rates

8-D.3 DISTRIBUTION OF RATES FOR TYPES OF DEBT AND EQUITY USED TO FINANCE REPLACEMENT HEATING PRODUCTS

Figure 8-D.3.1 through Figure 8-D.3.5 show the distribution of real interest rates for different types of debt used to finance replacement heating products. The data source for the

interest rates for home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1989, 1992, 1995, 1998, 2001, 2004, and 2007.[1] DOE adjusted the nominal rates to real rates using the annual inflation rate in each year. For home equity loans, DOE calculated effective interest rates in a similar manner as for mortgage rates, since interest on such loans is tax deductible.

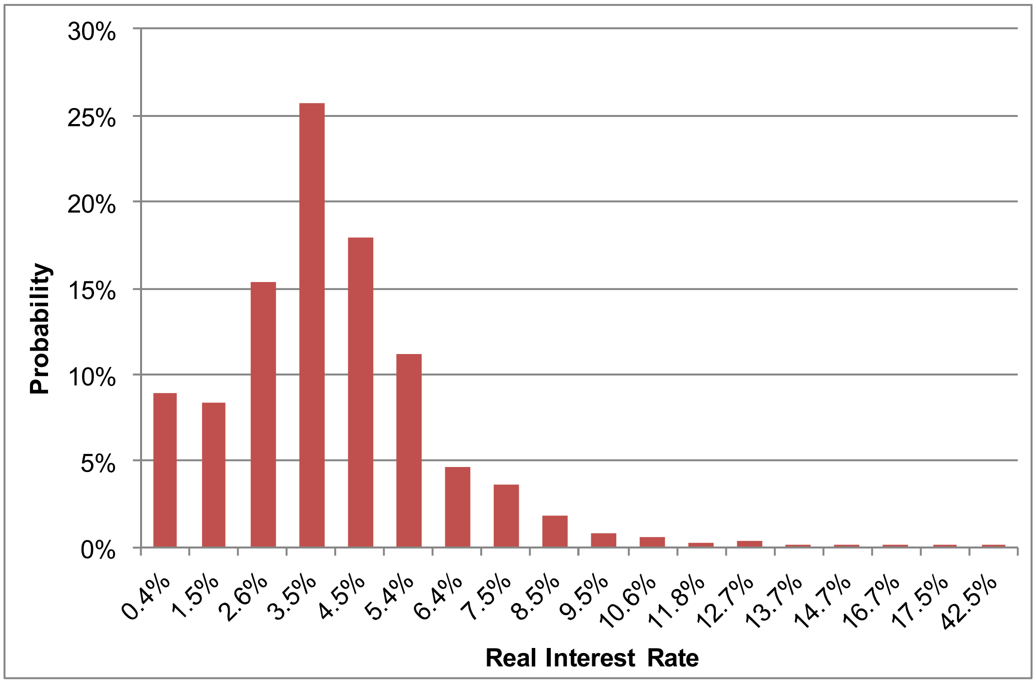

Figure 8-D.3.1 Distribution of Home Equity Loan Interest Rates

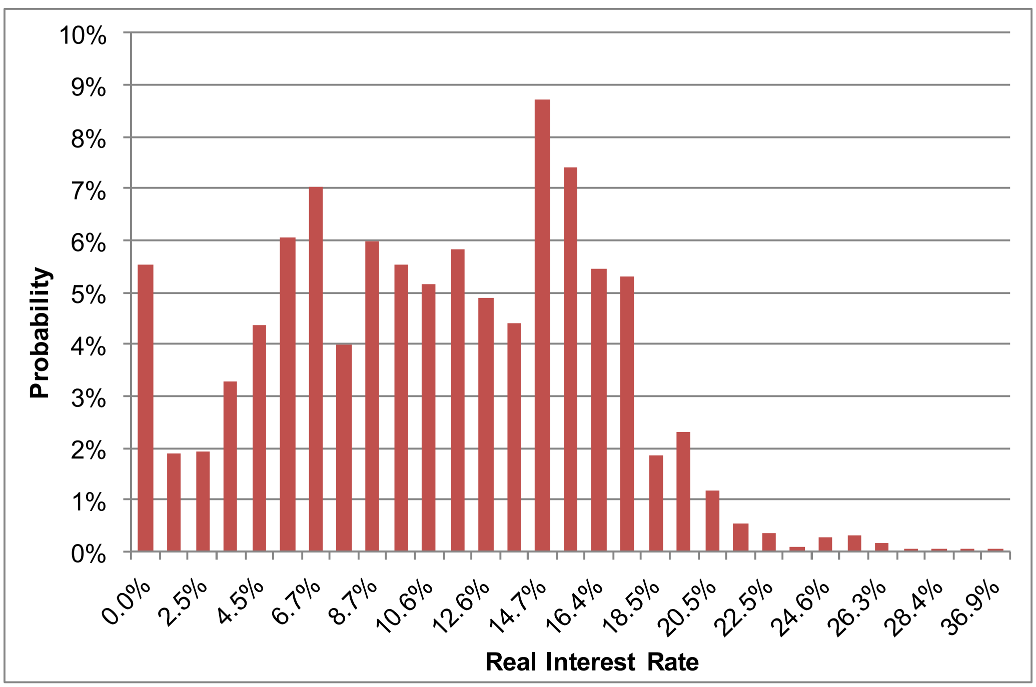

Figure 8-D.3.2 Distribution of Credit Card Interest Rates

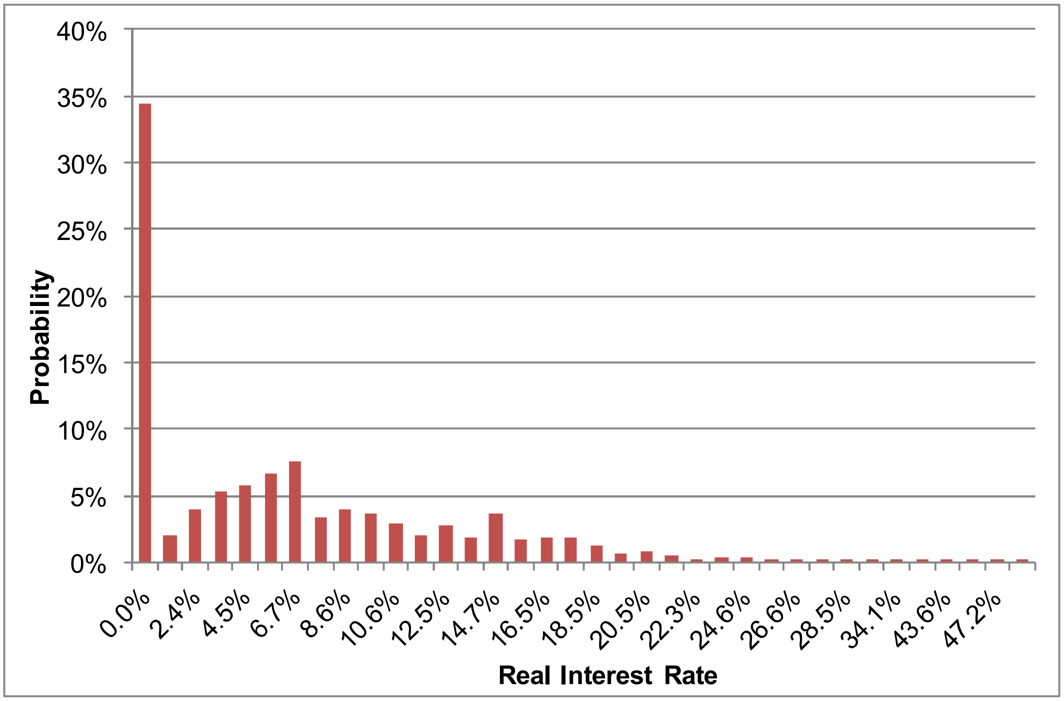

Figure 8-D.3.3 Distribution of Installment Loan Interest Rates

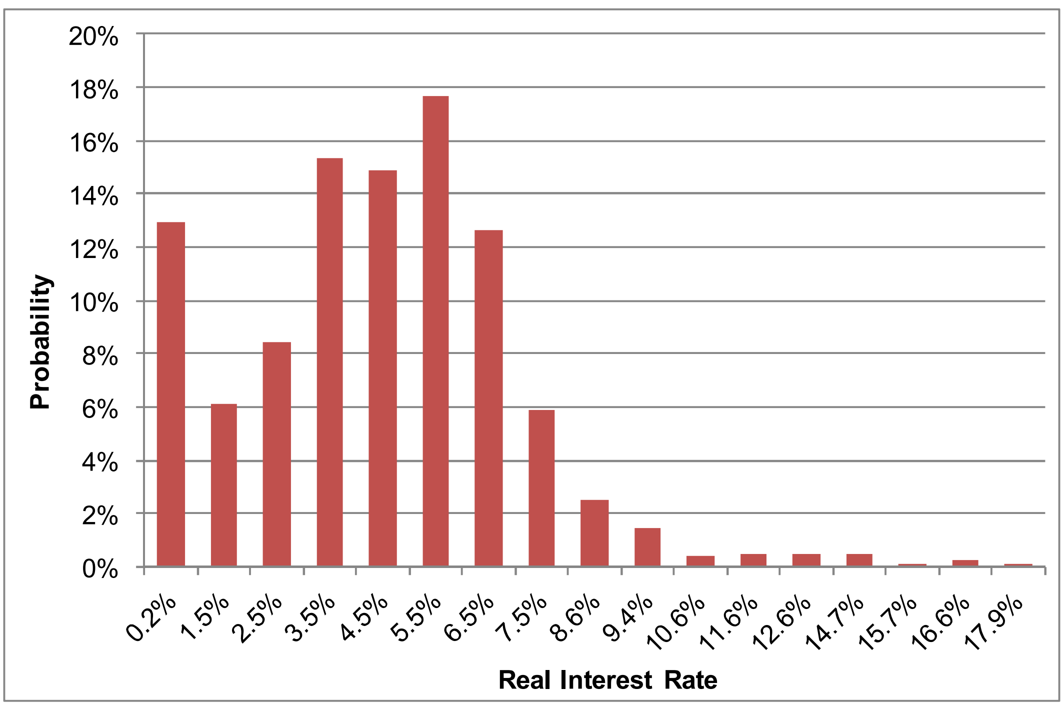

Figure 8-D.3.4 Distribution of Other Residence Loan Interest Rates

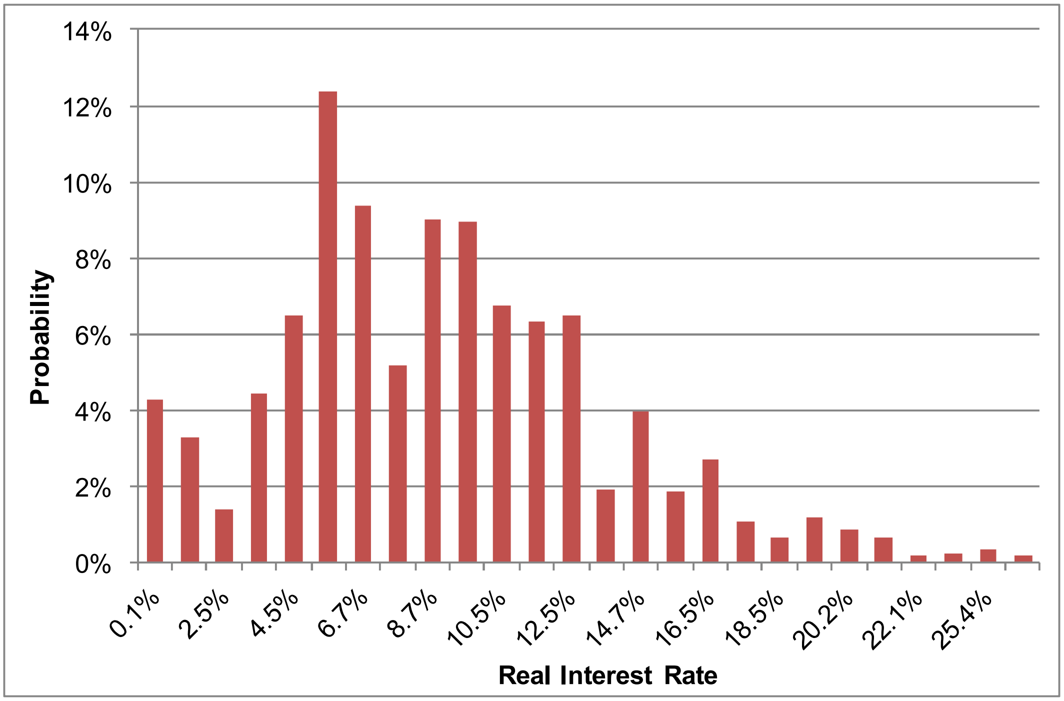

Figure 8-D.3.5 Distribution of Other Lines of Credit Loan Interest Rates

8-D.4 DISTRIBUTION OF RATES FOR TYPES OF EQUITY USED TO FINANCE REPLACEMENT HEATING PRODUCTS

Figure 8-D.4.1 through Figure 8-D.4.6 show the distribution of real interest rates for different types of equity used to finance replacement furnaces. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so DOE derived data for these classes from national-level historical data. The interest rates associated with certificates of deposit (CDs),[2] savings bonds,[3] and AAA corporate bonds[4] are from Federal Reserve Board time-series data covering 1977 to 2009. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data covering 1984 to 2009.[5] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500 from 1977 to 2009.[6] The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year from 1977 to 2009. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

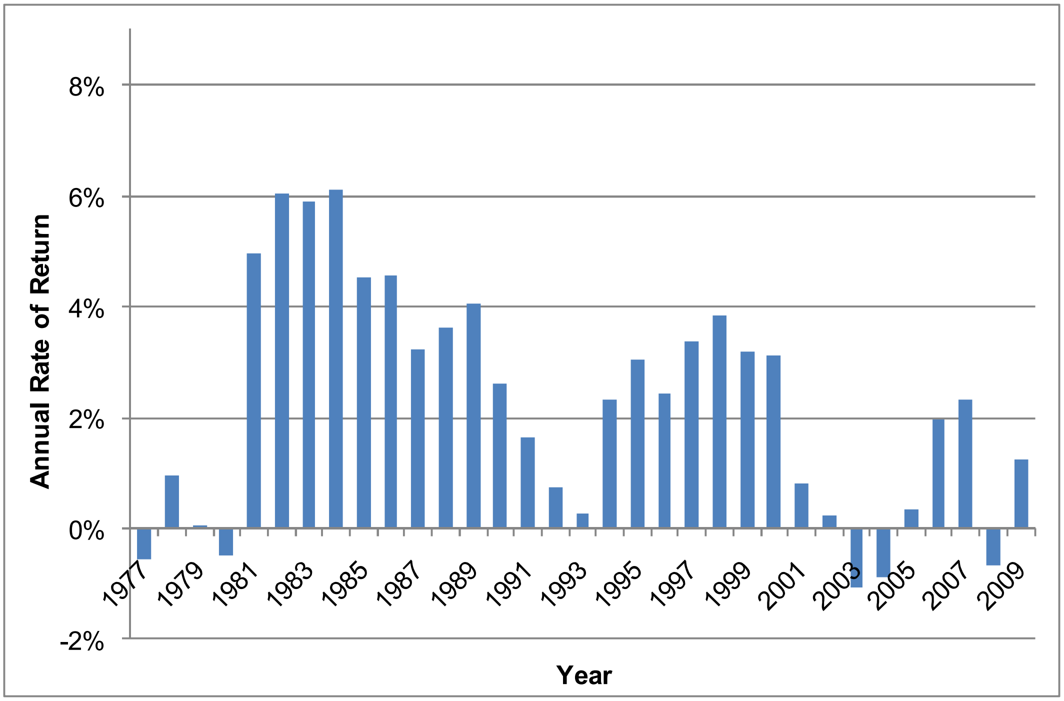

Figure 8-D.4.1 Distribution of Annual Rate of Return on CDs

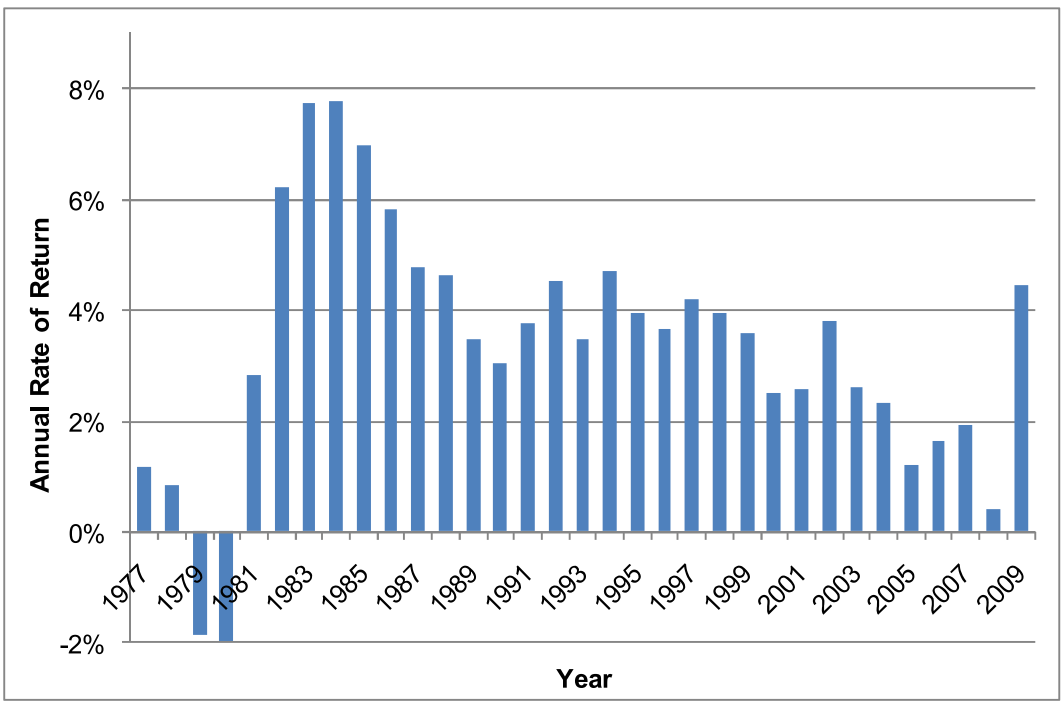

Figure 8-D.4.2 Distribution of Annual Rate of Return on Savings Bonds

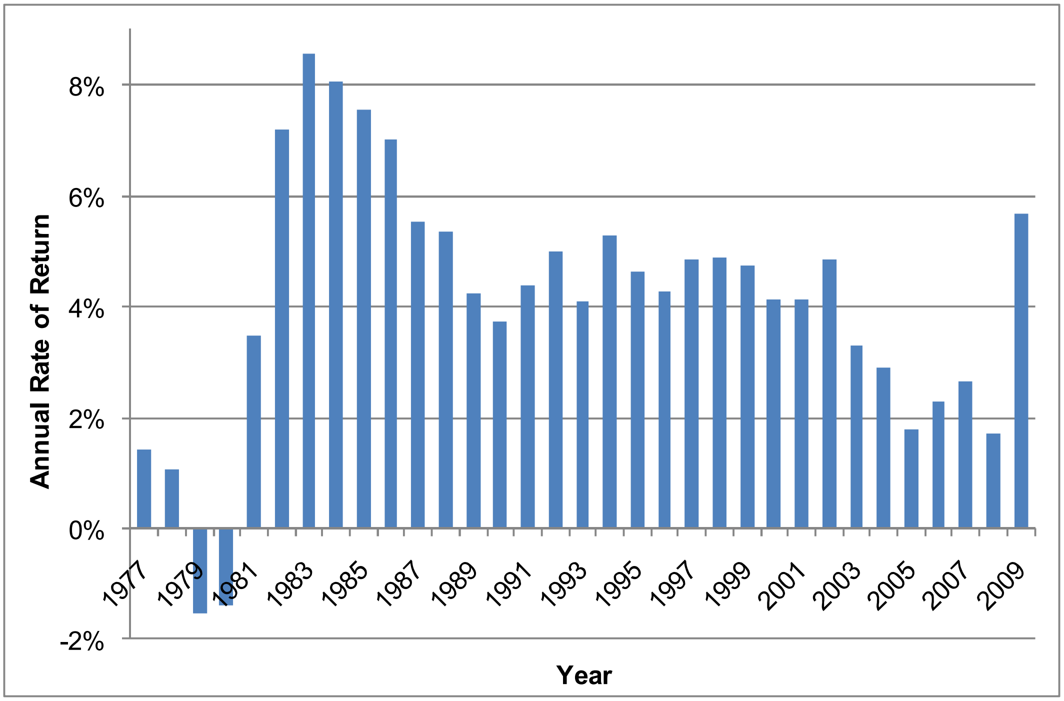

Figure 8-D.4.3 Distribution of Annual Rate of Return on Corporate AAA Bonds

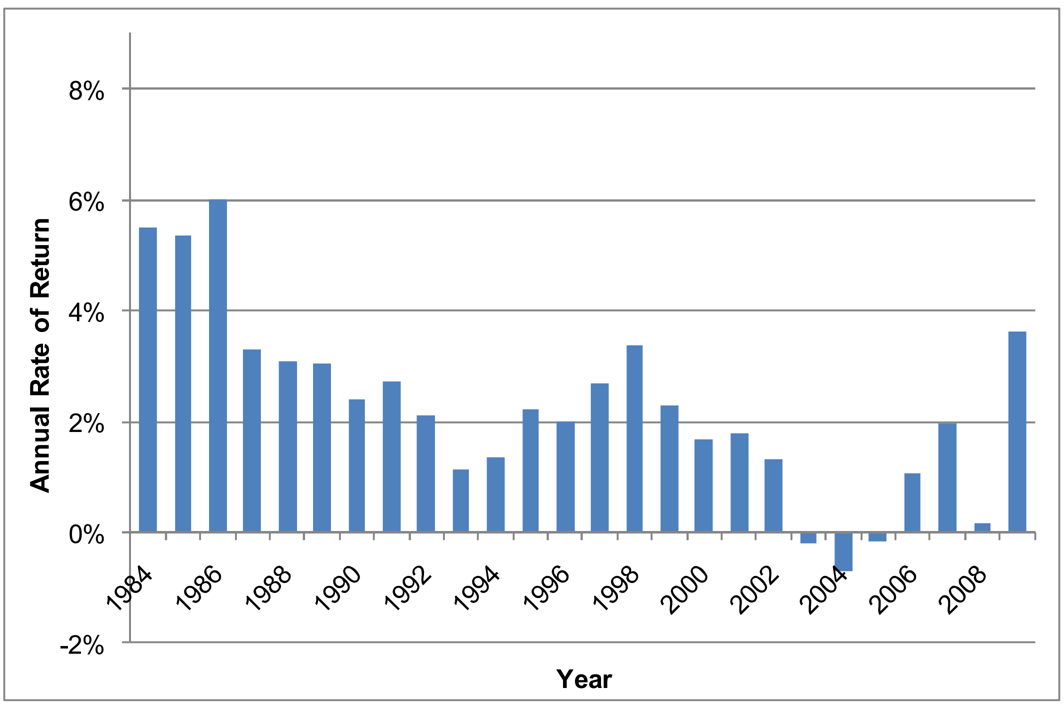

Figure 8-D.4.4 Distribution of Annual Rate of Savings Accounts

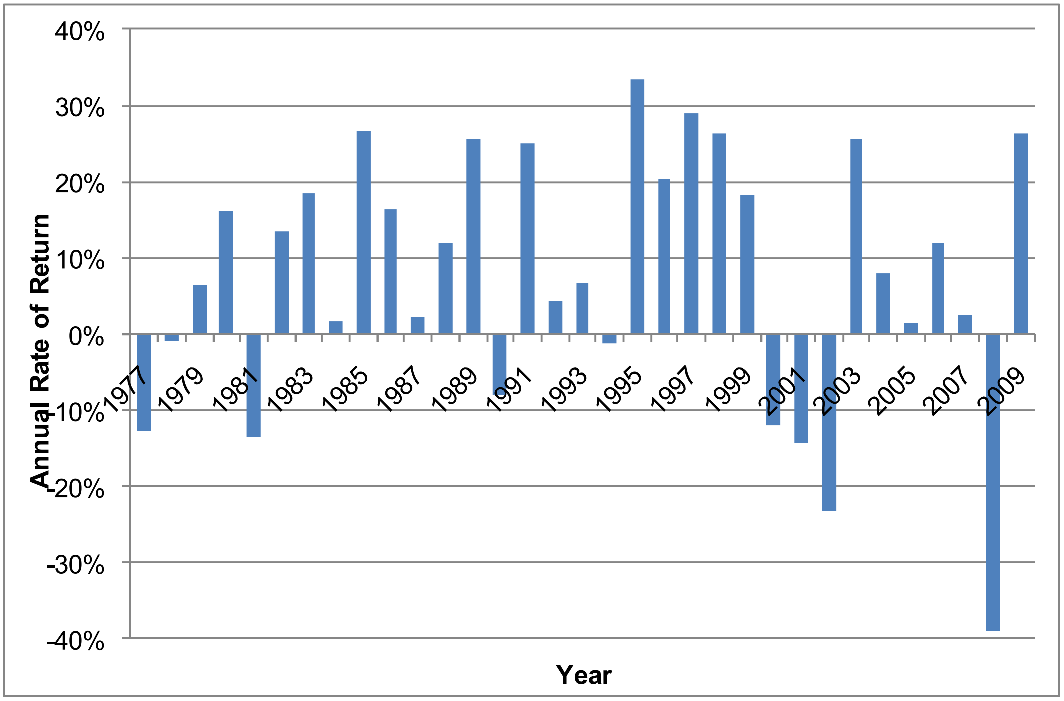

Figure 8-D.4.5 Distribution of Annual Rate of Return on S&P 500

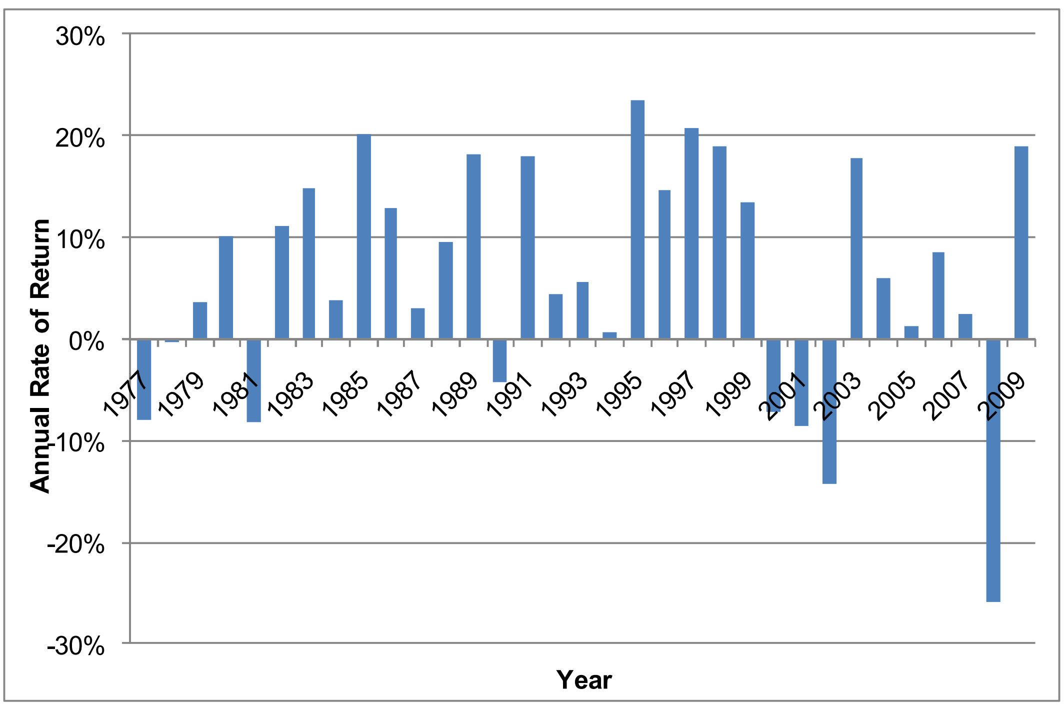

Figure 8-D.4.6 Distribution of Annual Rate of Return on Mutual Funds

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2. The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: CDs (secondary market), Maturity: 6-month, Frequency: Annual, Description: Average rate on 6-month negotiable certificates of deposit (secondary market), quoted on an investment basis,* 2010. (Last accessed 2/25/10, <http://www.federalreserve.gov/releases/H15/data.htm>

3. The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: State and local bonds, Maturity: 20-year, Frequency: Monthly, Description: Bond buyer go 20-bond municipal bond index,* 2010. (Last accessed 2/25/10, <http://www.federalreserve.gov/releases/H15/data.htm>

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5. Mortgage-X - Mortgage Information Service, *Cost of Savings Index (COSI) Index History,* 2010. (Last accessed February 25, 2010.) <http://mortgage-x.com/general/indexes/default.asp>

6. Damodaran Online Data Page, *Historical Returns on Stocks, Bonds and Bills-United States,* 2010. Damodaran. (Last accessed February 25, 2010.) <http://pages.stern.nyu.edu/~adamodar/>

APPENDIX 8-E. ESTIMATION OF EQUIPMENT PRICE TRENDS FOR RESIDENTIAL REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS

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8-E.1 INTRODUCTION

In the analysis for the final rule, DOE estimated long term trends in the manufacturer costs and retail prices of products meeting various efficiency levels in real terms, after 2010 (the year for which the engineering analysis estimated costs) and throughout the period of the analysis. In a Notice of Data Availability (NODA) published on February 22, 2011 (76 FR 9696), DOE stated that it may consider improving regulatory analysis by addressing equipment price trends. DOE also stated in the NODA that examination of historical price data for certain appliances and equipment that have been subject to energy conservation standards indicates that the assumption of constant real prices and costs may, in many cases, over-estimate long-term appliance and equipment price trends. Economic literature and historical data suggest that the real costs of these products may in fact trend downward over time according to "learning" or "experience" curves, or alternatively that productivity improvement trends and the corresponding product production costs for certain sectors of the US economy may be different than the price trends for the economy as a whole. A draft paper, "Using the Experience Curve Approach for Appliance Price Forecasting," posted on the DOE web site at http://www1.eere.energy.gov/buildings/appliance_standards/supplemental_info_equipment_price_forecasting.html, provided an initial summary of the data and literature available to DOE that is relevant to price forecasts for selected appliances and equipment.

The extensive literature on the "learning" or "experience" curve phenomenon is typically based on observations in the manufacturing sector (pioneered by Wright, 1936 and Alchian, 1963). The term "learning" is generally used to refer to a single, isolated firm or facility, whereas "experience" generally refers to multiple facilities and whole industries. In the experience curve method, the real cost of production (or proxy thereof) is related to the cumulative production or "experience" with a manufactured product. This experience is usually measured in terms of cumulative production. A common functional relationship used to model the evolution of production costs in this case is:

$$Y = a \cdot X^{b}$$

Where:

a = an initial price (or cost),
b = a positive constant known as the experience rate parameter,
X = cumulative production, and
Y = the price as a function of cumulative production.

Thus, as experience (production) accumulates, the cost of producing the next unit decreases. The percentage reduction in cost that occurs with each doubling of cumulative production is referred to as the experience rate (ER), given by:

$ER = 1 - 2^{-b}$

In typical experience curve formulations, the experience rate parameter is derived using two historical data series: price (or cost) and cumulative production, which is a function of shipments during a long time span.

On the other hand, the capability learning curves for many technologies, which track, for instance, the density of integrated circuits (i.e., Moore's law; Moore, 1965) or the bandwidth of communication channels, have been found empirically to follow the form $C/C_0 = e^{-\alpha t}$, where C is the technical capability and α is an empirically defined parameter. If the quantity of units deployed increases exponentially over time at a rate χ, then the learning curve and Moore's law formulations for price are equivalent. For a cumulative quantity that changes exponentially over time, then the relationship is given by

$$Y = a \cdot X^{-b} = a \cdot (X_0 e^{\chi t})^{-b} = a \cdot e^{-\chi b t} = a \cdot e^{-\alpha t}$$

Where:

a = an initial price (or cost),
b = a positive constant known as the experience rate parameter,
α = Moore's law exponent,
χ = cumulative production growth rate,
X = cumulative production,
X_0 = cumulative production at time zero, and
Y = the price as a function of cumulative production or time.

Because the details of DOE's price trend forecast methodology is still under development, DOE used several methods for extrapolating price trends. The final rule uses an experience curve model as the main price trend for the analysis, and incorporates several other models (including Moore's law models) as part of a sensitivity analysis.

8-E.2 PRICE, COST AND MARKET STRUCTURE

DOE uses a cost-based analysis in estimating equipment prices. To estimate equipment prices in both the standards and the baseline or no-standards case, DOE develops engineering cost estimates that DOE then uses to estimate manufacturer selling price. The manufacturer selling price includes direct manufacturing production costs (labor, material, and overhead estimated in DOE's manufacturer production costs) and all non-production costs (SG&A, R&D, and interest), along with profit. The process of the cost-based method for developing the manufacturer selling prices is described in the engineering analysis described in Chapter 5 of this TSD. To convert the manufacturer selling price to an equipment price for the consumer, DOE performs an analysis of distribution chain markups and estimates markups on both the baseline and incremental manufacture selling prices to determine equipment prices after distribution to the consumer.

In analyzing experience curves to estimate price trends, DOE uses producer and consumer price indices as a key data input and analyzes these data to estimate the experience curve exponent. This approach has only one model parameter to describe the price trend and assumes a simple relationship between producer price and retail equipment price. Specifically, the approach assumes that producer prices, distribution chain markups and equipment prices all scale proportionally over time for the same product.

DOE could have developed a more complex price trend forecasting model with more parameters that could explain different trends in different equipment price and cost components over time that might include changes in mark-up, material costs, general industrial productivity, and many other potential factors. Given the relatively few available data points, however, a complex model with many parameters presents a risk that such a model would "overfit" the data. Overfitting occurs when there are too many degrees of freedom in a statistical model compared to the data and the fits are sensitive to random noise unrelated to long term trends. Due to the risk of overfitting the limited available data and the relatively long extrapolation period, DOE has decided to not develop complex multi-parameter price trend estimation models at this time.

Due to the simple nature of the price trend estimation models, there are several well known economic and market phenomena that will not be captured in detail by the price trend forecast. Some effects might lead to an overestimate of the long term price trend and other effects may lead to an underestimate. For example, if there has been increasing market concentration historically on the part of manufacturers, this may have resulted in increasing manufacturer and wholesale markups over time. This would result in an observed historical producer price trend that did not decrease as fast as the underlying industrial experience rate. Depending on if market concentration accelerated or decelerated into the future this could lead to an over- or under-estimation of future price trends.

8-E.3 DATA EVALUATION AND ANALYSIS

To derive an experience rate parameter for residential refrigerators, refrigerator-freezers, and freezers, DOE obtained historical Consumer Price Index (CPI) and Producer Price Index (PPI) data for residential refrigerators and freezers from the Bureau of Labor Statistics (BLS). Because CPI data specific to residential freezers were not available, DOE used CPI and PPI data for residential refrigerators and freezers as representative of residential refrigerators, refrigerator-freezers, and freezers. DOE used CPI data spanning the time period 1947-1997 and PPI data for 1977-2010. The years of overlap (1977–1997) for refrigerator and freezer data were examined for differences, and a regression performed to allow normalization of the PPI data to the CPI data (see Figure 8-E.3.1 and Figure 8-E.3.2). An inflation-adjusted price index for residential refrigerators and freezers was calculated by dividing the combined CPI/PPI series by the

Chained GDP Price Index.[a] The inflation-adjusted combined price index (shown in Figure 8-E.3.3) was used in subsequent analysis steps.

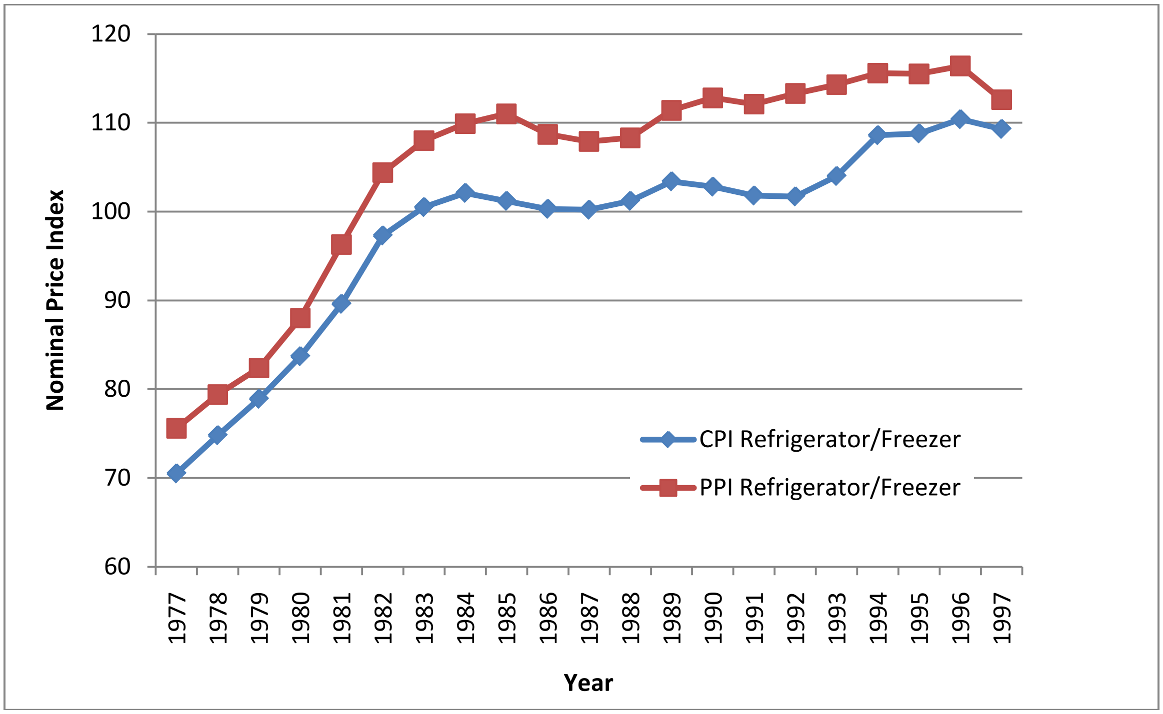

Figure 8-E.3.1 Nominal Consumer Price Index (CPI) and Nominal Producer Price Index (PPI) for Refrigerator/Freezer

[a] Available at http://www.gpoaccess.gov/usbudget/fy11/hist.html

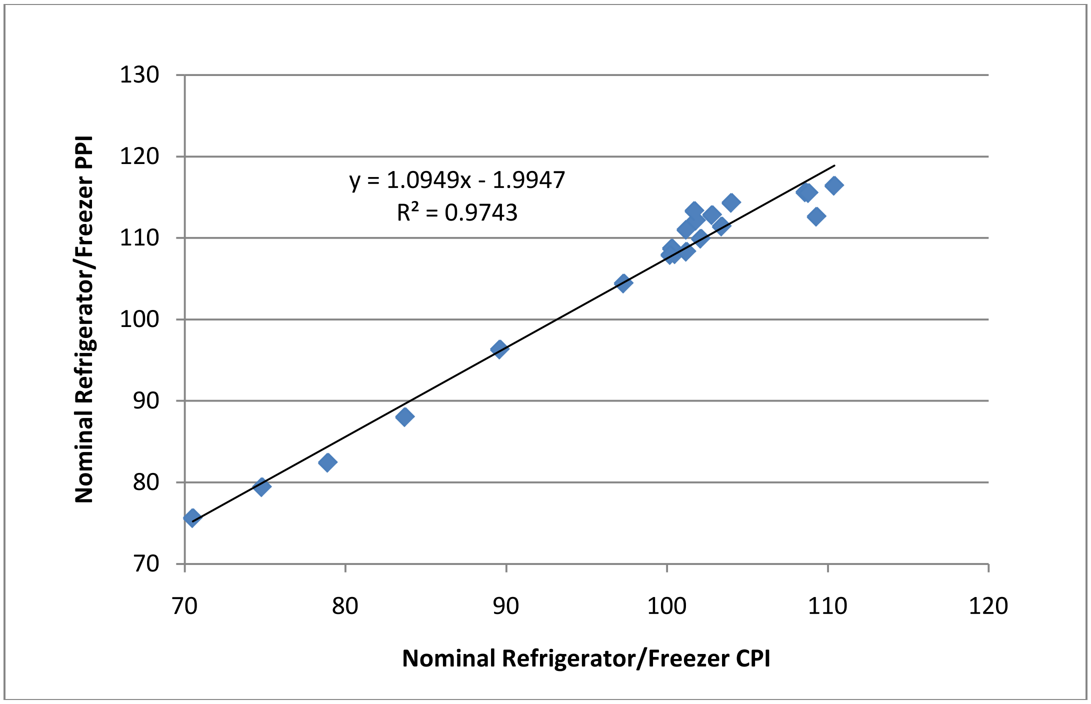

Figure 8-E.3.2 Linear Regression of Refrigerator/Freezer Nominal Consumer Price Index (CPI) versus Nominal Producer Price Index (PPI)

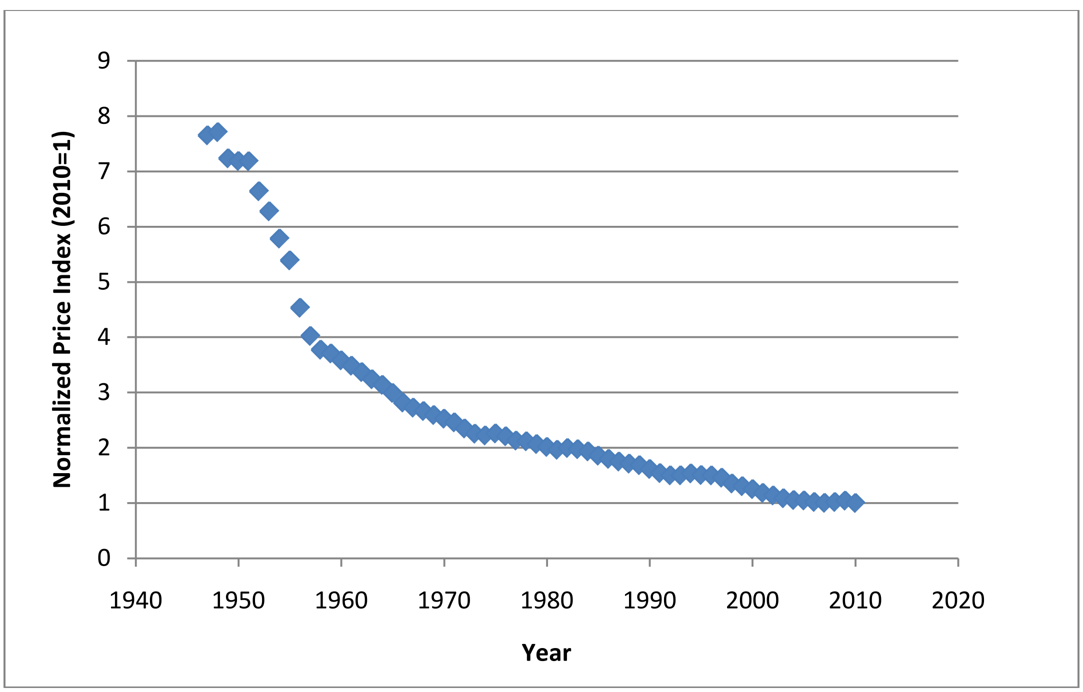

Figure 8-E.3.3 Historical Combined Price Index of Residential Refrigerators and Freezers, Normalized to 1 at 2010

DOE assembled a time-series of annual shipments for 1951-2008 for standard-size refrigerator-freezers, 1951-2007 for standard-size freezers, for 1966 and 1983-2007 for compact refrigerators and refrigerator-freezers, and for 1983-2007 for compact freezers (see chapter 9 of this TSD for source documentation). Annual shipments from 1930 for refrigerators and 1946 for freezers were obtained from AHAM.[b] The annual shipments data were used to estimate cumulative shipments (production). Projected shipments after 2007 were obtained from the base case projections made for the NIA (see chapter 9 of this TSD).

To fill in data gaps regarding compact refrigeration products, DOE used the following approaches. For compact refrigerators and refrigerator-freezers, a linear interpolation between 1966 and 1983 was used for intervening years. For compact freezers, an exponential fit to shipments for 1983–1992 was used to extrapolate back to 1951. Shipments of all four product types were summed to produce an overall shipments history from 1951 to 2007. Note that shipments are dominated by standard-sized products in all years (>80 percent), but especially before 1983. Figure 8-E.3.4 shows the full shipments time series used in the analysis.

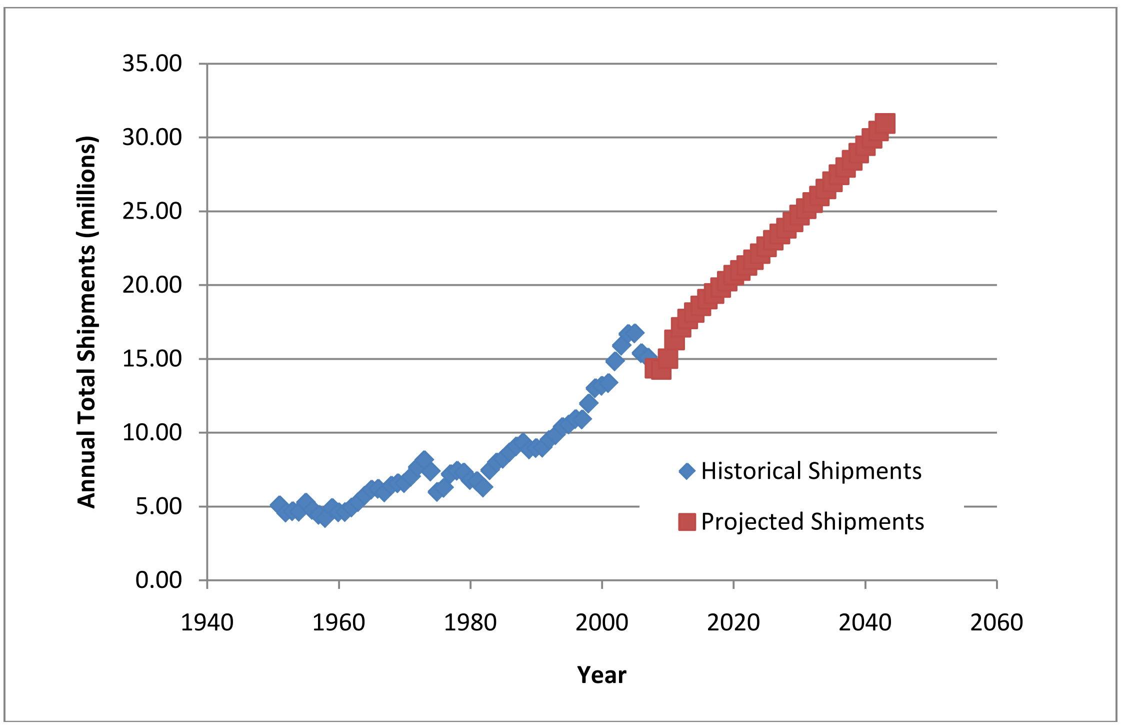

Figure 8-E.3.4 Historical and Projected Total Shipments of Residential Refrigerators and Freezers

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[b] Association of Home Appliance Manufacturers (AHAM), Factory Shipments of Major Appliances (U.S. Production including Exports + Imports), 23 January 2011.

To estimate an experience rate parameter, a least-squares power-law fit was performed on the unified price index versus cumulative shipments. See Figure 8-E.3.5.

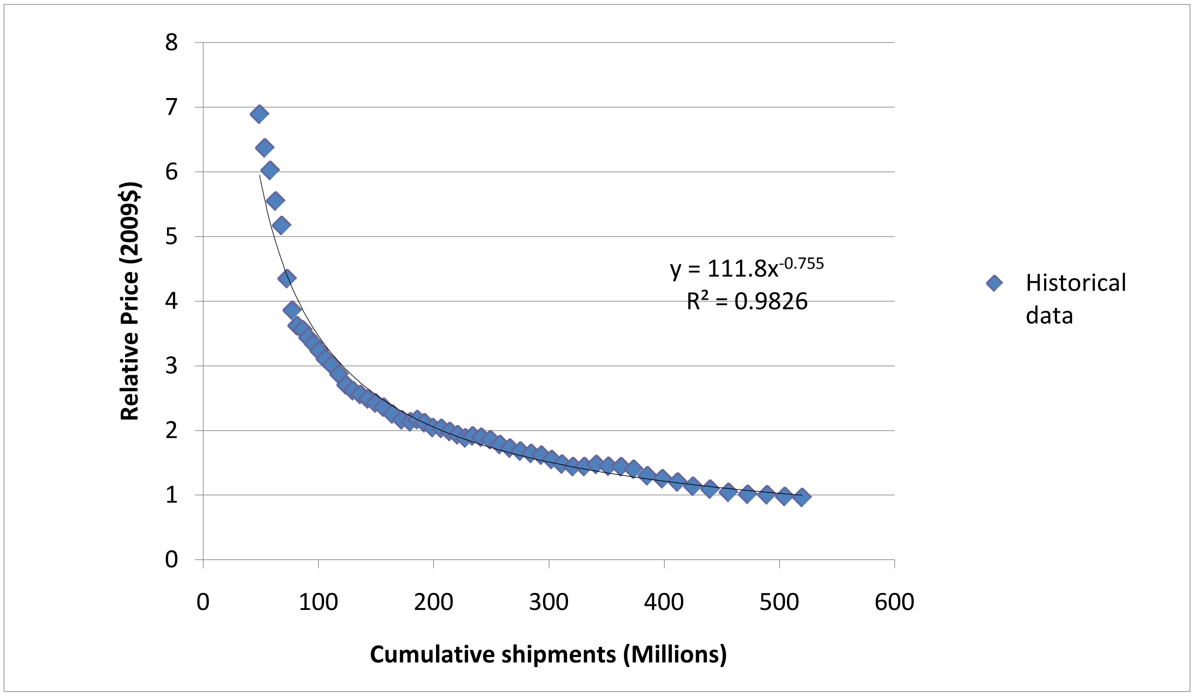

Figure 8-E.3.5 Relative Price versus Cumulative Shipments of Residential Refrigerators and Freezers, with Power Law Fit

The form of the fitting equation is:

$P(X) = P_o X^{-b}$,

where the two parameters, b (the experience rate parameter) and P_o (the price or cost of the first unit of production), are obtained by fitting the model to the data. DOE notes that the cumulative shipments on the right hand side of the equation can have a dependence on price, so there is an issue with simultaneity where the independent variable is not truly independent. DOE's use of a simple least squares fit is equivalent to an assumption of no significant first price elasticity effects in the cumulative shipments variable.

The parameter values obtained are:

$P_o = 112^{+17}_{-15}$ (95% confidence) for residential refrigerators and freezers
$b = 0.755 \pm 0.027$ (95% confidence) for residential refrigerators and freezers

The estimated experience rate (ER, defined as the fractional reduction in price expected from each doubling of cumulative production) is 40.7±1.1 % (95% confidence).

DOE then derived a price factor index, with 2010 equal to 1, to forecast prices in each future year in the analysis period. The index value in a given year is a function of the experience rate parameter and the cumulative production forecast through that year. Table 8-E.3.1 shows the price factors used in the analysis. DOE applied the same value to forecast prices for each residential refrigerator and freezer product class at each considered efficiency level.

Table 8-E.3.1 Price Factors for the Default Experience Rate

Year	Price factor
2010	1.000
2011	0.979
2012	0.957
2013	0.937
2014	0.916
2015	0.896
2016	0.877
2017	0.858
2018	0.840
2019	0.823
2020	0.805
2021	0.789
2022	0.773
2023	0.757
2024	0.742
2025	0.727
2026	0.713
2027	0.699
2028	0.685
2029	0.672
2030	0.659
2031	0.647
2032	0.635
2033	0.623
2034	0.611
2035	0.600
2036	0.589
2037	0.578
2038	0.568
2039	0.558
2040	0.548
2041	0.538
2042	0.528
2043	0.519

8-E.4 ALTERNATIVE PRICE TRENDS FOR SENSITIVITY ANALYSIS

DOE recognizes that there is uncertainty in its estimates of equipment price trends. In order to investigate the impact of different product price forecasts on the consumer net present value (NPV) for the considered TSLs for residential refrigerators and freezers, DOE considered several alternative price trends for a sensitivity analysis.

Uncertainty can potentially arise from possible systematic long term changes in the trend. To provide a potential indication of long term changes in the trend, DOE performed price trend fits to several component periods in the historical data. These component periods were chosen to correspond to the CPI data only, the PPI data only, with or without the region of overlap, and with or without the initial few years of data. The initial few years of CPI data were excluded from the default case because of anomalous post-war shipments and price trends, but are included in the sensitivity analysis. See Table 8-E.4.1 for a summary of the price trend fits.

Table 8-E.4.1 Experience Rate as a Function of Time Period

Index	Period	Experience Rate (%)
Unified (default case)	1951-2007	40.7±1.1 %
PPI only	1977-2007	43.4±2.0 %
PPI adjusted to CPI (via regression)	1977-2007	43.5±2.0 %
CPI only	1951-1997	40.0±1.5 %
CPI only, no PPI overlap	1951-1976	45.4±2.6 %
CPI only, with early data	1947-1997	39.2±1.3 %
CPI only, with early data, no PPI overlap	1947-1976	41.4±2.6 %

DOE also considered alternative models, such as a Moore's law model, to extrapolate the price trend. A Moore's law model uses time as an explanatory variable, instead of cumulative shipments. DOE used only on the PPI series for the Moore's law model because only the PPI covers the most recent time period. DOE used the inflation-adjusted household refrigeration equipment PPI to fit an exponential model with year as the explanatory variable. The exponential function takes the form of

$$Y = a \cdot e^{-\alpha t}$$

where Y is the household refrigeration equipment price index, t is the time variable which equals the year difference between the base year and any given year, a is a constant and α is the exponential parameter of the time variable. This model can be alternatively expressed as a percentage decline/increase in price per year.

DOE performed fits to the PPI data for three time periods; 1976-2010, 1976-1995, and 1991-2010. As a further sensitivity test on the fitting methodology, DOE also performed fits to the nominal PPI series first, and then inflation adjusted the resulting fit. In general, fitting the inflation-adjusted time series is preferred over fitting the nominal series, since fluctuations in macroeconomic conditions will introduce substantial noise in the nominal series. Correcting for inflation before fitting the exponential model removes this variability and improves the resulting fit. Nevertheless, DOE evaluated the fits to the nominal time series in order to consider a broad range of potential sensitivity cases, although the time period 1976-1996 is not included in the sensitivity analysis due to the rapid rise in inflation during the late 1970s and early 1980s. This period results in a poor and unrepresentative fit to the nominal PPI time series. A summary of all these exponential fits (including 95% confidence limits) are presented in Table 8-E.4.2.

Table 8-E.4.2 Exponential Real Price Decline Rate as a Function of Time Period

Table 8-E.4.2 **Index**	**Period**	**Real Price Decline (%/year)**
Real PPI	1976-2010	2.49±0.13 %
Real PPI	1991-2010	2.81±0.31 %
Real PPI	1976-1995	2.04±0.16 %
Nominal PPI	1976-2010	1.50±0.36 %
Nominal PPI	1991-2010	2.67±0.36 %

In addition to using the above cases, DOE also examined a forecast based on the “chained price index--other consumer durable goods except ophthalmic” that was forecasted for *AEO2010.* This index is the most disaggregated category that includes appliances. To develop an inflation-adjusted index, DOE normalized the above index with the “chained price index--gross domestic product” forecasted for *AEO2010.* To extend the adjusted index past 2035, DOE used the average annual growth rate in 2026-2035. This price trend has a real price decline of approximately 2.2% per year over the full time period considered in the NIA, with the price decline smaller in the first few years and larger in the later years.

For the national impacts analysis (see chapter 10), DOE examined the impacts of the above range of price trends on the benefits from potential standards using high, medium and low cases for the price trend. The low case results in the smallest decline in real prices in 2043, and is the lower 95% confidence interval for the exponential fit to the nominal PPI series from 1976-2010. The medium case is the default experience curve model described in Section 8-E.3. The medium case is the main case for the rest of the analysis for the final rule (including the life-cycle assessment and all other downstream analyses). The high case results in the largest decline in real prices in 2043, and is the upper 95% confidence interval for the exponential fit to the inflation-adjusted PPI series from 1991-2010. See Table 8-E.4.3 for a summary of the sensitivity cases. Figure 8-E.4.1 shows the default price factor index and the indexes corresponding to each of the sensitivities (for clarity, the 95% confidence intervals are omitted, except for when they constitute the high or low case). All indexes are adjusted for inflation.

Table 8-E.4.3 Price Trend Sensitivities

Sensitivity	Price Trend	Relevant Parameter
Medium (Default)	Experience curve with unified CPI/PPI 1951-2007	ER = 40.7%
High	Upper 95% confidence interval for exponential fit to inflation-adjusted PPI series 1991-2010	Price Decline = 3.12%/year
Low	Lower 95% confidence interval for exponential fit to nominal PPI series 1976-2010	Price Decline = 1.14%/year

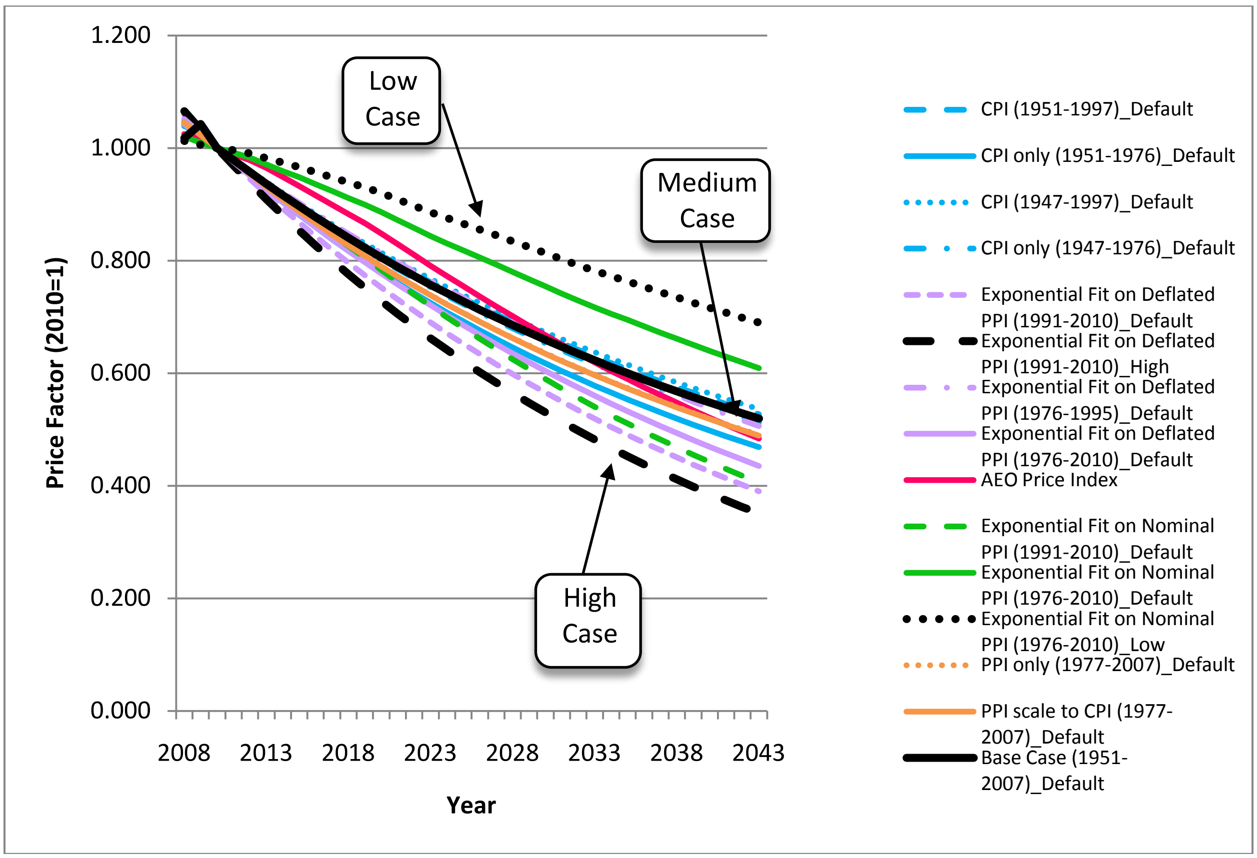

Figure 8-E.4.1 Main Price Factor Index (Medium Case) and Indexes for All Sensitivities.

8-E.4.1 Evaluation of t^2 Term in Exponential Model

DOE performed a brief evaluation of the impact of including a t^2 term to the exponential model (in log-linear space) to explore potential non-linearities in the time series. Specifically, DOE evaluated whether the addition of this term leads to a substantially different forecast. DOE compared two least squares fits to the price index vs. time with the following functional forms:

$$ln(PI) = A + B \cdot (Year - 2010)$$

and

$$ln(PI) = A + B \cdot (Year - 2010) + C \cdot (Year-2010)^2$$

where *ln()* is the natural log, *PI* is the inflation-adjusted price index from the NODA, *Year* is the time variable in years, and *A*, *B*, and C are the parameters that result from the least squares fit. The results of these fits and their extrapolation 35 years forward are illustrated in Figure 8-E.4.2, where the blue line is the price index data from the NODA, and the two thin black lines show the extrapolation of the linear and quadratic models (in log-linear space) for the data. The red dashed line illustrates an approximate experience curve extrapolation of the log of the price index. DOE determined that the addition of a t^2 term to the exponential model does not result in substantial changes from the default experience curve model, and that the addition of an extra term potentially overfits the data with too many degrees of freedom. DOE did not pursue this model any further in the sensitivity analysis.

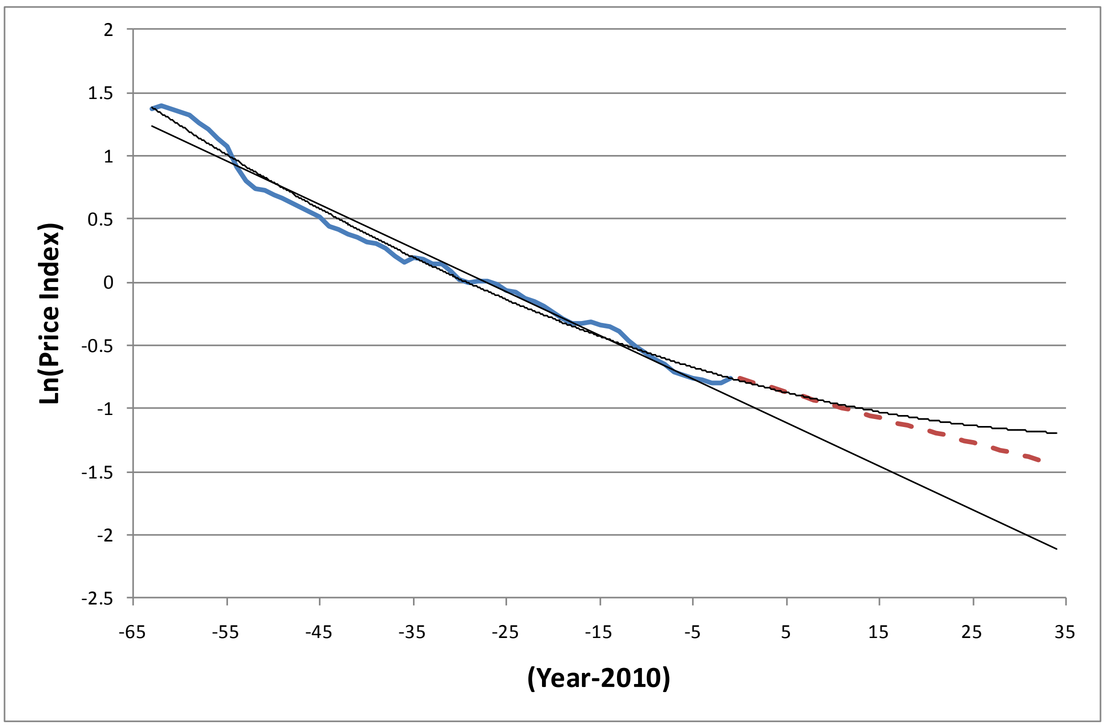

Figure 8-E.4.2 Price Index Extrapolations for Log-Linear, Log-Quadratic, and Experience Curve Models

8-E.5 COMPARISON TO PRICE TRENDS IN THE LITERATURE

Many previous studies have investigated the long-term price trend of various technologies. Some studies have utilized experience curves and others have used time-based models similar to Moore's law (for recent examples, see Weiss et al., 2010a, 2010b; Koh & Magee, 2006, 2008). A limited literature exists with respect to appliances in general and refrigerators in particular. The observed trends are based on market data as opposed to an index such as the PPI.

Dale et al. (2009) in particular reported on how technological innovation, which is a part of the general experience curve, factors into the trend of decreasing refrigerator prices over time. They compared historic price data with the price projections from previous TSDs associated with 1982 and 1995 rulemakings for refrigerator energy efficiency standards. By controlling for overall technological changes such as the size, features, and energy efficiency of refrigerators, Dale et al. found that a decline in prices can be partly attributed to technological innovation.

Table 8-E.5.1 summarizes the findings from the most relevant studies to date.

Table 8-E.5.1 Refrigerator and Freezer Price Trends from the Literature

Study*	Region	Time Period	Appliance	Approximate Real Price Decline (%/year)
Bass (1980)	USA	1922-1940	Refrigerators	2.6%
Laitner & Sanstad (2004)	USA	1980-1998	Refrigerators	3.2%
			Freezers	5.3%
Dale et al. (2009)	USA	1980-2001	Refrigerators	2.5%
Schiellerup (2002)	UK	1992-1999	Refrigerators	6.3%
			Freezers	5.0-5.1%
EES (2006)	Australia	1993-2005	Refrigerators	1.7%
			Freezers	2.5%
Weiss et al. (2010b)	Netherlands	1964-2008	Refrigerators	1.2%
		1970-2003	Freezers	1.1-1.5%

*For full citations see References

The historical refrigerator/freezer price trends in the literature generally fall within the range of sensitivities considered for this analysis. DOE therefore considers the medium (default) case used in the rest of the analysis as an appropriate price trend for its forecast. DOE also considers the range of sensitivities to be sufficiently large to include observed uncertainty based on previous analyses.

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APPENDIX 9-A. RELATIVE PRICE ELASTICITY OF DEMAND FOR APPLIANCES

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APPENDIX 9-A. RELATIVE PRICE ELASTICITY OF DEMAND FOR APPLIANCES

9-A.1 INTRODUCTION

This appendix summarizes DOE's study of the price elasticity of demand for home appliances, including refrigerators, clothes washers and dishwashers. DOE chose this particular set of appliances because of the availability of data to determine a price elasticity. This appendix begins with a review of the existing economics literature describing the impact of economic variables on the sale of durable goods in section 9A.2. In section 9A.3, the market for home appliances and changes in it over the past 20 years is described. In section 9A.4, DOE summarizes the results of its regression analysis and presents estimates of the price elasticity of demand for the three appliances. In section 9A.5, DOE presents development of an 'effective' purchase price elasticity. DOE's interpretation of its results is presented in section 9A.6. Finally, section 9A.7 describes the data used in DOE's analysis.

9-A.2 LITERATURE REVIEW

There are relatively few studies measuring the impact of price, income and efficiency on the sale of household appliances. In this section DOE provides a short review of this literature which suggests the likely importance of these variables.

9-A.2.1 Price

The goal of many of the studies covered in this review is to measure the impact of price on sales in a dynamic market. One study of the automobile market prior to 1970 finds the price elasticity of demand to decline over time. The author explains this as the result of buyers delaying purchases after a price increase but eventually making the purchase (Table 9A.2.1).[1] A contrasting study of household white goods also prior to 1970, finds the elasticity of demand to increase over time as more price-conscious buyers enter the market.[2] A recent analysis of refrigerator market survey data finds that consumer purchase probability decreases with survey asking price.[3] Estimates of the price elasticity of demand for different brands of the same product tend to vary. A review of 41 studies of the impact of price on market share found the average price elasticity to be -1.75.[4] The average estimate of price elasticity of demand reported in these studies is -0.33 in the appliance market and -0.47 in the combined automobile and appliance markets.

9-A.2.2 Income

Higher income households are more likely to own household appliances.[5] The impact of income on appliance shipments is explored in two econometric studies of the automobile and appliance markets. [1,2] The average income elasticity of demand is 0.50 in the appliance study cited in the literature review, much larger in the automobile study (Table 9.A.2.1).

9-A.2.3 Appliance Efficiency and Discount Rates

Many studies estimate the impact of appliance efficiency on consumer appliance choice. Typically, this impact is summarized by the implicit discount rate, i.e., the rate consumers appear to use to compare future appliance operating cost savings against an appliance purchase price premium.[a] One early and much cited study concludes that consumer behavior reflects a 20 percent implicit discount rate when purchasing room air conditioners (Table 9A.2.1).[6] A survey of several studies of different appliances suggests that the consumer implicit discount rate has a broad range and averages about 37 percent.[7]

Table 9-A.2.1 Estimates of the Impact of Price, Income and Efficiency on Automobile and Appliance Sales

Durable Good	Price Elasticity	Income Elasticity	Brand Price Elasticity	Implicit Discount Rate	Model	Data Years	Time Period
Automobiles[1]	-1.07	3.08	-	-	Linear Regression, stock adjustment	-	Short run
Automobiles[1]	-0.36	1.02	-	-	Linear Regression, stock adjustment	-	Long run
Clothes Dryers[2]	-0.14	0.26	-	-	Cobb-Douglas, diffusion	1947-1961	Mixed
Room Air Conditioners[2]	-0.37[8]	0.45	-	-	Cobb-Douglas, diffusion	1946-1962	Mixed
Dishwashers[2]	-0.42	0.79	-	-	Cobb-Douglas, diffusion	1947-1968	Mixed
Refrigerators[3]	-0.37	-	-	39%	Logit probability, survey data	1997	Short run
Various[4]	-	-	-1.76[9]	-	Multiplicative regression	-	Mixed
Room Air Conditioners[5]	-	-	-1.72	-	Non-linear diffusion	1949-1961	Short run
Clothes Dryers[5]	-	-	-1.32	-	Non-linear diffusion	1963-1970	Short run
Room Air Conditioners[6]	-	-	-	20%	Qualitative choice, survey data	-	-
Household Appliances[7]	-	-	-	37%[10]	Assorted	-	-

Sources: [1] S. Hymens. 1971; [2] P. Golder and G. Tellis, 1998; [3] D. Revelt and K. Train, 1997; [4] G. Tellis, 1988; [5] D. Jain and R. Rao; [6] J. Hausman; [7] K. Train, 1985.

Notes: [8] Logit probability results are not directly comparable to other elasticity estimates in this table.
[9] Average brand price elasticity across 41 studies.
[10] Averaged across several household appliance studies referenced in this work.

[a] A high implicit discount rate with regard to operating costs means that, based on market behavior, consumers appear to put relatively low economic value on the operating cost savings realized from more-efficient appliances. A high value may indicate lack of information, risk aversion and other factors as well as the value consumers place on savings accrued in the future.

9-A.3 VARIABLES DESCRIBING THE MARKET FOR REFRIGERATORS, CLOTHES WASHERS, AND DISHWASHERS

In this section DOE evaluates variables that appear to account for refrigerator, clothes washer and dishwasher shipments, including physical household/appliance variables, and economic variables.

9-A.3.1 Physical Household/Appliance Variables

Several variables influence the sale of refrigerators, clothes washers and dishwashers. The most important for explaining appliance sales trends are the annual number of new households formed (housing starts) and the number of appliances reaching the end of their operating life (replacements). Housing starts influence sales because new homes are often provided with, or soon receive, new appliances, including dishwashers and refrigerators. Replacements are correlated with sales because new appliances are typically purchased when old ones wear out. In principle, if households maintain a fixed number of appliances, shipments should equal housing starts plus appliance replacements.

9-A.3.2 Economic Variables

Appliance price, appliance operating cost and household income are important economic variables affecting shipments. Low prices and costs encourage household appliance purchases and a rise in income increases householder ability to purchase appliances. In principle, changes in economic variables should explain changes in the number of appliances per household.

During the 1980–2002 study period, annual shipments grew 69 percent for clothes washers, 81 percent for refrigerators and 105 percent for dishwashers (Table 9A.3.1). This rising shipments trend is explained in part by housing starts, which increased 6 percent and by appliance replacements, which rose between 49 percent and 90 percent, depending on the appliance, over the period (Table 9A.3.1).[b] For mature markets such as these, replacements exceed appliance sales associated with new housing construction.

Table 9-A.3.1 Physical Household/Appliance Variables

	Shipments[1] (millions)			Housing Starts[2] (millions)			Replacements[3] (millions)		
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**
Refrigerators	5.124	9.264	81%	1.723	1.822	6%	3.93	5.84	49%
Clothes Washers	4.426	7.492	69%	1.723	1.822	6%	3.66	5.50	50%
Dishwashers	2.738	5.605	105%	1.723	1.822	6%	1.99	3.79	90%

[1]Shipments: Number of units sold. **Sources:** AHAM Fact Book and Appliance Magazine.
[2]Housing Starts: Annual number of new homes constructed. **Source:** U.S. Census.
[3]Replacements: Average of annual lagged shipments, with lag equal to expected appliance operating life, ± 5 years.

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[b] Appliance replacements are determined from the expected operating life of refrigerators (19 years), clothes washers (14 years), and dishwashers (12 years) and from past shipments. Replacements are further discussed in section 9A.3.

Nevertheless, it is apparent that appliance shipments increased somewhat more rapidly than housing starts and replacements. This is shown by comparing the beginning and end points of lines representing "starts plus replacements" (uppermost solid line in Figure 9A.3.1) and "shipments" (diamond linked line in Figure 9A.3.1). In 1980 the "shipment" line begins below the "starts plus replacements" line. In 2002, the "shipments" line ends above the "starts plus replacements" line. This more rapid increase in shipments, compared to housing starts plus replacements, suggests that the appliance per household ratio increased over the study period.

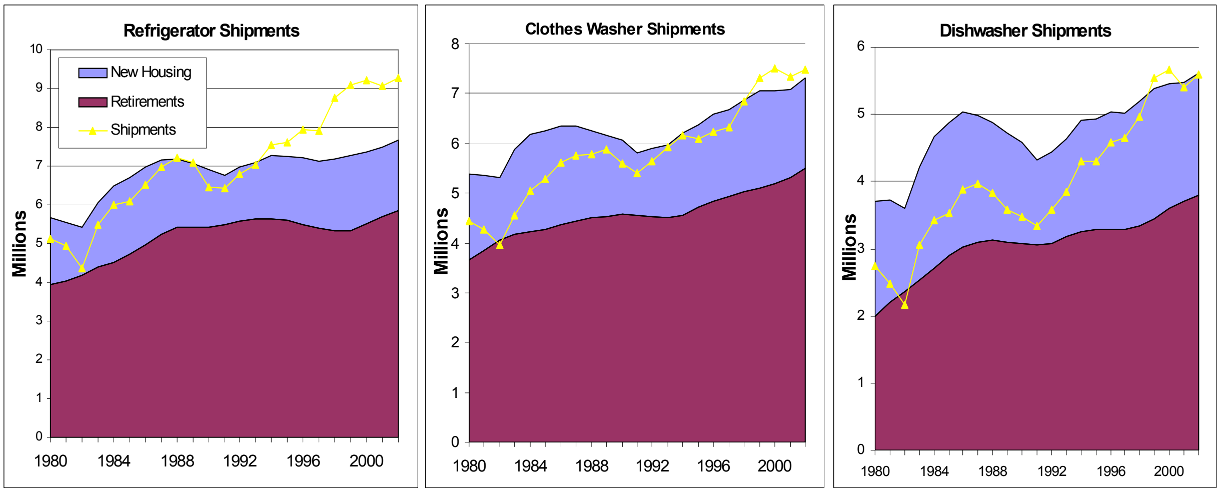


Figure 9-A.3.1 Trends in Appliance Shipment, Housing Starts and Replacements

Economic variables, including price, cost and income, may explain this increase in appliances per household. Over the period, appliance prices decreased 40 percent to 50 percent, operating costs fell between 33 percent and 72 percent, and median household income rose 16 percent (Table 9A.3.2).

Table 9-A.3.2 Economic Variables

	Price[1] (1999$)			Operating Cost[2] (1999$)			Household Income[3] (1999$)		
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**
Refrigerators	1208	726	-40%	333	94	-72%	37,447	43,381	16%
Clothes Washers	779	392	-50%	262	175	-33%	37,447	43,381	16%
Dishwashers	713	369	-48%	183	95	-48%	37,447	43,381	16%

[1]Price: Shipment weighted retail sales price. **Sources:** AHAM Fact Book and Appliance Magazine.
[2]Operating Cost: Annual electricity price times electricity consumption. **Source:** AHAM Fact Book.
[3]Income: Mean Household income. **Source:** U.S. Census.

9-A.4 REGRESSION ANALYSIS OF VARIABLES AFFECTING APPLIANCE SHIPMENTS

Little data is available for estimating the impact of economic variables on the demand for appliances. Industry operating cost data is incomplete—appliance energy use data is available for only 12 years of the 1980-2002 study period. Industry price data is also incomplete—available for only 8 years of the study period for each of the appliances.

The lack of data suggests that regression analysis can at best evaluate broad data trends, utilizing relatively few explanatory variables. This section begins by describing broad trends apparent in the economic and physical household data sets and then specifies a simple regression model to measure these trends, making assumptions to minimize the number of explanatory variables. Finally, results are presented of the regression analysis and the estimate of the price elasticity of demand for appliances. In this section (specifically section 9A.4.5), DOE also presents the results of regression analysis performed with more complex models, and used to test assumptions made to specify the simple model. These results support the simple model specification, and estimates of the price elasticity of appliance demand measured with that model.

9-A.4.1 Broad Trends

In this section DOE reviews trends in the physical household and economic data sets and posit a simple approach for estimating the price elasticity of appliance demand. As noted above, the physical household variables (starts and appliance replacements), explain most of the variability in appliance shipments over the period.[c] DOE assumes the rest of the variability in shipments (referred to as "residual shipments") is explained by economic variables, and present a tabular method for measuring price elasticities described below.

To illustrate this tabular approach, DOE defines two new variables—residual shipments and total price. Residual shipments are defined as the difference between shipments and physical household demand (starts plus replacements). Total price, represented by the following equation, is defined as appliance price plus the present value of lifetime appliance operating cost:[d]

$$\boldsymbol{TP = PP + PVOC}$$

where:

TP =	Total price,
PP =	Appliance purchase price, and
PVOC =	Present value of operating cost.

---

[c] A log regression of the form: Shipments = a + b • Housing Starts + c • Retirements, indicates that these two variables explain 89 percent of the variation in refrigerator shipments, 97 percent of the variation in clothes washer shipments, and 97 percent of the variation in dishwasher shipments.

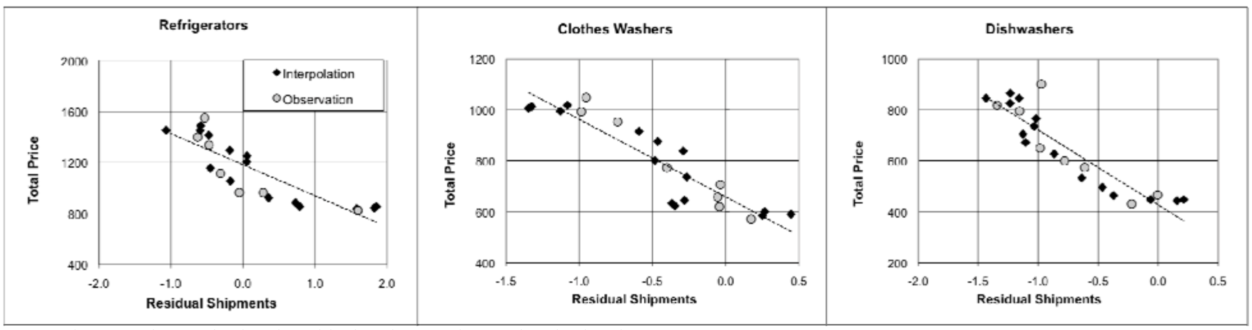
[d] Present value operating cost is calculated assuming a 19 year operating life for refrigerators, 14 year operating life for clothes washers, and a 12 year operating life for dishwashers. A 37 percent discount rate is used to sum annual operating costs into a present value operating cost.

Over the study period, residual shipments increase 30 percent for refrigerators, 19 percent for clothes washers, and 23 percent for dishwashers in proportion to total shipments. At the same time, total prices decline 47 percent, 45 percent and 48 percent for refrigerators, clothes washers, and dishwashers, respectively. Assuming that total price explains the entire change in per household appliance usage, a rough estimate is calculated of the total price elasticity of demand equal to -0.48 for refrigerators, -0.32 for clothes washers and -0.37 for dishwashers (Table 9A.4.1).

Table 9-A.4.1 Simple Estimate of Total Price Elasticity of Demand

	Residual Shipments (millions)				Total Price (199$)			
Appliance	**1980**	**2002**	**Difference**	**Change**	**1980**	**2002**	**Change**	**Elasticity**
Refrigerators	-0.5	1.6	2.1	30%	1541	820	-61%	-0.48
Clothes Washers	-1.0	0.2	1.1	19%	1042	567	-59%	-0.32
Dishwashers	-1.0	-0.01	1.0	23%	896	464	-64%	-0.37

The negative correlation between total price and residual shipments suggested by these negative price elasticities is illustrated in a graph of residual shipments on the x-axis and total price on the y-axis (Figure 9A.4.1).



Gray points are observed price data; black points are interpolated price data.

Figure 9-A.4.1 Residual Shipments and Appliance Price

Household income rose during the study period, making it easier for households to purchase appliances. Assuming that a rise in income has a similar impact on shipments as a decline in price, the impact of income is incorporated by defining a third variable, termed *relative* price, calculated as total price divided by household income and represented by the following equation:[e]

$$RP = \frac{TP}{Income}$$

where:

RP = Relative price,
TP = Total price, and
Income = Household income.

The percent decline in *relative* price for the three appliances divided by the percent decline in residual shipments suggests a rough estimate of *relative* price elasticity equal to -0.40 for refrigerators, -0.26 for clothes washers and -0.30 for dishwashers (Table 9A.4.2).

[e] Recall that the income elasticity of demand cited in the literature review is 0.50 and the price elasticity of demand cited in the review averages -0.35. This suggests that combining the effects of income and price will yield an elasticity less negative than price elasticity alone.

Table 9-A.4.2 Tabular Estimate of Relative Price Elasticity of Appliance Demand

	Residual Shipments (millions)			Relative Price (1999$)			
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**Elasticity**
Refrigerators	-0.532	1.597	30%	0.041	0.019	-74%	-0.40
Clothes Washers	-0.953	0.174	19%	0.028	0.013	-72%	-0.26
Dishwashers	-0.974	-0.005	23%	0.024	0.011	-76%	-0.30

9-A.4.2 Model Specification

The limited price data suggests using a simple regression model to estimate the impact of economic variables on shipments, using few explanatory variables. The following equation chosen for this analysis includes one physical household variable (starts plus replacements) and one *relative* price variable (the sum of purchase price plus operating cost, divided by income).

$$\boldsymbol{Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor} \qquad \textbf{Eq. 9A.1}$$

where:

Ship = Quantity of appliance sold,
RP = Relative price,
Starts = Number of new homes, and
Rplc = Number of appliances at the end of their operating life.

The natural logs are taken of all variables so that the estimated coefficients for each variable in the model may be interpreted as the percent change in shipments associated with the percent change in the variable. Thus, the coefficient b in this model is interpreted as the *relative* price elasticity of demand for the three appliances.

The following combined regression equation is used to estimate an average price elasticity of demand across the three appliances, using pooled data in a single regression. A combined regression specification is justified, given limited data availability and similarity in price and shipment behavior across appliances (see Figure 9A.4.1). Thus, the model represented by the combined regression equation is considered the basic model in DOE's analysis of appliance shipments.

$$\boldsymbol{Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor + d \times CW + e \times DW} \qquad \textbf{Eq. 9A.2}$$

where:

CW = Quantity of clothes washers sold, and
DW = Quantify of dishwashers sold.

9-A.4.3 Model Discussion

The most important assumption used to specify this model is that changes in economic variables over the study period—income, price, and operating cost—are responsible for all observed growth in residual appliance shipments. In other words, DOE assumes other possible explanations, such as changing consumer preferences and increases in the quality of appliances—had no impact. This assumption seems unlikely but without additional data, the impact of this assumption on the price elasticity of demand cannot be measured. DOE effectively assumes that changes in consumer preferences and appliance characteristics, while affecting which specific models are purchased, have relatively little impact on the total number of appliances purchased in a year.

Three additional assumptions used to specify this model deserve comment. The *relative* price variable is specified in the model, assuming that (1) the correct implicit discount rate is used to combine appliance price and operating cost and that (2) rising income has the same impact on shipments as falling total price. The "starts + replacements" variable is specified, assuming (3) that starts and replacements have similar impacts on shipments.

To investigate the first assumption about discount rates, DOE calculated "present value operating cost" using a 20 percent implicit discount rate and performed a second regression analysis based on the models described in equations. 9A.1 and 9A.2. The results of this analysis, presented in section 9A.4.5, indicate that the elasticity of *relative* price is relatively insensitive to changes in the discount rate.

To investigate the second and third assumptions, DOE specified a regression model separating income from total price and replacements from starts, thus adding two additional explanatory variables to the basic model as shown in the following equation:

$$\boldsymbol{Ship = a + b \times TP + c \times Incone + d \times Start + e \times Rplc + f \times CW + g \times DW} \qquad \textbf{Eq. 9A.3}$$

The results of the regression analysis of this model are also presented in section 9A.4.5. These results suggest that the elasticity of total price (coefficient b) is relatively insensitive to changes in the treatment of income and "starts + replacements" in the model.

9-A.4.4 Analysis Results

9A.4.4.1 Individual Appliance Model

The individual appliance regression equations are specified as followed (as shown earlier as Eq. 9A.1):

$$\boldsymbol{Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor}$$

In regression analysis of this model, the elasticity of *relative* price (b) is estimated to be

-0.40 for refrigerators, -0.31 for clothes washers and -0.32 for dishwashers (Table 9A.4.3), averaging -0.35. These elasticities are similar to those reported in the literature survey for appliances (Table 9A.2.1). They are remarkably similar to the price elasticity calculated using a tabular approach presented above (Table 9A.4.2).

The estimated coefficient associated with the "starts + replacements" variable is close to one. A coefficient equal to one for this variable would imply that shipments increase in direct proportion to an increase in "starts + replacements", holding economic variables constant. The high R squared values (above 95) and t statistics (above 5) in the results provide a measure of confidence in this analysis, despite the very small data set.

Table 9-A.4.3 Individual Appliance Model Results

	Refrigerator		Clothes Washer		Dishwasher	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Intercept	-1.51	-7.26	-1.47	-8.23	-2.08	-16.78
Relative Price	-0.40	-6.60	-0.31	-5.69	-0.32	-7.03
Starts + Replacements	1.05	5.90	1.08	6.41	1.35	11.46
R^2	0.954		0.954		0.975	
Observations	23		23		23	

9A.4.4.2 Combined Appliance Model

The combined appliance regression equation is specified as follows (as shown earlier as Eq. 9A.2):

$$\boldsymbol{Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor + d \times CW + e \times DW}$$

This regression analysis indicates that the model fits the existing shipments data well (high R squared) and that the variables included in the model are statistically significant (Table 9A.4.4). The elasticity of *relative* price estimated with this model is -0.34, close to the average value estimated in the individual appliance models (-0.35). It is also similar to elasticity estimates reported in the literature survey and calculated using the tabular approach above.

Table 9-A.4.4 Combined Appliance Model Result

Variable	**Coefficient**	**t-stat**
Intercept	-1.60	-15.54
Relative Price	-0.34	-10.74
Starts + Replacements	1.21	13.95
CW	-0.20	-9.04
DW	-0.32	-6.58
R^2	0.983	
Observations	69	

9-A.4.5 Additional Regression Specifications and Results

As described above in section 9A.4.3, DOE used three assumptions to specify its appliance models. The first is that the implicit price variable in the basic regression model is specified using a 37 percent implicit discount rate, to aggregate appliance price and operating cost. The second states that the implicit price variable is defined assuming that rising income has the same impact on shipments as falling total price. The third states that the "starts + replacements" variable is defined assuming that housing starts have a similar impact on shipments as appliance replacements.

9A.4.5.1 Lower Consumer Discount Rate

To investigate the first assumption about discount rates, DOE calculated "present value operating cost" using a 20 percent implicit discount rate and performed a second regression analysis based on the models described in equations 9A.1 and 9A.2. The estimated coefficient associated with the *relative* price variable in these regressions is almost identical to the coefficients estimated for same variable reported above using a 37 percent implicit discount rate. The elasticity of *relative* price calculated using a 20 percent discount rate is -0.33 in the combined regression and averages -0.35 for the three appliances (Table 9A.4.5). The elasticity of price calculated using a 37 percent discount rate is -0.34 in the combined regression and averages -0.35 for the three appliances. DOE concludes from this analysis that the elasticity of *relative* price is relatively insensitive to changes in the discount rate.

Table 9-A.4.5 Combined and Individual Results, 20 percent discount rate

Three Appliances		
Variable	**Coefficient**	**t-Stat**
Intercept	-1.53	-14.61
Total Price / Income	-0.33	-10.69
Starts + Retirements	1.20	13.65
CW	-0.18	-8.69
DW	-0.32	-6.57
R^2	0.982	
Observations	69	

	Refrigerator		Clothes Washers		Dishwasher	
Variable	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**
Intercept	-1.36	-6.26	-1.41	-7.49	-2.04	-17.23
Total Price / Income	-0.38	-6.50	-0.32	-5.29	-0.33	-7.30
Starts + Retirements	1.04	5.73	1.06	5.83	1.34	11.64
R^2		0.953		0.950		0.977
Observations		23		23		23

9A.4.5.2 Disaggregated Variables

To investigate the second and third assumptions, DOE constructed a regression model separating income from total price and replacements from starts, thus adding two additional explanatory variables to the basic model (as shown earlier as Eq. 9A.3).

$$\boldsymbol{Ship = a + b \times TP + c \times Incone + d \times Start + e \times Rplc + f \times CW + g \times DW}$$

The estimated coefficient associated with the total price variable in these regressions is almost identical to the coefficients estimated for the *relative* price variable reported above. The elasticity of total price in the above equation is -0.36 in the combined appliance regression and averages -0.35 for the three appliances (Table 9A.4.6). The elasticity of *relative* price based on the model described in equation 9A.2 is -0.34 in the combined regression (Table 9A.4.4) and averages -0.35 across the individual appliances (Table 9A.4.3). DOE concludes that the price elasticity calculated in this analysis is relatively insensitive to the specification of household income and "starts + replacements" variables in the model.

Table 9-A.4.6 Disaggregated Regression Results, 37 percent discount rate

Three Appliances		
Variable	**Coefficient**	**t-Stat**
Intercept	-2.92	-1.26
Income	0.58	2.92
Total Price	-0.36	-7.06
Housing Starts	0.44	10.02
Retirements	0.62	8.12
CW	-0.24	-9.25
DW	-0.46	-7.68
R^2		0.985
Observations		69

	Refrigerator		Clothes Washers		Dishwasher	
Variable	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**
Intercept	-6.19	-2.24	-6.64	-1.63	1.00	0.23
Income	0.89	3.80	0.87	2.31	0.20	0.52
Total Price	-0.35	-5.48	-0.27	-2.51	-0.43	-5.18
Housing Starts	0.41	7.38	0.25	3.29	0.62	8.24
Retirements	0.56	6.06	0.56	2.09	0.65	5.86
R^2		0.984		0.958		0.979
Observations		23		23		23

9-A.5 LONG RUN IMPACTS

As noted above in Table 9A.2.1 in section 9A.2, the literature review provides price elasticities over short and long time periods, also referred to as short run and long run price elasticities. As noted in the first two rows of Table 9A.2.1, one source (i.e., Hymans) shows that the price elasticity of demand is significantly different over the short run and long run for automobiles.[1] Because DOE's forecasts of shipments and national impacts due to standards is over a 30-year time period, consideration must be given as to how the *relative* price elasticity is affected once a new standard takes effect.

DOE considers the *relative* price elasticities determined above in section 9A.4 to be short run elastcities. DOE was unable to identify sources specific to household durable goods, such as appliances, to indicate how short run and long run price elasticities differ. Therefore, to estimate how the *relative* price elasticity changes over time, DOE relied on the Hymans study pertaining to automobiles. Based on the Hymans study, Table 9A.5.1 shows how the automobile price elasticity of demand changes in the years following a purchase price change. With increasing years after the price change, the price elasticity becomes more inelastic until it reaches a terminal value around the tenth year after the price change.

Table 9-A.5.1 Change in Price Elasticity of Demand for Automobiles following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Price Elasticity of Demand	-1.20	-0.93	-0.75	-0.55	-0.42	-0.40
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33

Source: Hymans, 1971.

Based on the relative change in the automobile price elasticity of demand shown in Table 9A.5.1, DOE developed a time series of *relative* price elasticities for home appliances. Table 9A.5.2 presents the time series.

Table 9-A.5.2 Change in *Relative* Price Elasticity for Home Appliances following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33
Relative Price Elasticity	-0.34	-0.26	-0.21	-0.16	-0.12	-0.11

9-A.6 SUMMARY

This appendix describes the results of a literature search, tabular analysis and regression analysis of the impact of price and other variables on appliance shipments. In the literature, DOE finds only a few studies of appliance markets that are relevant to this analysis, and no studies using time series price and shipments data after 1980. The information that can be summarized from the literature, suggests that the demand for appliances is price inelastic. Other information in the literature suggests that appliances are a normal good, such that rising incomes increase the demand for appliances. Finally, the literature suggests that consumers use relatively high implicit discount rates, when comparing appliance prices and appliance operating costs.

There is not enough price and operating cost data available to perform complex analysis of dynamic changes in the appliance market. In this analysis, DOE uses data available for refrigerators, clothes washers and dishwashers to evaluate broad market trends and to perform simple regression analysis.

These data indicate that there has been a rise in appliance shipments and a decline in appliance price and operating cost over the period. Household income has also risen during this time. To simplify the analysis, DOE combined the available economic information into one variable, termed *relative* price, and used this variable in a tabular analysis of market trends, and a regression analysis.

DOE's tabular analysis of trends in the number of appliances per household suggests that the price elasticity of demand for the three appliances is inelastic. Our regression analysis of these same variables suggests that the *relative* price elasticity of demand is -0.34. The price elasticity is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using very simple statistical analysis. More important, the measure is based on an assumption that economic variables, including price, income and operating costs, explain most of the trend in appliances per household in the United States since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but they are not accounted for in this analysis.

9-A.7 DATA USED IN THE ANALYSIS

- **Appliance Shipments:** Shipments are defined as the annual number of units shipped in millions. These data were collected from the Association of Home Appliance Manufacturers (AHAM)[8] and Appliance Magazine[9] as annual values for each year, 1980–2002. AHAM was used for the period 1989–2002 while Appliance Magazine was used for the period 1980–1988.

- **Appliance Price:** Price is defined as the shipments weighted retail sales price of the unit in 1999 dollars. Price values for 1980, 1985, 1986, 1991, 1993, 1994, 1998, and 2002 were collected from AHAM Fact Books.[10] Price values for other years were interpolated from these eight years of data.

- **Housing Starts:** Housing starts data were collected from U.S. Census construction statistics (C25 reports) as annual values for each year, 1980–2002.[11]

- **Replacements:** Retirement-driven replacements are estimated with the assumption that some fraction of sales arise from consumers replacing equipment at the end of its useful life. Since each appliance has a different expected lifespan (19 years for refrigerators[12], 14 years for clothes washers[13], 12 years for dishwashers[14]), replacements are calculated differently for each appliance type. Replacements are estimated as the average of shipments 14–24 years previous for refrigerators, 9–19 years previous for clothes washers, and 7–17 years previous for dishwashers. Historical shipments data were collected from AHAM and Appliance Magazine.

- **Annual Electricity Consumption:** Electricity Use (UEC) is defined as the energy consumption of the unit in kilowatt-hours. Electricity consumption is dependent on appliance capacity and efficiency. These data were provided by AHAM for 1980, 1990–1997 and 1999–2002.[15] Data were interpolated in the years for which data were not available.

- **Operating Cost:** Operating Cost is the present value of the electricity consumption of an appliance over its expected lifespan. The lifespans of refrigerators, clothes washers and dishwashers are assumed to be 19, 14, and 12 years respectively. Discount rates of 20 percent[6] and 37 percent[16] were used, producing similar estimates of price elasticity. A study by Hausman recommended a discount rate of "about 20 percent" in its introduction, and presented results ranging from 24.1 percent to 29 percent based on his calculations for room air conditioners. A study by Train suggests a range of implicit discount rates averaging 35 percent for appliances.

- **Income:** Median annual household income in 2003 dollars. This data was collected for each year, 1980–2002, from Table H-6 of the U.S. Census.[17]

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APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NIA SPREADSHEETS

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APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NIA SPREADSHEETS

10-A.1 INTRODUCTION

The results obtained for the shipments analysis and the national impact analysis (NIA) can be examined and reproduced using the Microsoft Excel spreadsheet available on the U.S. Department of Energy Building Technologies website at: http://www.eere.energy.gov/buildings/appliance_standards/.

There are a total of four NIA spreadsheets, one each for the following product types: standard-size refrigerator-freezers, standard-size freezers, compact refrigerators, and commercial compact freezers. The four spreadsheets posted on the DOE website represent the latest versions and have been tested with Microsoft Excel 2003.

To execute the spreadsheet requires Microsoft Excel 2003 or a later version. The NIA spreadsheet performs calculations to forecast the change in national energy use and net present value due to an energy conservation standard. The energy use and associated costs for a given standard are determined first by calculating the shipments and then calculating the energy use and costs for all equipment shipped under that standard. The differences between the standards and base cases can then be compared and the overall energy savings and present values determined.

10-A.1.1 Standard-Size Refrigerator-Freezers

The standard-size refrigerator-freezer NIA spreadsheet or workbook consists of the following worksheets:

Input and Summary Contains user input selections under "User Inputs" and a summary table, Cumulative Energy Savings and NPV for the selected standard level efficiency distribution. The sheet contains the efficiency levels being considered for standard-size refrigerator-freezers and the associated incremental prices. This sheet also contains base and standards case efficiency trends for standard-size refrigerator-freezers, and efficiency weighted average energy use and equipment price for the base and standards cases.

Historical Shipment & Market Share Contains data for historical sales of standard-size refrigerator-freezers by product class. The forecast market share between top-mount and side/bottom-mount refrigerator-freezers is provided.

Base Case Contains the calculations for determining the shipments, energy consumption, and operating costs for the base case. The sheet starts with the stock accounting of the equipment and uses the survival function to calculate the surviving stock. It then performs calculations of replacements, and shipments going into new housing. The sheet calculates replacement units, shipments going into new units, and early replacement shipments, and aggregates them into total shipments.

Base Energy Calc	Contains additional stock accounting calculations to properly allocate shipments, energy use, and costs to top-mount and side/bottom-mount refrigerator-freezers for the base case.
Standards Case	Contains stock accounting of the equipment that calculates annual shipments estimates, energy savings, and operating cost savings for the standards case. The energy and cost savings in a single year are the difference between the base case energy use and costs and the standard case energy use and costs for that year.
Standards Energy Calc	Contains additional stock accounting calculations to properly allocate shipments, energy use, and costs to top-mount and side/bottom-mount refrigerator-freezers for the standards case.
Housing Projections	Contains the projected new housing construction starts and total housing stock for the three economic scenarios (Reference, Low Growth, and High Growth). Also provides the early replacement rate.
Fuel Prices	Contains projected average energy prices for the three economic scenarios.
Heat Rates	Contains the marginal site to source conversion factors that are used in the source energy savings calculations, for both electricity and gas.
Lifetime	Contains the probability of survival of a standard-size refrigerator-freezer at a given age and the average lifetime of a unit.

10-A.1.2 Standard-Size Freezers

The standard-size freezer NIA spreadsheet or workbook consists of the following worksheets:

Input and Summary	Contains user input selections under "User Inputs" and a summary table, Cumulative Energy Savings and NPV for the selected standard level efficiency distribution. The sheet contains the efficiency levels being considered for standard-size freezers and the associated incremental prices. This sheet also contains base

and standards case efficiency trends for standard-size freezers, and efficiency weighted average energy use and equipment price for the base and standards cases.

Historical Shipment Contains data for historical sales of standard-size freezers by product class.

Base Case Contains the calculations for determining the shipments, energy consumption, and operating costs for the base case. The sheet starts with the stock accounting of the equipment and uses the survival function to calculate the surviving stock. It then performs calculations of replacements, and shipments going into new housing. The sheet calculates replacement units, shipments going into new units, and shipments going to first time owners (existing households that do not already own the product), and aggregates them into total shipments.

Standards Case Contains stock accounting of the equipment that calculates annual shipments estimates, energy savings, and operating cost savings for the standards case. The energy and cost savings in a single year are the difference between the base case energy use and costs and the standard case energy use and costs for that year.

Housing Projections Contains the projected new housing construction starts and total housing stock for the three economic scenarios (Reference, Low Growth, and High Growth). Also provides the early replacement rate.

Fuel Prices Contains projected average energy prices for the three economic scenarios.

Heat Rates Contains the marginal site to source conversion factors that are used in the source energy savings calculations, for both electricity and gas.

Lifetime Contains the probability of survival of a standard-size refrigerator-freezer at a given age and the average lifetime of a unit.

10-A.1.3 Compact Refrigerators

The compact refrigerator NIA spreadsheet or workbook consists of the following worksheets:

Input and Summary Contains user input selections under "User Inputs" and a summary table, Cumulative Energy Savings and NPV for the selected standard level efficiency distribution. The sheet contains the efficiency levels being considered for compact refrigerators and the associated incremental prices. This sheet also contains base and standards case efficiency trends for compact refrigerators, and efficiency weighted average energy use and equipment price for the base and standards cases.

Historical Shipment	Contains data for historical sales of compact refrigerators by product class. Also provides historical saturations of compact refrigerators in lodging, residential, and commercial buildings.
Base Case	Contains the calculations for determining the shipments, energy consumption, and operating costs for the base case. The sheet starts with the stock accounting of the equipment and uses the survival function to calculate the surviving stock. It then performs calculations of replacements, and shipments going into new housing, new lodging, and new commercial buildings, and aggregates them into total shipments.
Standards Case	Contains stock accounting of the equipment that calculates annual shipments estimates, energy savings, and operating cost savings for the standards case. The energy and cost savings in a single year are the difference between the base case energy use and costs and the standard case energy use and costs for that year.
Housing & Comm Flrspc Project	Contains the projected new housing construction starts, total housing stock, projected new commercial floorspace projections, and total lodging and commercial floorspace stock for the three economic scenarios (Reference, Low Growth, and High Growth).
Fuel Prices	Contains projected average energy prices for the three economic scenarios.
Heat Rates	Contains the marginal site to source conversion factors that are used in the source energy savings calculations, for both electricity and gas.
Lifetime	Contains the probability of survival of a standard-size refrigerator-freezer at a given age and the average lifetime of a unit.

10-A.1.4 Compact Freezers

The compact freezer NIA spreadsheet or workbook consists of the following worksheets:

Input and Summary	Contains user input selections under "User Inputs" and a summary table, Cumulative Energy Savings and NPV for the selected standard level efficiency distribution. The sheet contains the efficiency levels being considered for compact freezers and the associated incremental prices. This sheet also contains base and standards case efficiency trends for compact freezers, and efficiency weighted average energy use and equipment price for the base and standards cases.
Historical Shipment	Contains data for historical sales of compact freezers by product class.
Base Case	Contains the calculations for determining the shipments, energy consumption, and operating costs for the base case. The sheet starts with the stock accounting of the equipment and uses the survival function to calculate the surviving stock. It then performs calculations of replacements, and shipments going to first time owners (existing households that do not already own the product), and aggregates them into total shipments.
Standards Case	Contains stock accounting of the equipment that calculates annual shipments estimates, energy savings, and operating cost savings for the standards case. The energy and cost savings in a single year are the difference between the base case energy use and costs and the standard case energy use and costs for that year.
Housing Projections	Contains the projected new housing construction starts and total housing stock for the three economic scenarios (Reference, Low Growth, and High Growth). Housing data used solely to determine a compact freezer saturation in new housing.
Fuel Prices	Contains projected average energy prices for the three economic scenarios.
Heat Rates	Contains the marginal site to source conversion factors that are used in the source energy savings calculations, for both electricity and gas.
Lifetime	Contains the probability of survival of a standard-size refrigerator-freezer at a given age and the average lifetime of a unit.

10-A.2 BASIC INSTRUCTIONS

Basic instructions for operating the NIA spreadsheets are as follows:

1. Once the NIA spreadsheets have been downloaded from the Web, open the file using Excel. At the bottom, click on the tab for the worksheet 'Input and Summary'.

2. Use Excel's View/Zoom commands at the top menu bar to change the size of the display to make it fit your monitor.

3. The user can change the model parameters listed in the grey box labelled "User Inputs". The parameters are:
    a. Discounting future values: To change the value used for discounting NPV and national energy savings, and the year in which to discount to.
    b. Relative Price Elasticity: To change value, use the drop-down arrow and select the desired impact (this parameter is not considered in the cooking products analysis).
    c. Economic Growth: To the change value, use the drop-down arrow and select the desired Growth level (Reference, Low, or High).

4. Once the parameters have been set, click the "Select CSL' button to choose which candidate standard level to analyze. The associated efficiency distributions and growth trends are fixed as specified in Chapter 10 of this preliminary technical support document.

5. The results are automatically updated and are reported in the summary table for each product class to the right of the "User Inputs" box.

APPENDIX 10-B. NATIONAL ENERGY SAVINGS AND NET PRESENT VALUE USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS

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APPENDIX 10-B. NATIONAL ENERGY SAVINGS AND NET PRESENT VALUE USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS

10-B.1 INTRODUCTION

This appendix presents national energy savings (NES) and net present value (NPV) results using inputs from alternative economic growth scenarios. The scenarios use the energy price and housing starts forecasts in the High Economic Growth case and the Low Economic Growth case from EIA's *Annual Energy Outlook 2010* (AEO 2010).[i]

Figures 10-B.1.1 and 10-B.1.2 show the forecasts for housing starts and residential electricity prices under the different economic growth scenarios. *AEO2010* provides a forecast to 2035. To estimate the trend after 2035, DOE followed guidelines that the EIA had provided to the Federal Energy Management Program, which called for using the average rate of change for electricity during 2025–2035.

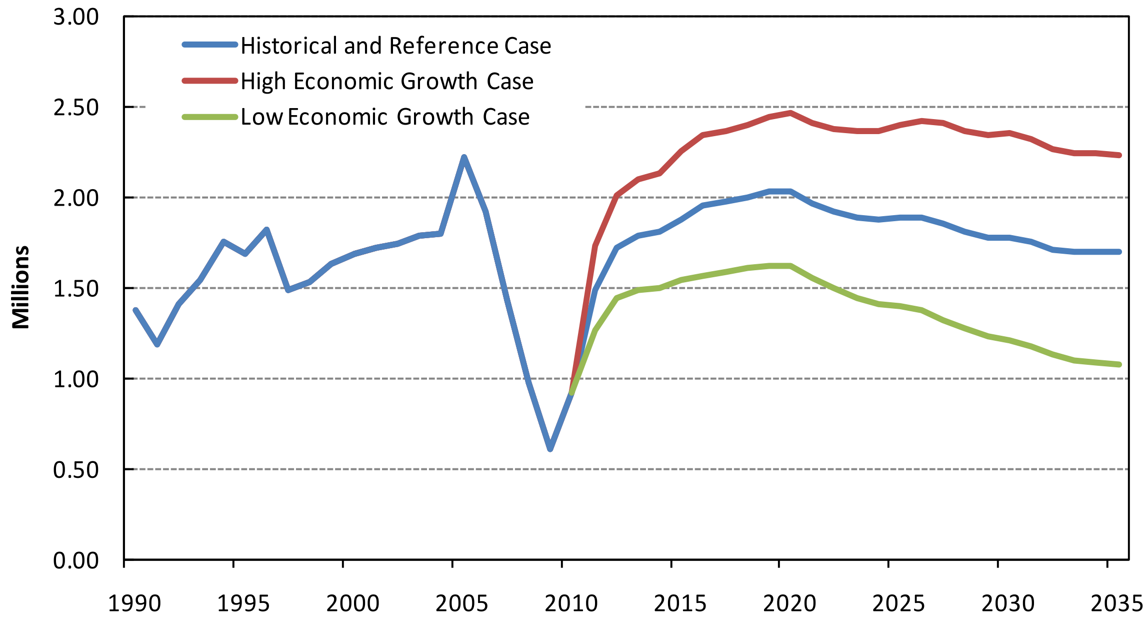

Figure 10-B.1.1 Housing Starts Forecast Under Alternative *AEO2010* Economic Growth Scenarios

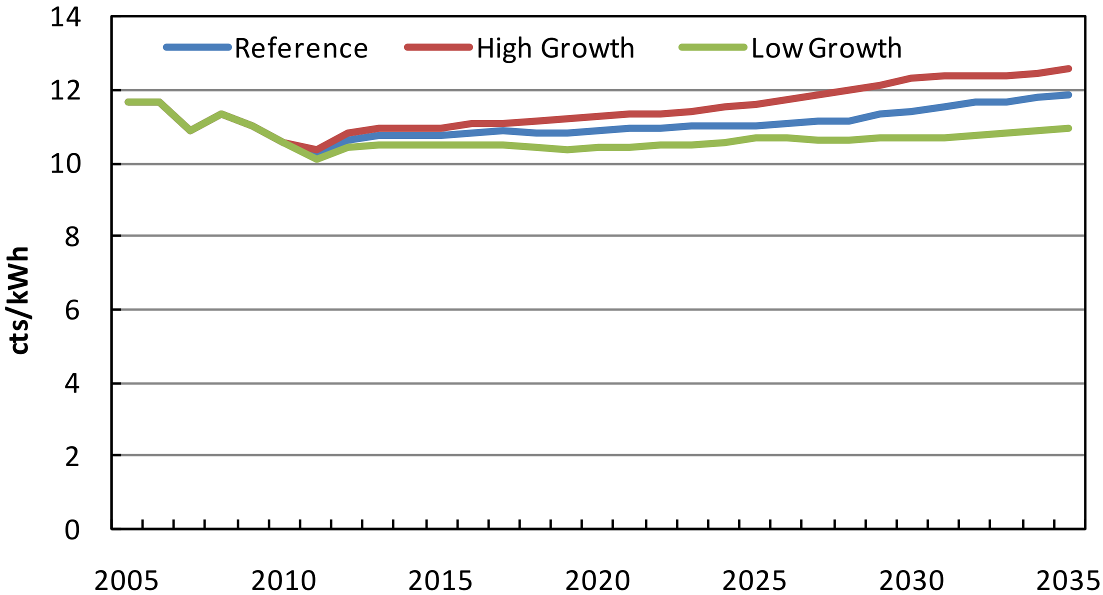

Figure 10-B.1.2 Average Residential Electricity Price Forecasts under Alternative *AEO2010* Economic Growth Scenarios

10-B.2 NIA RESULTS IN HIGH ECONOMIC GROWTH SCENARIO

10-B.2.1 NES Results in High Economic Growth Scenario

Table 10-B.2.1 Standard-Size Refrigerator-Freezers: Cumulative National Energy Savings in Quads, High Economic Growth Scenario

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	Product classes 5, 5A, and 5I	Product classes 4, 4I, and 7
1	1.72	0.10	0.57
2	1.72	0.10	0.94
3	2.21	0.10	0.94
4	2.66	0.48	1.28
5	3.09	0.70	1.48

Table 10-B.2.2 Standard-Size Freezers: Cumulative National Energy Savings in Quads, High Economic Growth Scenario

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
1	0.44	0.29
2	0.68	0.37
3	0.79	0.44
4	0.89	0.51
5	0.92	0.58

Table 10-B.2.3 Compact Refrigeration Products: Cumulative National Energy Savings in Quads, High Economic Growth Scenario

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
1	0.30	0.03
2	0.37	0.03
3	0.42	0.04
4	0.52	0.07
5	0.55	0.09

Table 10-B.2.4 Built-In Refrigeration Products: Cumulative National Energy Savings in Quads, High Economic Growth Scenario

Trial Standard Level	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
1	0.00	0.00	0.01	0.00
2	0.01	0.00	0.01	0.01
3	0.01	0.00	0.03	0.01
4	0.01	0.02	0.03	0.01
5	0.01	0.02	0.04	0.01

10-B.2.2 NPV Results in High Economic Growth Scenario

Table 10-B.2.5 Cumulative Net Present Value of Consumer Benefits for Standard-Size Refrigerator-Freezers, 3-Percent Discount Rate, High Economic Growth Scenario

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	Product classes 5, 5A, and 5I	Product classes 4, 4I, and 7
	billion 2009 dollars		
1	8.55	0.92	5.15
2	8.55	0.92	4.65
3	8.22	0.92	4.65
4	0.10	(3.05)	(1.44)
5	(13.10)	(7.25)	(6.66)

Table 10-B.2.6 Cumulative Net Present Value of Consumer Benefits for Standard-Size Refrigerator-Freezers, 7-Percent Discount Rate, High Economic Growth Scenario

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	Product classes 5, 5A, and 5I	Product classes 4, 4I, and 7
	billion 2009 dollars		
1	1.40	0.31	1.68
2	1.40	0.31	0.77
3	0.30	0.31	0.77
4	(4.93)	(2.45)	(3.09)
5	(12.78)	(5.07)	(6.23)

Table 10-B.2.7 Cumulative Net Present Value of Consumer Benefits for Standard-Size Freezers, 3-Percent Discount Rate, High Economic Growth Scenario

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
	billion 2009 dollars	
1	4.45	3.10
2	6.23	2.78
3	6.03	3.25
4	5.16	2.35
5	1.52	0.35

Table 10-B.2.8 Cumulative Net Present Value of Consumer Benefits for Standard-Size Freezers, 7-Percent Discount Rate, High Economic Growth Scenario

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
	billion 2009 dollars	

1	1.42	1.01
2	1.83	0.67
3	1.50	0.75
4	0.83	0.15
5	(1.19)	(1.08)

Table 10-B.2.9 Cumulative Net Present Value of Consumer Benefits for Compact Refrigeration Products, 3-Percent Discount Rate, High Economic Growth Scenario

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
	billion 2009 dollars	
1	1.54	0.19
2	0.99	0.19
3	1.16	0.16
4	(0.37)	(0.21)
5	(4.57)	(0.90)

Table 10-B.2.10 Cumulative Net Present Value of Consumer Benefits for Compact Refrigeration Products, 7-Percent Discount Rate, High Economic Growth Scenario

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
	billion 2009 dollars	
1	0.62	0.08
2	0.29	0.08
3	0.35	0.06
4	(0.50)	(0.17)
5	(2.76)	(0.58)

Table 10-B.2.11 Cumulative Net Present Value of Consumer Benefits for Built-In Refrigeration Products, 3-Percent Discount Rate, High Economic Growth Scenario

Trial Standard Level	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
	billion 2009 dollars			
1	0.04	0.02	0.05	0.05
2	0.05	0.01	0.05	0.05
3	(0.00)	0.01	(0.43)	(0.01)
4	(0.10)	(0.37)	(0.43)	(0.01)
5	(0.18)	(0.57)	(0.86)	(0.06)

Table 10-B.2.12 Cumulative Net Present Value of Consumer Benefits for Built-In Refrigeration Products, 7-Percent Discount Rate, High Economic Growth Scenario

Trial Standard Level	Built-in All Refrigerators (3A-BI)	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers (9-BI)
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
	billion 2009 dollars			
1	0.01	0.01	0.01	0.02
2	0.02	(0.00)	0.01	0.01
3	(0.02)	(0.00)	(0.29)	(0.03)
4	(0.07)	(0.22)	(0.29)	(0.03)
5	(0.12)	(0.33)	(0.53)	(0.06)

10-B.3 NIA RESULTS IN LOW ECONOMIC GROWTH SCENARIO

10-B.3.1 NES Results in Low Economic Growth Scenario

Table 10-B.3.1 Standard-Size Refrigerator-Freezers: Cumulative National Energy Savings in Quads, Low Economic Growth Scenario

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	Product classes 5, 5A, and 5I	Product classes 4, 4I, and 7
1	1.52	0.09	0.50
2	1.52	0.09	0.82
3	1.94	0.09	0.82
4	2.33	0.42	1.12
5	2.72	0.61	1.30

Table 10-B.3.2 Standard-Size Freezers: Cumulative National Energy Savings in Quads, Low Economic Growth Scenario

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
1	0.41	0.27
2	0.64	0.34
3	0.74	0.41
4	0.83	0.48
5	0.86	0.54

Table 10-B.3.3 Compact Refrigeration Products: Cumulative National Energy Savings in Quads, Low Economic Growth Scenario

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
1	0.25	0.03
2	0.31	0.03
3	0.35	0.04
4	0.43	0.07
5	0.45	0.09

Table 10-B.3.4 Built-In Refrigeration Products: Cumulative National Energy Savings in Quads, Low Economic Growth Scenario

Trial Standard Level	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
	Product class 3A-BI	**Product classes 5-BI and 5I-BI**	**Product classes 4-BI, 4I-BI and 7-BI**	**Product classes 9-BI and 9I-BI**
1	0.00	0.00	0.01	0.00
2	0.01	0.00	0.01	0.01
3	0.01	0.00	0.03	0.01
4	0.01	0.01	0.03	0.01
5	0.01	0.02	0.03	0.01

10-B.3.2 NPV Results in Low Economic Growth Scenario

Table 10-B.3.5 Cumulative Net Present Value of Consumer Benefits for Standard-Size Refrigerator-Freezers, 3-Percent Discount Rate, Low Economic Growth Scenario

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	**Product classes 5, 5A, and 5I**	**Product classes 4, 4I, and 7**
	billion 2009 dollars		
1	4.81	0.65	3.58
2	4.81	0.65	2.58
3	3.78	0.65	2.58
4	(4.00)	(3.39)	(3.26)
5	(16.18)	(7.40)	(8.10)

Table 10-B.3.6 Cumulative Net Present Value of Consumer Benefits for Standard-Size Refrigerator-Freezers, 7-Percent Discount Rate, Low Economic Growth Scenario

Trial Standard Level	Top-Mount Refrigerator-Freezers	Bottom-Mount Refrigerator-Freezers	Side-by-Side Refrigerator-Freezers
	Product classes 1, 1A, 2, 3, 3A, 3I and 6	Product classes 5, 5A, and 5I	Product classes 4, 4I, and 7
	billion 2009 dollars		
1	0.31	0.22	1.17
2	0.31	0.22	0.17
3	(0.91)	0.22	0.17
4	(5.77)	(2.41)	(3.41)
5	(12.92)	(4.83)	(6.28)

Table 10-B.3.7 Cumulative Net Present Value of Consumer Benefits for Standard-Size Freezers, 3-Percent Discount Rate, Low Economic Growth Scenario

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
	billion 2009 dollars	
1	3.33	2.35
2	4.55	1.92
3	4.16	2.21
4	3.18	1.26
5	(0.25)	(0.72)

Table 10-B.3.8 Cumulative Net Present Value of Consumer Benefits for Standard-Size Freezers, 7-Percent Discount Rate, Low Economic Growth Scenario

Trial Standard Level	Upright Freezers	Chest Freezers
	Product classes 8, 9 and 9I	Product classes 10 and 10A
	billion 2009 dollars	

1	1.07	0.77
2	1.31	0.41
3	0.93	0.44
4	0.25	(0.16)
5	(1.66)	(1.35)

Table 10-B.3.9 Cumulative Net Present Value of Consumer Benefits for Compact Refrigeration Products, 3-Percent Discount Rate, Low Economic Growth Scenario

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
	billion 2009 dollars	
1	0.96	0.15
2	0.41	0.15
3	0.50	0.11
4	(0.89)	(0.29)
5	(4.38)	(1.02)

Table 10-B.3.10 Cumulative Net Present Value of Consumer Benefits for Compact Refrigeration Products, 7-Percent Discount Rate, Low Economic Growth Scenario

Trial Standard Level	Compact Refrigerators	Compact Freezers
	Product classes 11, 11A, 12, 13, 13I, 13A, 14, 14I, 15 and 15I	Product classes 16, 17, 18
	billion 2009 dollars	
1	0.39	0.07
2	0.07	0.07
3	0.10	0.03
4	(0.67)	(0.20)
5	(2.58)	(0.62)

Table 10-B.3.11 Cumulative Net Present Value of Consumer Benefits for Built-In Refrigeration Products, 3-Percent Discount Rate, Low Economic Growth Scenario

Trial Standard Level	Built-in All Refrigerators	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
	billion 2009 dollars			
1	0.03	0.01	0.03	0.04
2	0.04	(0.00)	0.03	0.03
3	(0.01)	(0.00)	(0.43)	(0.03)
4	(0.10)	(0.35)	(0.43)	(0.03)
5	(0.17)	(0.52)	(0.81)	(0.08)

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Table 10-B.3.12 Cumulative Net Present Value of Consumer Benefits for Built-In Refrigeration Products, 7-Percent Discount Rate, Low Economic Growth Scenario

Trial Standard Level	Built-in All Refrigerators (3A-BI)	Built-in Bottom-Mount Refrigerator-Freezers	Built-in Side-by-Side Refrigerator-Freezers	Built-in Upright Freezers (9-BI)
	Product class 3A-BI	Product classes 5-BI and 5I-BI	Product classes 4-BI, 4I-BI and 7-BI	Product classes 9-BI and 9I-BI
	billion 2009 dollars			
1	0.01	0.01	0.00	0.01
2	0.01	(0.01)	0.00	(0.00)
3	(0.02)	(0.01)	(0.27)	(0.04)
4	(0.07)	(0.20)	(0.27)	(0.04)
5	(0.11)	(0.31)	(0.49)	(0.07)

REFERENCES

[i] U.S. Department of Energy–Energy Information Administration. *Annual Energy Outlook 2010 with Projections to 2035*. April 2010. U.S. DOE–EIA: Washington, D.C. DOE/EIA-0383(2010).

APPENDIX 10-C. NATIONAL NET PRESENT VALUE USING ALTERNATIVE PRODUCT PRICE FORECASTS

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APPENDIX 10-C. NATIONAL NET PRESENT VALUE USING ALTERNATIVE PRODUCT PRICE FORECASTS

10-C.1 INTRODUCTION

The NPV results presented in chapter 10 reflect a price trend based on an experience curve derived using historical data on shipments and refrigeration equipment PPI. The average annual rate of price decline in the default case is 1.87 percent. For the NIA, DOE also analyzed two sensitivity cases that use a price trend based on an exponential in time extrapolation of refrigeration equipment PPI data. DOE selected a high price decline case and a low price decline case from among a number of price trends that it analyzed (see appendix 8E of the final rule TSD). The high price decline case is based on the upper end of the 95 percent confidence interval for an exponential fit to the inflation-adjusted PPI series in 1991-2010. The low price decline case is based on the lower end of the 95 percent confidence interval for an exponential fit to the nominal PPI series in 1976-2010. The annual rate of price decline is 3.12 percent in the high price decline case and 1.14 percent in the low price decline case.

The results presented in this appendix combine the NPV of the consumer savings, calculated for each TSL using 3 and 7 percent discount rates, with the present value of the potential economic benefits resulting from reduced CO_2 and NO_X emissions. For these results, the economic benefits from reduced CO_2 emissions were calculated using a SCC value of $22.1/metric ton in 2010 (in 2009$) for CO_2, increasing at 3% per year, and a discount rate of 3%. The economic benefits from reduced NO_X emissions were calculated using a value of $2,519/ton (in 2009$), which is the average of the low and high values used in DOE's analysis, and either a 3% or 7% discount rate. See chapter 16 for information regarding the derivation of these values. All results refer to lifetime impacts of products shipped in 2014-2043.

The results presented here are annualized values. DOE used a two-step calculation process to convert the time-series of costs and benefits into annualized values. First, DOE calculated a present value in 2011, the year used for discounting the NPV of total consumer costs and savings, for the time-series of costs and benefits using discount rates of three and seven percent for all costs and benefits except for the value of CO_2 reductions. For the latter, DOE used the discount rate appropriate for each SCC time series. From the present value, DOE then calculated the fixed annual payment over a 30-year period, starting in 2011, that yields the same present value. The fixed annual payment is the annualized value. Although DOE calculated annualized values, this does not imply that the time-series of cost and benefits from which the annualized values were determined would be a steady stream of payments.

10-C.2 STANDARD-SIZE REFRIGERATOR-FREEZERS: COMBINED NPV RESULTS USING ALTERNATIVE PRICE TREND SENSITIVITIES

Table 10-C.2.1 Standard-Size Refrigerator-Freezers: Annualized Present Value of Consumer Impacts (3 Percent Discount Rate) and Annualized Present Value of Monetized Benefits from CO_2 and NO_X Emissions Reductions (3 Percent Discount Rate)

Trial Standard Level		Default	Large Price Decline	Small Price Decline
		Billion 2009$		
1	Incr. Installed Cost	9.831	8.307	11.689
	Operating Cost Savings	27.652	27.652	27.652
	Value of Emissions Reductions	4.850	4.850	4.850
	Net Present Value	22.671	24.195	20.813
2	Incr. Installed Cost	12.982	10.957	15.449
	Operating Cost Savings	31.712	31.712	31.712
	Value of Emissions Reductions	5.594	5.594	5.594
	Net Present Value	24.325	26.350	21.857
3	Incr. Installed Cost	17.215	14.530	20.488
	Operating Cost Savings	37.406	37.406	37.406
	Value of Emissions Reductions	6.578	6.578	6.578
	Net Present Value	26.769	29.455	23.496
4	Incr. Installed Cost	38.395	32.351	45.748
	Operating Cost Savings	50.548	50.548	50.548
	Value of Emissions Reductions	8.968	8.968	8.968
	Net Present Value	21.120	27.165	13.768
5	Incr. Installed Cost	59.968	50.479	71.502
	Operating Cost Savings	60.149	60.149	60.149
	Value of Emissions Reductions	10.725	10.725	10.725
	Net Present Value	10.906	20.396	-0.627

Table 10-C.2.2 Standard-Size Refrigerator-Freezers: Annualized Present Value of Consumer Impacts (7 Percent Discount Rate) and Annualized Present Value of Monetized Benefits from CO_2 and NO_X Emissions Reductions (Discount Rate of 3% for CO_2 and 7% for NO_X)

Trial Standard Level		**Default**	**Large Price Decline**	**Small Price Decline**
		Billion 2009$		
1	Incr. Installed Cost	5.639	4.906	6.574
	Operating Cost Savings	10.846	10.846	10.846
	Value of Emissions Reductions	4.701	4.701	4.701
	Net Present Value	9.908	10.641	8.973
2	Incr. Installed Cost	7.418	6.446	8.655
	Operating Cost Savings	12.419	12.419	12.419
	Value of Emissions Reductions	5.422	5.422	5.422
	Net Present Value	10.423	11.395	9.186
3	Incr. Installed Cost	9.835	8.546	11.476
	Operating Cost Savings	14.649	14.649	14.649
	Value of Emissions Reductions	6.375	6.375	6.375
	Net Present Value	11.190	12.479	9.549
4	Incr. Installed Cost	21.815	18.925	25.486
	Operating Cost Savings	19.730	19.730	19.730
	Value of Emissions Reductions	8.692	8.692	8.692
	Net Present Value	6.607	9.497	2.936
5	Incr. Installed Cost	33.958	29.430	39.705
	Operating Cost Savings	23.404	23.404	23.404
	Value of Emissions Reductions	10.395	10.395	10.395
	Net Present Value	-0.159	4.369	-5.906

10-C.3 STANDARD-SIZE FREEZERS: COMBINED NPV RESULTS USING ALTERNATIVE PRICE TREND SENSITIVITIES

Table 10-C.3.1 Standard-Size Freezers: Annualized Present Value of Consumer Impacts (3 Percent Discount Rate) and Annualized Present Value of Monetized Benefits from CO_2 and NO_X Emissions Reductions (3 Percent Discount Rate)

Trial Standard Level		Default	Large Price Decline	Small Price Decline
		Billion 2009$		
1	Incr. Installed Cost	1.445	1.221	1.719
	Operating Cost Savings	9.723	9.723	9.723
	Value of Emissions Reductions	1.586	1.586	1.586
	Net Present Value	9.864	10.088	9.590
2	Incr. Installed Cost	3.339	2.818	3.975
	Operating Cost Savings	14.033	14.033	14.033
	Value of Emissions Reductions	2.279	2.279	2.279
	Net Present Value	12.972	13.493	12.336
3	Incr. Installed Cost	4.751	4.008	5.657
	Operating Cost Savings	16.384	16.384	16.384
	Value of Emissions Reductions	2.684	2.684	2.684
	Net Present Value	14.317	15.060	13.411
4	Incr. Installed Cost	7.170	6.046	8.539
	Operating Cost Savings	18.197	18.197	18.197
	Value of Emissions Reductions	3.046	3.046	3.046
	Net Present Value	14.073	15.197	12.704
5	Incr. Installed Cost	11.880	10.012	14.157
	Operating Cost Savings	19.477	19.477	19.477
	Value of Emissions Reductions	3.255	3.255	3.255
	Net Present Value	10.851	12.719	8.575

Table 10-C.3.2 Standard-Size Freezers: Annualized Present Value of Consumer Impacts (7 Percent Discount Rate) and Annualized Present Value of Monetized Benefits from CO_2 and NO_X Emissions Reductions (Discount Rate of 3% for CO_2 and 7% for NO_X)

Trial Standard Level		**Default**	**Large Price Decline**	**Small Price Decline**
		Billion 2009$		
1	Incr. Installed Cost	0.828	0.720	0.965
	Operating Cost Savings	3.642	3.642	3.642
	Value of Emissions Reductions	1.537	1.537	1.537
	Net Present Value	4.350	4.458	4.213
2	Incr. Installed Cost	1.906	1.655	2.225
	Operating Cost Savings	5.248	5.248	5.248
	Value of Emissions Reductions	2.208	2.208	2.208
	Net Present Value	5.550	5.801	5.231
3	Incr. Installed Cost	2.708	2.352	3.163
	Operating Cost Savings	6.123	6.123	6.123
	Value of Emissions Reductions	2.601	2.601	2.601
	Net Present Value	6.016	6.373	5.562
4	Incr. Installed Cost	4.081	3.542	4.768
	Operating Cost Savings	6.796	6.796	6.796
	Value of Emissions Reductions	2.951	2.951	2.951
	Net Present Value	5.665	6.205	4.979
5	Incr. Installed Cost	6.744	5.847	7.885
	Operating Cost Savings	7.261	7.261	7.261
	Value of Emissions Reductions	3.154	3.154	3.154
	Net Present Value	3.670	4.567	2.529

10-C.4 COMPACT REFRIGERATION PRODUCTS: COMBINED NPV RESULTS USING ALTERNATIVE PRICE TREND SENSITIVITIES

Table 10-C.4.1 Compact Refrigeration Products: Annualized Present Value of Consumer Impacts (3 Percent Discount Rate) and Annualized Present Value of Monetized Benefits from CO_2 and NO_X Emissions Reductions (3 Percent Discount Rate)

Trial Standard Level		Default	Large Price Decline	Small Price Decline
		Billion 2009$		
1	Incr. Installed Cost	0.845	0.706	1.013
	Operating Cost Savings	2.651	2.651	2.651
	Value of Emissions Reductions	0.436	0.436	0.436
	Net Present Value	2.242	2.381	2.075
2	Incr. Installed Cost	1.646	1.376	1.972
	Operating Cost Savings	3.264	3.264	3.264
	Value of Emissions Reductions	0.536	0.536	0.536
	Net Present Value	2.153	2.424	1.828
3	Incr. Installed Cost	1.950	1.631	2.334
	Operating Cost Savings	3.784	3.784	3.784
	Value of Emissions Reductions	0.621	0.621	0.621
	Net Present Value	2.455	2.774	2.071
4	Incr. Installed Cost	3.879	3.254	4.634
	Operating Cost Savings	4.680	4.680	4.680
	Value of Emissions Reductions	0.780	0.780	0.780
	Net Present Value	1.582	2.207	0.826
5	Incr. Installed Cost	7.387	6.226	8.802
	Operating Cost Savings	5.053	5.053	5.053
	Value of Emissions Reductions	0.858	0.858	0.858
	Net Present Value	-1.476	-0.314	-2.890

Table 10-C.4.2 Compact Refrigeration Products: Annualized Present Value of Consumer Impacts (7 Percent Discount Rate) and Annualized Present Value of Monetized Benefits from CO_2 and NO_X Emissions Reductions (Discount Rate of 3% for CO_2 and 7% for NO_X)

Trial Standard Level		Default	Large Price Decline	Small Price Decline
		Billion 2009$		
1	Incr. Installed Cost	0.468	0.403	0.550
	Operating Cost Savings	1.224	1.224	1.224
	Value of Emissions Reductions	0.423	0.423	0.423
	Net Present Value	1.179	1.244	1.098
2	Incr. Installed Cost	0.913	0.786	1.071
	Operating Cost Savings	1.510	1.510	1.510
	Value of Emissions Reductions	0.520	0.520	0.520
	Net Present Value	1.118	1.244	0.960
3	Incr. Installed Cost	1.084	0.935	1.272
	Operating Cost Savings	1.754	1.754	1.754
	Value of Emissions Reductions	0.603	0.603	0.603
	Net Present Value	1.273	1.422	1.085
4	Incr. Installed Cost	2.175	1.880	2.547
	Operating Cost Savings	2.184	2.184	2.184
	Value of Emissions Reductions	0.757	0.757	0.757
	Net Present Value	0.766	1.061	0.394
5	Incr. Installed Cost	4.198	3.642	4.906
	Operating Cost Savings	2.394	2.394	2.394
	Value of Emissions Reductions	0.833	0.833	0.833
	Net Present Value	-0.970	-0.414	-1.678

10-C.5 BUILT-IN REFRIGERATION PRODUCTS: COMBINED NPV RESULTS USING ALTERNATIVE PRICE TREND SENSITIVITIES

Table 10-C.5.1 Built-in Refrigeration Products: Annualized Present Value of Consumer Impacts (3 Percent Discount Rate) and Annualized Present Value of Monetized Benefits from CO_2 and NO_X Emissions Reductions (3 Percent Discount Rate)

Trial Standard Level		Default	Large Price Decline	Small Price Decline
		Billion 2009$		
1	Incr. Installed Cost	0.054	0.046	0.065
	Operating Cost Savings	0.230	0.230	0.230
	Value of Emissions Reductions	0.040	0.040	0.040
	Net Present Value	0.216	0.224	0.205
2	Incr. Installed Cost	0.124	0.104	0.147
	Operating Cost Savings	0.330	0.330	0.330
	Value of Emissions Reductions	0.058	0.058	0.058
	Net Present Value	0.265	0.284	0.241
3	Incr. Installed Cost	0.735	0.619	0.877
	Operating Cost Savings	0.649	0.649	0.649
	Value of Emissions Reductions	0.116	0.116	0.116
	Net Present Value	0.029	0.145	-0.112
4	Incr. Installed Cost	1.134	0.955	1.351
	Operating Cost Savings	0.770	0.770	0.770
	Value of Emissions Reductions	0.143	0.143	0.143
	Net Present Value	-0.220	-0.042	-0.437
5	Incr. Installed Cost	1.737	1.463	2.071
	Operating Cost Savings	0.932	0.932	0.932
	Value of Emissions Reductions	0.171	0.171	0.171
	Net Present Value	-0.634	-0.360	-0.967

Table 10-C.5.2 Built-in Refrigeration Products: Annualized Present Value of Consumer Impacts (7 Percent Discount Rate) and Annualized Present Value of Monetized Benefits from CO_2 and NO_X Emissions Reductions (Discount Rate of 3% for CO_2 and 7% for NO_X)

Trial Standard Level		Default	Large Price Decline	Small Price Decline
		Billion 2009$		
1	Incr. Installed Cost	0.031	0.027	0.036
	Operating Cost Savings	0.089	0.089	0.089
	Value of Emissions Reductions	0.039	0.039	0.039
	Net Present Value	0.097	0.101	0.092
2	Incr. Installed Cost	0.071	0.061	0.082
	Operating Cost Savings	0.127	0.127	0.127
	Value of Emissions Reductions	0.056	0.056	0.056
	Net Present Value	0.113	0.122	0.101
3	Incr. Installed Cost	0.417	0.362	0.487
	Operating Cost Savings	0.250	0.250	0.250
	Value of Emissions Reductions	0.112	0.112	0.112
	Net Present Value	-0.055	0.001	-0.125
4	Incr. Installed Cost	0.644	0.559	0.753
	Operating Cost Savings	0.298	0.298	0.298
	Value of Emissions Reductions	0.139	0.139	0.139
	Net Present Value	-0.208	-0.122	-0.316
5	Incr. Installed Cost	0.986	0.855	1.152
	Operating Cost Savings	0.361	0.361	0.361
	Value of Emissions Reductions	0.166	0.166	0.166
	Net Present Value	-0.459	-0.329	-0.625

APPENDIX 12-A. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDES

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APPENDIX 12-A MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDES

12-A.1 RESIDENTIAL REFRIGERATION PRODUCTS MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

January 13, 2010

The Department of Energy (DOE) conducts the manufacturer impact analysis (MIA) as part of the rulemaking process for amended energy conservation standards for refrigerators, refrigerator-freezers, and freezers. In this analysis, DOE uses publicly available information and information provided by manufacturers during interviews to assess possible impacts on manufacturers due to amended energy conservation standards.

DOE explicitly analyzes the seven product classes in the tables below. For all product classes, DOE is currently considering eight efficiency levels (ELs) that correspond to percentage improvements over the existing standards. In responding to this questionnaire, please refer to the efficiency levels in the table below. DOE explains how it intends to determine the minimum efficiencies for the remaining product classes in the engineering chapter of the technical support document.[1]

Baseline Efficiencies for Analyzed Product Classes

Product Class Number	Product Type	Product Class Description	Equation for maximum energy use (kWh/yr))*
3	**Refrigerator-Freezers**	Automatic Defrost with Top-Mounted Freezer Without Through the Door (TTD) Ice Service	10.72 AV + 310.2
5	**Refrigerator-Freezers**	Automatic Defrost with Bottom-Mounted Freezer Without TTD Ice Service	5.32 AV + 542.5
7	**Refrigerator-Freezers**	Automatic Defrost with Side-Mounted Freezer With TTD Ice Service	11.33 AV + 462.8
9	**Freezers**	Upright Freezers with Automatic Defrost	12.32 AV + 326.1
10	**Freezers**	Chest Freezers and all Other Freezers Except Compact Freezers	9.71 AV + 143.7
11	**Compact Refrigerators and Freezers**	Compact Refrigerators and Refrigerator-Freezers with Manual Defrost	12.04 AV + 336.4
18	**Compact Refrigerators and Freezers**	Compact Chest Freezers	10.27 AV + 152

AV= adjusted volume in cubic feet
* These definitions are based on testing according to the current energy test procedure. DOE expects to propose revisions in the energy test procedure to harmonize with expected test temperatures under consideration for IEC test procedure 62552 and will adjust the equations accordingly. However, for the purpose of identifying the efficiency levels of products in the table below, it is assumed that the percent efficiency level (i.e. the difference between baseline energy use and improved product energy use divided by baseline energy use and multiplied by 100%) does not depend on which test procedure is used to determine energy use.

Efficiency Levels Under Consideration for all Product Classes

Percentage Decrease in kWh/yr from Calculated Baseline Efficiency							
EL 1	**EL 2**	**EL 3**	**EL 4**	**EL 5**	**EL 6**	**EL 7**	**EL 8**
10%	15%	20%	25%	30%	35%	40%	45%

[1] Please see http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers_prelim_tsd_mtg.html for a complete description.

1 KEY ISSUES

1.1 In general, what are the key issues for your company regarding amended energy conservation standards for residential refrigeration products and this rulemaking?

1.2 For the issues identified, does the severity change for different product classes? Do some issues become more significant at higher efficiency levels? Are certain issues more of a concern for certain product classes?

1.3 How can DOE most effectively incorporate these issues in the MIA?

2 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to residential refrigeration production. However, the context within which the plant operates and the details of plant production and costs are not always readily available from public sources. Therefore, DOE invites you to provide these details confidentially in your own words to the extent possible and practical. Understanding the organizational setting around the residential refrigeration industry profit center will help DOE understand the probable future of the manufacturing activity with and without amended energy conservation standards.

2.1 Do you have a parent company, and/or any subsidiaries relevant to the residential refrigeration industry?

2.2 Do you manufacture any products other than residential refrigeration products? If so, what other products do you manufacture? What percentage of your total manufacturing revenue corresponds to residential refrigeration products?

2.3 What product classes of refrigeration products do you manufacturer?

2.4 Where are your residential refrigeration production facilities located, and what types of products are manufactured at each location? Could you provide annual shipment figures for your company's residential refrigeration manufacturing at each location by product line (i.e., top-mount refrigerator-freezers, bottom-mount refrigerator-freezers, etc.)?

2.5 At your manufacturing facilities, would potential residential refrigeration product redesigns be difficult to implement? If so, would your company modify the existing facility or develop a new facility?

2.6 What are your employment levels at each of these facilities?

2.7 What is your company's approximate market share in the standard-size refrigerator-freezer, standard-size freezer, and compact refrigerator and freezers markets?

3 ENGINEERING AND LIFE CYCLE COST ANALYSIS FOLLOW-UP

3.1 For the products directly analyzed for the Engineering Analysis that represent the bulk of residential refrigeration product sales, can you comment on the progressive use of design options for achieving the successively higher efficiency levels (compared with the design option information presented by efficiency level in Appendix 5A of the preliminary TSD)?

3.2 Are the incremental design option costs used in the Engineering Analysis and described in Chapter 5 of the preliminary TSD representative of costs your company pays for these design options? If not, please provide a quantitative indication of the differences.

3.3 How would the cost-efficiency curves of low-production-volume product classes differ from those developed for the directly-analyzed product classes most closely related to them? The table below provides an indication of expectations for representation of low-volume product classes. Please comment for your key products of the low-volume product classes.

Low-volume Product Classes	1A, 1, 2, 3A	4	5A	6	8	10A	11A, 12, 13, 13A, 14, 15	16,17
Representative Product Class	3	7	5	3	10	9	11	18

3.4 Do you sell any standard-size all-refrigerators with manual (not off-cycle) defrost?

3.5 Do you sell any compact upright freezers with automatic defrost (PC 17)? If so, can you describe your product line(s) for this class and provide shipment estimates?

3.6 Do you have warrantee and/or maintenance cost data illustrating the impact of any of the following design options on maintenance cost: electronic controls, high-efficiency single-speed compressors, variable-speed compressors, brushless DC fans, VIPs, and humidity sensors?

3.7 What are the expected differences in cost per unit area of VIP applied to a product between application to the door and application to the cabinet? Are these costs differences for labor costs, material costs, capital costs, or other types of costs?

3.8 What is your company's level of operation (by shipment volume) in other world markets where significant reductions in energy use have been or are expected to be mandated, particularly India and the EU?

3.9 How would repair and maintenance costs be impacted by more stringent energy conservation standards? How would the frequency of repair and maintenance be affected? How would the nature of the repair and maintenance work needed change with more stringent energy conservation standards?

3.10 Can you provide any information on consumer placement of built-in undercounter products and built-in upright freezers and on implications of possible wall thickness increases?

3.11 For standard size refrigerator-freezers, what percent reduction in internal volume would you implement prior to use of VIPs in order to maintain external dimensions?

3.12 Which product classes might be candidates for energy/adjusted volume curve slope changes? Do you have any information that would inform DOE's development of a response to this issue?

3.13 What information can be provided to provide a better understanding of the variation of costs to achieve efficiency levels? What information can be provided to provide a better understanding of how cost-efficiency curves for the low-volume product classes not directly analyzed are different?

3.14 What platform differences exist between product class 4 and product class 7? Between product class 6 and product class 3? Between product class 5 and product class 5A?

3.15 Can you provide engineering details for baseline efficiency built-in units and ENERGY STAR built-in units, such as typical wall thickness, insulation used, evaporator and condenser description, fan types and wattages, and compressor model or capacity? Can you provide specific data for a representative model for each applicable product class?

3.16 Do you see any possible loopholes in the proposed AHAM built-in definition? "Refrigerators, freezers and refrigerators with freezer units that are 7.75 cubic feet or greater; are totally encased by cabinetry or panels by either accepting a custom front panel or being equipped with an integral factory-finished face; are intended to be securely fastened to adjacent cabinetry, walls or floor; has sides which are not fully finished and are not intended to be visible after installation."

3.17 Can you provide any data showing how much of the expected benefits of VIPs are actually achieved in prototypes or manufactured products? Can you provide any data regarding panel failures in the field? Can you provide any data on scrap rates at the factory (what percentage of delivered VIPs must be scrapped)? Can you provide any data regarding resistivity decline of "good" panels over a span of years up to typical product lifetime?

3.18 How do the design option costs for your company compare to the values DOE used in its analysis as described in the preliminary TSD?

3.19 How do the bulk materials costs for your company compare to the values DOE used in its analysis as described in the preliminary TSD?

3.20 For variable anti-sweat heaters, what is the typical maximum wattage for a French door product and what is a typical control algorithm?

3.21 For variable defrost used with single-compressor/dual-evaporator systems, is it common to have more than one defrost cycle? How is this treated in the energy test? For products with more than one defrost cycle, do the defrost cycles ever overlap?

4 MARKUPS AND PROFITABILITY

DOE estimated the manufacturer production costs for the seven analyzed product classes of refrigeration products. DOE defines manufacturer production cost as all direct costs associated with manufacturing a product. It includes direct labor, direct materials, and overhead (which includes depreciation costs).

Manufacturer selling price is the average cost manufacturers charge their first consumers, but does not include additional costs along the distribution channels. The manufacturer selling price includes non-production costs including research and development; selling, general, and administrative expenses; shipping cost; and profit. The manufacturer markup is a multiplier applied to manufacturer production cost to cover these non-production costs and yield a profit. DOE estimated a baseline markup of 1.26 for refrigeration products.

One of the primary objectives of the MIA is to assess the impact of amended energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how setting an amended energy conservation standard would impact your company's markup structure and profitability.

4.1 Is there a significant difference between the baseline markup DOE calculated and your company's baseline markups for standard-size refrigerator-freezers, standard-size freezers, and compact refrigerators and freezers? Is the 1.26 baseline markup factor representative of an average industry markup?

4.2 Do profit levels currently vary by product class or product line?

4.3 DOE would like to understand how the baseline manufacturer markup changes at higher efficiency levels. Do you currently earn a premium for more efficient products (i.e., ENERGY STAR or higher)? Please explain why or why not.

4.4 Does your markup change with selected design options? Is the markup on incremental costs for more efficient designs different than the markup on the baseline models (as is assumed for retailer markups used in the analyses)?

4.5 Would you expect changes in your estimated profitability following an amended energy conservation standard? If so, please explain why.

5 SHIPMENT PROJECTIONS

An amended energy conservation standard can change overall shipments by altering product attributes, marketing approaches, product availability, and prices. The industry revenue calculations are based on the shipment projections developed in DOE's shipments model. The shipments model includes forecasts for the base case shipments (i.e., total industry shipments absent amended energy conservation standards) and the standards case shipments (i.e., total industry shipments with amended energy conservation standards).

To determine efficiency distributions after the effective date of the standard, DOE used a "roll-up + market shift" scenario for 2014 and subsequent years. DOE assumed that product efficiencies in the base case that did not meet the standard under consideration would roll up to meet the new standard in 2014. DOE further assumed that the ENERGY STAR program would continue to promote efficient appliances after revised standards are introduced in 2014, resulting in a gradual market shift to higher efficiencies after the compliance date of the standard.

5.1 How do you think amended energy conservation standards will impact the sales of more efficient products? For example, would customers continue to buy products that exceed the energy conservation standard level? Would your response change for higher mandated efficiency levels?

5.2 DOE assumed that revised standards would cause product purchase prices to increase, resulting in reduced demand or shipments (price elasticity effect). DOE assumed an elasticity coefficient of -0.40, meaning a 10% increase in price would result in a 4% decrease in shipments. Do you agree with this assumption? How sensitive do you think shipments will be to price changes? Does it vary with product class?

6 FINANCIAL PARAMETERS

DOE's contractor has developed a "strawman" model of the residential refrigeration products industry financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. This section attempts to understand how your company's financial situation differs from the industry aggregate picture.

6.1 Please compare your financial parameters to the GRIM parameters tabulated below.

Table 6.1 Financial Parameters for Residential Refrigeration Product Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual (If Significantly Different from DOE's Estimate)
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	33.9	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	7.2	
Working Capital	Current assets less current liabilities (percentage of revenues)	2.9	
Net PPE	Net plant property and equipment (percentage of revenues)	19.9	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	12.5	
R&D	Research and development expenses (percentage of revenues)	2.2	
Depreciation	Amortization of fixed assets (percentage of revenues)	3.4	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	3.5	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	79.4	

6.2 Are the figures in Table 6.1 representative of residential refrigeration manufacturing?

6.3 Do any of the financial parameters in Table 6.1 change based on product type or product class? Please describe any differences.

6.4 How would you expect an amended energy conservation standard to impact any of the financial parameters for the industry?

7 CONVERSION COSTS

Amended energy conservation standards may cause your company to incur capital and product conversion costs to redesign existing products and make changes to existing production lines to be compliant with the amended energy conservation standard. Capital conversion costs are one-time investments in plant, property, and equipment (PPE) necessitated by an amended energy conservation standard. These may be incremental changes to existing PPE or the replacement of existing PPE. In addition to capital conversion costs, product conversion costs are costs related research, product development, testing, marketing and other costs for redesigning products necessitated by an amended energy conservation standard. Depending on their magnitude, the conversion costs can have a substantial impact on the outputs used by DOE to evaluate the industry impacts. Understanding the nature and magnitude of the conversion costs is critical

portion of the MIA. Table 7.1 shows the design options used to research higher efficiencies for the major product categories covered by this rulemaking. Please refer to Table 7.1 when considering your response to the following questions.

Table 7.1 Design Options Used to Improve Efficiency for each Major Product Category

Product Type	Design Options
Top-Mount Refrigerator-Freezers	More efficient compressors, larger evaporators, larger condensers, brushless DC fan motors, adaptive defrost, and VIPs in the cabinet
Side-Mount Refrigerator-Freezers	More efficient compressors, brushless DC fan motors, adaptive defrost, larger evaporators, larger condensers, VIPs in the cabinet, VIPs in the door, and variable speed compressors
Bottom-Mount Refrigerator-Freezers	More efficient compressors, brushless DC fan motors, variable anti-sweat heater control, adaptive defrost, larger condensers, larger evaporators, and VIPs in the cabinet
Upright Freezers	Brushless DC fan motors, thicker insulation, adaptive defrost, more efficient compressors, larger evaporators, forced convection condensers, VIPs in the cabinet, and VIPs in the door
Chest Freezers	Larger condensers, larger evaporators, thicker insulation, more efficient compressors, variable speed compressors, VIPs in the bottom wall, and VIPs in the door
Compact Refrigerator-Freezers	Larger evaporators, thicker insulation, more efficient compressors, larger condensers, VIPs in the cabinet, and VIPs in the door
Compact Chest Freezers	More efficient compressors, thicker insulation, VIPs in the bottom wall, and variable speed compressors

7.1 Are there certain efficiency levels for which the design changes would require relatively minor changes to existing products? Are there certain efficiency levels where the capital or product conversion costs significantly increase? Would your answer change for different product categories? Please describe these changes qualitatively.

7.2 For each of the product categories shown in Table 7.1, which design options could be made within existing cabinet designs and which would result in major product redesigns?

7.3 For the design options in Table 7.1, what kind of changes would need to be implemented to production lines for each major product category? How much would these changes and other capital expenses cost?

7.4 Would the changes in 7.3 be similar across all of your production lines and factories for each product category?

7.5 For each of the product categories, please qualify the number of and cost of new production equipment, molds, foaming fixtures, etc. that would be required to implement the specified design changes. Please consider which design changes would require changes to existing cavity designs/wrapper shells.

7.6 What level of product development and other product conversion costs would you expect to incur for each of these design changes for each major product category?

7.7 For any design changes that would require new production equipment, please describe how much downtime would be required. What impact would downtime have on your business? Are there any design changes that could not be implemented before the compliance date of the final rule for certain product classes?

7.8 Please provide additional qualitative information to help DOE understand the types and nature of your investments, including the plant and tooling changes and the product development effort required at different efficiency levels.

8 CUMULATIVE REGULATORY BURDEN

Cumulative regulatory burden refers to the burden that industry faces from overlapping effects of new or revised DOE standards, voluntary standards, and/or other regulatory actions affecting the same product or industry.

8.1 Are there other recent or impending regulations that residential refrigeration manufacturers face (from DOE or otherwise)? If so, could you identify the regulation and the corresponding possible effective dates for those regulations? Below is a list of regulations that could possibly affect manufacturers of residential refrigerators, refrigerator-freezers, and freezers. Please provide any comments on the listed regulations in addition to other regulations.

Table 8.1 Other Regulations Identified by DOE

Regulation	Estimated or Actual Effective Date(s)	Comments
DOE's Energy Conservation Standards for Other Products and Equipment		
International Energy-Efficiency Standards		
Climate Change Legislation limiting or banning hydrofluorocarbons (discussed in section 9)		

8.2 What level of expense are you expecting to incur as a result of these regulations?

8.3 Under what circumstances would you be able to coordinate any expenditure related to these other regulations with an amended energy conservation standard, thereby lessening the cumulative burden?

8.4 DOE research has identified the production tax credits in Table 8.2 for manufacturers of residential refrigeration products. Similar tax credits have also been proposed in the current version of the House energy bill. Has your company received benefit from the tax credits under the Energy Policy Act of 2005 (EPACT 2005) and Energy Improvement and Extension Act of

2008 (EIEA 2008)? Do you know of any current or future tax credits or other benefits available to your company for manufacturing more efficient refrigeration products? If so, please describe.

Table 8.2 Federal Production Tax Credits Identified by DOE

Tax Credit Program	Effective Date		Rolling Average Basis	Efficiency Improvement Requirements	Tax Credit per Unit
	Start	End			
EPACT 2005	2006	2006	3 years	15%	$75
	2006	2007	3 years	20%	$125
	2006	2007	3 years	25%	$175
EIEA 2008	2008	2008	2 years	20%	$50
	2008	2009	2 years	23%	$75
	2008	2010	2 years	25%	$100
	2008	2010	2 years	30%	$200

9 IMPACTS OF POTENTIAL HFC REGULATIONS

9.1 Do you have data indicating the thermal performance of insulation foam using cyclopentane blowing agent? How does this compare with information you have seen regarding the performance of foam blown with HFC-245fa?

9.2 What are your expectations regarding the shift away from HFC foam blowing agents and away from HFC-134a refrigerant? Please indicate the percentage of your production using each of these as a function of year. If this depends on a specific key event, such as passage of greenhouse gas legislation, please provide an alternative curve assuming the occurrence of this event.

9.3 What are your expectations regarding the UL initiative to reconsider HC limits in refrigeration products? Can you comment on the efficiency of refrigerators that use HCs compared to those that do not?

9.4 What are your expectations of added capital and one-time costs associated with full conversion away from HFC blowing agents? Added capital and one-time costs associated with full conversion away from HFC-134a refrigerant? Added per-product cost associated with each of these conversions? What kinds of changes to your existing factories would be required to handle the blowing agents or refrigerants required if you stopped using HFCs? What would these changes cost? What level of product development would such a change require and what would this effort cost?

10 DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in refrigerator, refrigerator-freezer, and freezer employment and solicit manufacturer views on how domestic employment patterns might be affected by amended energy conservation standards.

10.1 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please explain how they would change if higher efficiency levels are required.

10.2 Would the workforce skills necessary under amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?

10.3 Would amended energy conservation standards require extensive retraining of your service/field technicians? If so, could you expand on how your service infrastructure would be impacted in general as a result of amended energy conservation standards?

11 EXPORTS / FOREIGN COMPETITION / OUTSOURCING

Disparity between domestic and foreign energy conservation standards could impact exports or imports. Labor content and material changes, resulting from amended energy conservation standards, may impact sourcing decisions.

11.1 What percentage of your company's residential refrigeration sales are in the United States? What percentage of your residential refrigeration sales are **produced** in the United States?

11.2 Are there any foreign companies with North American production facilities?

11.3 Would amended energy conservation standards impact your domestic vs. foreign manufacturing or sourcing decisions? Is there an efficiency level that would cause you to move exiting domestic production facilities outside the U.S.?

11.4 What percentage of the U.S. market for residential refrigerator-freezers, standard-size freezers, and compact refrigerators and freezers manufacturers is made outside the U.S.?

12 CONSOLIDATION

Amended energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the

Department of Justice are both interested in any potential reduction in competition that would result from an amended energy conservation standard.

12.1 Please comment on industry consolidation and related trends over the last 5 years.

12.2 In the absence of amended energy conservation standards, do you expect any further industry consolidation? Please describe your expectations.

12.3 How would amended energy conservation standards affect your or other companies' ability to compete?

13 IMPACTS ON SMALL BUSINESS

13.1 The Small Business Administration (SBA) denotes a small business in the residential refrigeration manufacturing industry as having less than 1,000 total employees, including the parent company and all subsidiaries.[2] By this definition, is your company considered a small business?

13.2 Are there any reasons that a small business manufacturer might be at a disadvantage relative to a larger business under amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

13.3 Are there any niche manufacturers, small businesses manufacturers, and/or component manufacturers for which the adoption of amended energy conservation standards would have a severe impact? If so, would manufacturers of these products have different incremental impacts from implemented amended energy conservation standards than from the rest of the industry?

[2] DOE uses the small business size standards published on August 22, 2008, as amended, by the SBA to determine whether a company is a small business. To be categorized as a small business, a household refrigerator and home freezer manufacturers and its affiliates may employ a maximum of 1,000 employees. The 1,000 employee threshold includes all employees in a business's parent company and any other subsidiaries.

12-A.2 COMPACT REFRIGERATORS AND FREEZERS MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

January 13, 2010

The Department of Energy (DOE) conducts the manufacturer impact analysis (MIA) as part of the rulemaking process for amended energy conservation standards for refrigerators, refrigerator-freezers, and freezers. In this analysis, DOE uses publicly available information and information provided by manufacturers during interviews to assess possible impacts on manufacturers due to amended energy conservation standards.

DOE explicitly analyzes the compact product classes in the tables below. For all product classes, DOE is currently considering eight efficiency levels (ELs) that correspond to percentage improvements over the existing standards. In responding to this questionnaire, please refer to the efficiency levels in the table below. DOE explains how it intends to determine the minimum efficiencies for the remaining product classes in the engineering chapter of the technical support document.[3]

Baseline Efficiencies for Analyzed Product Classes

Product Class Number	Product Type	Product Class Description	Equation for maximum energy use (kWh/yr))*
11	**Compact Refrigerators and Freezers**	Compact Refrigerators and Refrigerator-Freezers with Manual Defrost	12.04 AV + 336.4
18	**Compact Refrigerators and Freezers**	Compact Chest Freezers	10.27 AV + 152

AV= adjusted volume in cubic feet
* These definitions are based on testing according to the current energy test procedure. DOE expects to propose revisions in the energy test procedure to harmonize with expected test temperatures under consideration for IEC test procedure 62552 and will adjust the equations accordingly. However, for the purpose of identifying the efficiency levels of products in the table below, it is assumed that the percent efficiency level (i.e. the difference between baseline energy use and improved product energy use divided by baseline energy use and multiplied by 100%) does not depend on which test procedure is used to determine energy use.

Efficiency Levels Under Consideration for all Product Classes

Percentage Decrease in kWh/yr from Calculated Baseline Efficiency							
EL 1	**EL 2**	**EL 3**	**EL 4**	**EL 5**	**EL 6**	**EL 7**	**EL 8**
10%	15%	20%	25%	30%	35%	40%	45%

1 KEY ISSUES

1.1 In general, what are the key issues for your company regarding amended energy conservation standards for residential refrigeration products and this rulemaking?

[3] Please see http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers_prelim_tsd_mtg.html for a complete description.

1.2 For the issues identified, does the severity change for different product classes? Do some issues become more significant at higher efficiency levels? Are certain issues more of a concern for certain product classes?

1.3 How can DOE most effectively incorporate these issues in the MIA?

2 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to residential refrigeration production. However, the context within which the plant operates and the details of plant production and costs are not always readily available from public sources. Therefore, DOE invites you to provide these details confidentially in your own words to the extent possible and practical. Understanding the organizational setting around the residential refrigeration industry profit center will help DOE understand the probable future of the manufacturing activity with and without amended energy conservation standards.

2.1 Do you have a parent company, and/or any subsidiaries relevant to the residential refrigeration industry?

2.2 Do you manufacture any products other than residential refrigeration products? If so, what other products do you manufacture? What percentage of your total manufacturing revenue corresponds to residential refrigeration products?

2.3 What product classes of refrigeration products do you manufacturer?

2.4 Where are your residential refrigeration production facilities located, and what types of products are manufactured at each location? Could you provide annual shipment figures for your company's residential refrigeration manufacturing at each location by product line?

2.5 At your manufacturing facilities, would potential residential refrigeration product redesigns be difficult to implement? If so, would your company modify the existing facility or develop a new facility?

2.6 What are your employment levels at each of these facilities?

2.7 What is your company's approximate market share in the compact refrigerator and freezers markets?

3 ENGINEERING AND LIFE CYCLE COST ANALYSIS FOLLOW-UP

3.1 For the products directly analyzed for the Engineering Analysis that represent the bulk of residential refrigeration product sales, can you comment on the progressive use of design options for achieving the successively higher efficiency levels (compared with the design option information presented by efficiency level in Appendix 5A of the preliminary TSD)?

3.2 Are the incremental design option costs used in the Engineering Analysis and described in Chapter 5 of the preliminary TSD representative of costs your company pays for these design options? If not, please provide a quantitative indication of the differences.

3.3 How would the cost-efficiency curves of low-production-volume product classes differ from those developed for the directly-analyzed product classes most closely related to them? The table below provides an indication of expectations for representation of low-volume product classes. Please comment for your key products of the low-volume product classes.

Low-volume Product Classes	11A, 12, 13, 13A, 14, 15	16,17
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3.4 Do you sell any standard-size all-refrigerators with manual (not off-cycle) defrost?

3.5 Do you sell any compact upright freezers with automatic defrost (PC 17)? If so, can you describe your product line(s) for this class and provide shipment estimates?

3.6 Do you have warrantee and/or maintenance cost data illustrating the impact of any of the following design options on maintenance cost: electronic controls, high-efficiency single-speed compressors, variable-speed compressors, brushless DC fans, VIPs, and humidity sensors?

3.7 What are the expected differences in cost per unit area of VIP applied to a product between application to the door and application to the cabinet? Are these costs differences for labor costs, material costs, capital costs, or other types of costs?

3.8 What is your company's level of operation (by shipment volume) in other world markets where significant reductions in energy use have been or are expected to be mandated, particularly India and the EU?

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DOE's contractor has developed a "strawman" model of the residential refrigeration products industry financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. This section attempts to understand how your company's financial situation differs from the industry aggregate picture.

6.1 Please compare your financial parameters to the GRIM parameters tabulated below.

Table 6.1 Financial Parameters for Residential Refrigeration Product Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual (If Significantly Different from DOE's Estimate)
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	33.9	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	7.2	
Working Capital	Current assets less current liabilities (percentage of revenues)	2.9	
Net PPE	Net plant property and equipment (percentage of revenues)	19.9	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	12.5	
R&D	Research and development expenses (percentage of revenues)	2.2	
Depreciation	Amortization of fixed assets (percentage of revenues)	3.4	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	3.5	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	79.4	

6.2 Are the figures in Table 6.1 representative of residential refrigeration manufacturing?

6.3 Do any of the financial parameters in Table 6.1 change based on product type or product class? Please describe any differences.

6.4 How would you expect an amended energy conservation standard to impact any of the financial parameters for the industry?

7 CONVERSION COSTS

Amended energy conservation standards may cause your company to incur capital and product conversion costs to redesign existing products and make changes to existing production lines to be compliant with the amended energy conservation standard. Capital conversion costs are one-time investments in plant, property, and equipment (PPE) necessitated by an amended energy conservation standard. These may be incremental changes to existing PPE or the replacement of existing PPE. In addition to capital conversion costs, product conversion costs are costs related research, product development, testing, marketing and other costs for redesigning products necessitated by an amended energy conservation standard. Depending on their magnitude, the conversion costs can have a substantial impact on the outputs used by DOE to evaluate the industry impacts. Understanding the nature and magnitude of the conversion costs is critical

portion of the MIA. Table 7.1 shows the design options used to research higher efficiencies for the major compact product categories covered by this rulemaking. Please refer to Table 7.1 when considering your response to the following questions.

Table 7.1 Design Options Used to Improve Efficiency for each Major Compact Product Category

Product Type	**Design Options**
Compact Refrigerator-Freezers	Larger evaporators, thicker insulation, more efficient compressors, larger condensers, VIPs in the cabinet, and VIPs in the door
Compact Chest Freezers	More efficient compressors, thicker insulation, VIPs in the bottom wall, and variable speed compressors

7.1 Are there certain efficiency levels for which the design changes would require relatively minor changes to existing products? Are there certain efficiency levels where the capital or product conversion costs significantly increase? Would your answer change for different product categories? Please describe these changes qualitatively.

7.2 For each of the product categories shown in Table 7.1, which design options could be made within existing cabinet designs and which would result in major product redesigns?

7.3 For the design options in Table 7.1, what kind of changes would need to be implemented to production lines for each major product category? How much would these changes and other capital expenses cost?

7.4 Would the changes in 7.3 be similar across all of your production lines and factories for each product category?

7.5 For each of the product categories, please qualify the number of and cost of new production equipment, molds, foaming fixtures, etc. that would be required to implement the specified design changes. Please consider which design changes would require changes to existing cavity designs/wrapper shells.

7.6 What level of product development and other product conversion costs would you expect to incur for each of these design changes for each major product category?

7.7 For any design changes that would require new production equipment, please describe how much downtime would be required. What impact would downtime have on your business? Are there any design changes that could not be implemented before the compliance date of the final rule for certain product classes?

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8 CUMULATIVE REGULATORY BURDEN

Cumulative regulatory burden refers to the burden that industry faces from overlapping effects of new or revised DOE standards, voluntary standards, and/or other regulatory actions affecting the same product or industry.

8.1 Are there other recent or impending regulations that residential refrigeration manufacturers face (from DOE or otherwise)? If so, could you identify the regulation and the corresponding possible effective dates for those regulations? Below is a list of regulations that could possibly affect manufacturers of residential refrigeration products. Please provide any comments on the listed regulations in addition to other regulations.

Table 8.1 Other Regulations Identified by DOE

Regulation	Estimated or Actual Effective Date(s)	Comments
DOE's Energy Conservation Standards for Other Products and Equipment		
International Energy-Efficiency Standards		
Climate Change Legislation limiting or banning hydrofluorocarbons (discussed in section 9)		

8.2 What level of expense are you expecting to incur as a result of these regulations?

8.3 Under what circumstances would you be able to coordinate any expenditure related to these other regulations with an amended energy conservation standard, thereby lessening the cumulative burden?

8.4 DOE research has identified the production tax credits in Table 8.2 for manufacturers of residential refrigeration products. Similar tax credits have also been proposed in the current version of the House energy bill. Has your company received benefit from the tax credits under the Energy Policy Act of 2005 (EPACT 2005) and Energy Improvement and Extension Act of 2008 (EIEA 2008)? Do you know of any current or future tax credits or other benefits available to your company for manufacturing more efficient refrigeration products? If so, please describe.

Table 8.2 Federal Production Tax Credits Identified by DOE

Tax Credit Program	Effective Date		Rolling Average Basis	Efficiency Improvement Requirements	Tax Credit per Unit
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	2006	2007	3 years	20%	$125
	2006	2007	3 years	25%	$175
EIEA 2008	2008	2008	2 years	20%	$50
	2008	2009	2 years	23%	$75
	2008	2010	2 years	25%	$100
	2008	2010	2 years	30%	$200

9 IMPACTS OF POTENTIAL HFC REGULATIONS

9.1 Do you have data indicating the thermal performance of insulation foam using cyclopentane blowing agent? How does this compare with information you have seen regarding the performance of foam blown with HFC-245fa?

9.2 What are your expectations regarding the shift away from HFC foam blowing agents and away from HFC-134a refrigerant? Please indicate the percentage of your production using each of these as a function of year. If this depends on a specific key event, such as passage of greenhouse gas legislation, please provide an alternative curve assuming the occurrence of this event.

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10 DIRECT EMPLOYMENT IMPACT ASSESSMENT

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10.1 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please explain how they would change if higher efficiency levels are required.

10.2 Would the workforce skills necessary under amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?

10.3 Would amended energy conservation standards require extensive retraining of your service/field technicians? If so, could you expand on how your service infrastructure would be impacted in general as a result of amended energy conservation standards?

11 EXPORTS / FOREIGN COMPETITION / OUTSOURCING

Disparity between domestic and foreign energy conservation standards could impact exports or imports. Labor content and material changes, resulting from amended energy conservation standards, may impact sourcing decisions.

11.1 What percentage of your company's residential refrigeration sales are in the United States? What percentage of your residential refrigeration sales are **produced** in the United States?

11.2 Are there any foreign companies with North American production facilities?

11.3 Would amended energy conservation standards impact your domestic vs. foreign manufacturing or sourcing decisions? Is there an efficiency level that would cause you to move exiting domestic production facilities outside the U.S.?

11.4 What percentage of the U.S. market for compact refrigerators and freezers manufacturers is made outside the U.S.?

12 CONSOLIDATION

Amended energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the Department of Justice are both interested in any potential reduction in competition that would result from an amended energy conservation standard.

12.1 Please comment on industry consolidation and related trends over the last 5 years.

12.2 In the absence of amended energy conservation standards, do you expect any further industry consolidation? Please describe your expectations.

12.3 How would amended energy conservation standards affect your or other companies' ability to compete?

13 IMPACTS ON SMALL BUSINESS

13.1 The Small Business Administration (SBA) denotes a small business in the residential refrigeration manufacturing industry as having less than 1,000 total employees, including the parent company and all subsidiaries.[4] By this definition, is your company considered a small business?

13.2 Are there any reasons that a small business manufacturer might be at a disadvantage relative to a larger business under amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

13.3 Are there any niche manufacturers, small businesses manufacturers, and/or component manufacturers for which the adoption of amended energy conservation standards would have a severe impact? If so, would manufacturers of these products have different incremental impacts from implemented amended energy conservation standards than from the rest of the industry?

[4] DOE uses the small business size standards published on August 22, 2008, as amended, by the SBA to determine whether a company is a small business. To be categorized as a small business, a household refrigerator and home freezer manufacturers and its affiliates may employ a maximum of 1,000 employees. The 1,000 employee threshold includes all employees in a business's parent company and any other subsidiaries.

12-A.3 STANDARD SIZE REFRIGERATION PRODUCTS MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

January 13, 2010

The Department of Energy (DOE) conducts the manufacturer impact analysis (MIA) as part of the rulemaking process for amended energy conservation standards for refrigerators, refrigerator-freezers, and freezers. In this analysis, DOE uses publicly available information and information provided by manufacturers during interviews to assess possible impacts on manufacturers due to amended energy conservation standards.

DOE explicitly analyzes the standard-size product classes in the tables below. For all product classes, DOE is currently considering eight efficiency levels (ELs) that correspond to percentage improvements over the existing standards. In responding to this questionnaire, please refer to the efficiency levels in the table below. DOE explains how it intends to determine the minimum efficiencies for the remaining product classes in the engineering chapter of the technical support document.[5]

Baseline Efficiencies for Analyzed Product Classes

Product Class Number	Product Type	Product Class Description	Equation for maximum energy use (kWh/yr))*
3	**Refrigerator-Freezers**	Automatic Defrost with Top-Mounted Freezer Without Through the Door (TTD) Ice Service	10.72 AV + 310.2
5	**Refrigerator-Freezers**	Automatic Defrost with Bottom-Mounted Freezer Without TTD Ice Service	5.32 AV + 542.5
7	**Refrigerator-Freezers**	Automatic Defrost with Side-Mounted Freezer With TTD Ice Service	11.33 AV + 462.8
9	**Freezers**	Upright Freezers with Automatic Defrost	12.32 AV + 326.1
10	**Freezers**	Chest Freezers and all Other Freezers Except Compact Freezers	9.71 AV + 143.7

AV= adjusted volume in cubic feet

* These definitions are based on testing according to the current energy test procedure. DOE expects to propose revisions in the energy test procedure to harmonize with expected test temperatures under consideration for IEC test procedure 62552 and will adjust the equations accordingly. However, for the purpose of identifying the efficiency levels of products in the table below, it is assumed that the percent efficiency level (i.e. the difference between baseline energy use and improved product energy use divided by baseline energy use and multiplied by 100%) does not depend on which test procedure is used to determine energy use.

Efficiency Levels Under Consideration for all Product Classes

Percentage Decrease in kWh/yr from Calculated Baseline Efficiency							
EL 1	**EL 2**	**EL 3**	**EL 4**	**EL 5**	**EL 6**	**EL 7**	**EL 8**
10%	15%	20%	25%	30%	35%	40%	45%

1 KEY ISSUES

[5] Please see http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers_prelim_tsd_mtg.html for a complete description.

1.1 In general, what are the key issues for your company regarding amended energy conservation standards for residential refrigeration products and this rulemaking?

1.2 For the issues identified, does the severity change for different product classes? Do some issues become more significant at higher efficiency levels? Are certain issues more of a concern for certain product classes?

1.3 How can DOE most effectively incorporate these issues in the MIA?

2 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to residential refrigeration production. However, the context within which the plant operates and the details of plant production and costs are not always readily available from public sources. Therefore, DOE invites you to provide these details confidentially in your own words to the extent possible and practical. Understanding the organizational setting around the residential refrigeration industry profit center will help DOE understand the probable future of the manufacturing activity with and without amended energy conservation standards.

2.1 Do you have a parent company, and/or any subsidiaries relevant to the residential refrigeration industry?

2.2 Do you manufacture any products other than residential refrigeration products? If so, what other products do you manufacture? What percentage of your total manufacturing revenue corresponds to residential refrigeration products?

2.3 What product classes of refrigeration products do you manufacturer?

2.4 Where are your residential refrigeration production facilities located, and what types of products are manufactured at each location? Could you provide annual shipment figures for your company's residential refrigeration manufacturing at each location by product line (i.e., top-mount refrigerator-freezers, bottom-mount refrigerator-freezers, etc.)?

2.5 At your manufacturing facilities, would potential residential refrigeration product redesigns be difficult to implement? If so, would your company modify the existing facility or develop a new facility?

2.6 What are your employment levels at each of these facilities?

2.7 What is your company's approximate market share in the standard-size refrigerator-freezer and standard-size freezer markets?

3 ENGINEERING AND LIFE CYCLE COST ANALYSIS FOLLOW-UP

3.1 For the products directly analyzed for the Engineering Analysis that represent the bulk of residential refrigeration product sales, can you comment on the progressive use of design options for achieving the successively higher efficiency levels (compared with the design option information presented by efficiency level in Appendix 5A of the preliminary TSD)?

3.2 Are the incremental design option costs used in the Engineering Analysis and described in Chapter 5 of the preliminary TSD representative of costs your company pays for these design options? If not, please provide a quantitative indication of the differences.

3.3 How would the cost-efficiency curves of low-production-volume product classes differ from those developed for the directly-analyzed product classes most closely related to them? The table below provides an indication of expectations for representation of low-volume product classes. Please comment for your key products of the low-volume product classes.

Low-volume Product Classes	1A, 1, 2, 3A	4	5A	6	8	10A
Representative Product Class	3	7	5	3	10	9

3.4 Do you sell any standard-size all-refrigerators with manual (not off-cycle) defrost?

3.5 Do you sell any compact upright freezers with automatic defrost (PC 17)? If so, can you describe your product line(s) for this class and provide shipment estimates?

3.6 Do you have warrantee and/or maintenance cost data illustrating the impact of any of the following design options on maintenance cost: electronic controls, high-efficiency single-speed compressors, variable-speed compressors, brushless DC fans, VIPs, and humidity sensors?

3.7 What are the expected differences in cost per unit area of VIP applied to a product between application to the door and application to the cabinet? Are these costs differences for labor costs, material costs, capital costs, or other types of costs?

3.8 What is your company's level of operation (by shipment volume) in other world markets where significant reductions in energy use have been or are expected to be mandated, particularly India and the EU?

3.9 How would repair and maintenance costs be impacted by more stringent energy conservation standards? How would the frequency of repair and maintenance be affected? How would the nature of the repair and maintenance work needed change with more stringent energy conservation standards?

3.10 Can you provide any information on consumer placement of built-in undercounter products and built-in upright freezers and on implications of possible wall thickness increases?

3.11 For standard size refrigerator-freezers, what percent reduction in internal volume would you implement prior to use of VIPs in order to maintain external dimensions?

3.12 Which product classes might be candidates for energy/adjusted volume curve slope changes? Do you have any information that would inform DOE's development of a response to this issue?

3.13 What information can be provided to provide a better understanding of the variation of costs to achieve efficiency levels? What information can be provided to provide a better understanding of how cost-efficiency curves for the low-volume product classes not directly analyzed are different?

3.14 What platform differences exist between product class 4 and product class 7? Between product class 6 and product class 3? Between product class 5 and product class 5A?

3.15 Can you provide engineering details for baseline efficiency built-in units and ENERGY STAR built-in units, such as typical wall thickness, insulation used, evaporator and condenser description, fan types and wattages, and compressor model or capacity? Can you provide specific data for a representative model for each applicable product class?

3.16 Do you see any possible loopholes in the proposed AHAM built-in definition? "Refrigerators, freezers and refrigerators with freezer units that are 7.75 cubic feet or greater; are totally encased by cabinetry or panels by either accepting a custom front panel or being equipped with an integral factory-finished face; are intended to be securely fastened to adjacent cabinetry, walls or floor; has sides which are not fully finished and are not intended to be visible after installation."

3.17 Can you provide any data showing how much of the expected benefits of VIPs are actually achieved in prototypes or manufactured products? Can you provide any data regarding panel failures in the field? Can you provide any data on scrap rates at the factory (what percentage of delivered VIPs must be scrapped)? Can you provide any data regarding resistivity decline of "good" panels over a span of years up to typical product lifetime?

3.18 How do the design option costs for your company compare to the values DOE used in its analysis as described in the preliminary TSD?

3.19 How do the bulk materials costs for your company compare to the values DOE used in its analysis as described in the preliminary TSD?

3.20 For variable anti-sweat heaters, what is the typical maximum wattage for a French door product and what is a typical control algorithm?

3.21 For variable defrost used with single-compressor/dual-evaporator systems, is it common to have more than one defrost cycle? How is this treated in the energy test? For products with more than one defrost cycle, do the defrost cycles ever overlap?

4 MARKUPS AND PROFITABILITY

DOE estimated the manufacturer production costs for the analyzed product classes of refrigeration products. DOE defines manufacturer production cost as all direct costs associated with manufacturing a product. It includes direct labor, direct materials, and overhead (which includes depreciation costs).

Manufacturer selling price is the average cost manufacturers charge their first consumers, but does not include additional costs along the distribution channels. The manufacturer selling price includes non-production costs including research and development; selling, general, and administrative expenses; shipping cost; and profit. The manufacturer markup is a multiplier applied to manufacturer production cost to cover these non-production costs and yield a profit. DOE estimated a baseline markup of 1.26 for refrigeration products.

One of the primary objectives of the MIA is to assess the impact of amended energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how setting an amended energy conservation standard would impact your company’s markup structure and profitability.

4.1 Is there a significant difference between the baseline markup DOE calculated and your company’s baseline markups for standard-size refrigerator-freezers and standard-size freezers? Is the 1.26 baseline markup factor representative of an average industry markup?

4.2 Do profit levels currently vary by product class or product line?

4.3 DOE would like to understand how the baseline manufacturer markup changes at higher efficiency levels. Do you currently earn a premium for more efficient products (i.e., ENERGY STAR or higher)? Please explain why or why not.

4.4 Does your markup change with selected design options? Is the markup on incremental costs for more efficient designs different than the markup on the baseline models (as is assumed for retailer markups used in the analyses)?

4.5 Would you expect changes in your estimated profitability following an amended energy conservation standard? If so, please explain why.

5 SHIPMENT PROJECTIONS

An amended energy conservation standard can change overall shipments by altering product attributes, marketing approaches, product availability, and prices. The industry revenue calculations are based on the shipment projections developed in DOE's shipments model. The shipments model includes forecasts for the base case shipments (i.e., total industry shipments absent amended energy conservation standards) and the standards case shipments (i.e., total industry shipments with amended energy conservation standards).

To determine efficiency distributions after the effective date of the standard, DOE used a "roll-up + market shift" scenario for 2014 and subsequent years. DOE assumed that product efficiencies in the base case that did not meet the standard under consideration would roll up to meet the new standard in 2014. DOE further assumed that the ENERGY STAR program would continue to promote efficient appliances after revised standards are introduced in 2014, resulting in a gradual market shift to higher efficiencies after the compliance date of the standard.

5.1 How do you think amended energy conservation standards will impact the sales of more efficient products? For example, would customers continue to buy products that exceed the energy conservation standard level? Would your response change for higher mandated efficiency levels?

5.2 DOE assumed that revised standards would cause product purchase prices to increase, resulting in reduced demand or shipments (price elasticity effect). DOE assumed an elasticity coefficient of -0.40, meaning a 10% increase in price would result in a 4% decrease in shipments. Do you agree with this assumption? How sensitive do you think shipments will be to price changes? Does it vary with product class?

6 FINANCIAL PARAMETERS

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Product Type	**Design Options**
Top-Mount Refrigerator-Freezers	More efficient compressors, larger evaporators, larger condensers, brushless DC fan motors, adaptive defrost, and VIPs in the cabinet
Side-Mount Refrigerator-Freezers	More efficient compressors, brushless DC fan motors, adaptive defrost, larger evaporators, larger condensers, VIPs in the cabinet, VIPs in the door, and variable speed compressors
Bottom-Mount Refrigerator-Freezers	More efficient compressors, brushless DC fan motors, variable anti-sweat heater control, adaptive defrost, larger condensers, larger evaporators, and VIPs in the cabinet
Upright Freezers	Brushless DC fan motors, thicker insulation, adaptive defrost, more efficient compressors, larger evaporators, forced convection condensers, VIPs in the cabinet, and VIPs in the door
Chest Freezers	Larger condensers, larger evaporators, thicker insulation, more efficient compressors, variable speed compressors, VIPs in the bottom wall, and VIPs in the door

7.1 Are there certain efficiency levels for which the design changes would require relatively minor changes to existing products? Are there certain efficiency levels where the capital or product conversion costs significantly increase? Would your answer change for different product categories? Please describe these changes qualitatively.

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Are there any design changes that could not be implemented before the compliance date of the final rule for certain product classes?

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Disparity between domestic and foreign energy conservation standards could impact exports or imports. Labor content and material changes, resulting from amended energy conservation standards, may impact sourcing decisions.

11.1 What percentage of your company's residential refrigeration sales are in the United States? What percentage of your residential refrigeration sales are **produced** in the United States?

11.2 Are there any foreign companies with North American production facilities?

11.3 Would amended energy conservation standards impact your domestic vs. foreign manufacturing or sourcing decisions? Is there an efficiency level that would cause you to move exiting domestic production facilities outside the U.S.?

11.4 What percentage of the U.S. market for standard size refrigerators, refrigerator-freezers, and freezers is made outside the U.S.?

12 CONSOLIDATION

Amended energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the Department of Justice are both interested in any potential reduction in competition that would result from an amended energy conservation standard.

12.1 Please comment on industry consolidation and related trends over the last 5 years.

12.2 In the absence of amended energy conservation standards, do you expect any further industry consolidation? Please describe your expectations.

12.3 How would amended energy conservation standards affect your or other companies' ability to compete?

13 IMPACTS ON SMALL BUSINESS

13.1 The Small Business Administration (SBA) denotes a small business in the residential refrigeration manufacturing industry as having less than 1,000 total employees, including the parent company and all subsidiaries.[6] By this definition, is your company considered a small business?

13.2 Are there any reasons that a small business manufacturer might be at a disadvantage relative to a larger business under amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

13.3 Are there any niche manufacturers, small businesses manufacturers, and/or component manufacturers for which the adoption of amended energy conservation standards would have a severe impact? If so, would manufacturers of these products have different incremental impacts from implemented amended energy conservation standards than from the rest of the industry?

[6] DOE uses the small business size standards published on August 22, 2008, as amended, by the SBA to determine whether a company is a small business. To be categorized as a small business, a household refrigerator and home freezer manufacturers and its affiliates may employ a maximum of 1,000 employees. The 1,000 employee threshold includes all employees in a business's parent company and any other subsidiaries.

APPENDIX 12-B. GOVERNMENT REGULATORY IMPACT MODEL (GRIM) OVERVIEW

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APPENDIX 12-B. GOVERNMENT REGULATORY IMPACT MODEL (GRIM) OVERVIEW

12-B.1 INTRODUCTION AND PURPOSE

The purpose of the Government Regulatory Impact Model (GRIM) is to help quantify the impacts of energy conservation standards and other regulations on manufacturers. The basic mode of analysis is to estimate the change in the value of the industry or manufacturers(s) following a regulation or a series of regulations. The model structure also allows an analysis of multiple products with regulations taking effect over a period of time, and of multiple regulations on the same products.

Industry net present value is defined, for the purpose of this analysis, as the discounted sum of industry free cash flows plus a discounted terminal value. The model calculates the actual cash flows by year and then determines the present value of those cash flows both without an energy conservation standard (*i.e.*, the base case) and under different trial standard levels (TSLs) (*i.e.*, the standards case).

Output from the model consists of summary financial metrics, graphs of major variables, and, when appropriate, access to the complete cash flow calculation.

12-B.2 MODEL DESCRIPTION

The basic structure of the GRIM is a standard annual cash flow analysis that uses manufacturer selling prices, manufacturing costs, a shipments forecast, and financial parameters as inputs and accepts a set of regulatory conditions as changes in costs and investments. The cash flow analysis is separated into two major blocks: income and cash flow. The income calculation determines net operating profit after taxes. The cash flow calculation converts net operating profit after taxes into an annual cash flow by including investment and non-cash items. Below are definitions of listed items on the printout of the output sheet (see Section 12A.6.3).

(1) ***Unit Sales:*** Total annual shipments for the industry were obtained from the National Impact Analysis Spreadsheet;

(2) ***Revenues:*** Annual revenues - computed by multiplying products' unit prices at each efficiency level by the appropriate manufacturer markup;

(3) ***Labor:*** The portion of cost of goods sold (COGS) that includes direct labor, commissions, dismissal pay, bonuses, vacation, sick leave, social security contributions, fringe, and assembly labor up-time;

(4) ***Material:*** The portion of COGS that includes materials;

(5) Overhead: The portion of COGS that includes indirect labor, indirect material, energy use, maintenance, depreciation, property taxes, and insurance related to assets. While included in overhead, the depreciation is shown as a separate line item;

(6) Depreciation: The portion of overhead that includes an allowance for the total amount of fixed assets used to produce that one unit. Annual depreciation computed as a percentage of ***COGS.*** While included in overhead, the depreciation is shown as a separate line item;

(7) Stranded Assets: In the year the standard becomes effective, a one time write-off of stranded assets is accounted for;

(8) Standard SG&A: Selling, general, and administrative costs are computed as a percentage of ***Revenues (2)***;

(9) R&D: GRIM separately accounts for ordinary research and development (R&D) as a percentage of ***Revenues (2)***;

(10) Product Conversion Costs: Product conversion costs are one-time investments in research, development, testing, marketing, and other costs focused on making products designs comply with the new energy conservation standard. The GRIM allocates these costs over the period between the standard's announcement and compliance dates;

(11) Earnings Before Interest and Taxes (EBIT): Includes profits before deductions for interest paid and taxes;

(12) EBIT as a Percentage of Sales (EBIT/Revenues): GRIM calculates EBIT as a percentage of sales to compare with the industry's average reported in financial statements;

(13) Taxes: Taxes on ***EBIT (11)*** are calculated by multiplying the tax rate contained in Major Assumptions by ***EBIT (11)***.

(14) Net Operating Profits After Taxes (NOPAT): Computed by subtracting ***Cost of Goods Sold ((3) to (6))***, ***SG&A (8)***, ***R&D (9)***, ***Product Conversion Costs (10)***, and ***Taxes (13)*** from ***Revenues (2)***.

(15) NOPAT repeated: NOPAT is repeated in the Statement of Cash Flows;

(16) Depreciation repeated: Depreciation and Stranded Assets are added back in the Statement of Cash Flows because they are non-cash expenses;

(17) Change in Working Capital: Change in cash tied up in accounts receivable, inventory, and other cash investments necessary to support operations is calculated by multiplying working capital (as a percentage of revenues) by the change in annual revenues.

(18) Cash Flow From Operations: Calculated by taking ***NOPAT (15)***, adding back non-cash items such as a ***Depreciation (16)***, and subtracting the ***Change in Working Capital (17)***;

(19) ***Ordinary Capital Expenditures:*** Ordinary investments in property, plant, and equipment to maintain and replace existing production assets, computed as a percentage of ***Revenues (2)***;

(20) ***Capital Conversion Costs:*** Capital conversion costs are one-time investments in property, plant, and equipment to adapt or change existing production facilities so that new product designs can be fabricated and assembled under the new regulation; The GRIM allocates these costs over the period between the standard's announcement and compliance dates;

(21) ***Capital Investment:*** Total investments in property, plant, and equipment are computed by adding ***Ordinary Capital Expenditures (19)*** and ***Capital Conversion Costs (20)***;

(22) ***Free Cash Flow:*** Annual cash flow from operations and investments; computed by subtracting ***Capital Investment (21)*** from ***Cash Flow from Operations (18)***;

(23) ***Terminal Value:*** Estimate of the continuing value of the industry after the analysis period. Computed by growing the Free Cash Flow at the beginning of 2045 at a constant rate in perpetuity;

(24) ***Present Value Factor:*** Factor used to calculate an estimate of the present value of an amount to be received in the future;

(25) ***Discounted Cash Flow: Free Cash Flows (22)*** multiplied by the ***Present Value Factor (24)***. For the end of 2043, the discounted cash flow includes the discounted ***Terminal Value (23)***; and

(26) ***Industry Value thru the end of 2043:*** The sum of ***Discounted Cash Flows (25)***.

12-B.3 DETAILED CASH FLOW EXAMPLE

Standards Case Income and Cash Flow Statements

This tab computes key parameters from an income statement based on unit sales, revenues and COGS, and initial financial inputs (parameters as a % of revenue). It also computes an INPV based on a discounted cash flow model.

	2008	2009	Base Year 2010	Announcement Year 2011	2012	2013	Standard Year 2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Industry Income Statement (Base Case)																	
Unit Sales	9.061	8.990	9.639	10.683	11.356	11.743	9.926	10.637	11.196	11.572	11.966	12.252	12.516	12.708	12.918	13.166	13.400
Revenues	$ 4,645.8	$ 4,487.3	$ 4,692.5	$ 5,212.5	$ 5,552.0	$ 5,753.0	$ 7,527.5	$ 8,046.3	$ 8,457.7	$ 8,739.9	$ 9,036.4	$ 9,258.8	$ 9,465.2	$ 9,614.1	$ 9,776.7	$ 9,968.3	$ 10,151.5
Cost of Sales																	
Labor	$ 601.6	$ 583.0	$ 611.7	$ 679.3	$ 723.3	$ 749.3	$ 728.1	$ 777.7	$ 817.1	$ 844.3	$ 872.9	$ 894.6	$ 914.7	$ 929.1	$ 944.9	$ 963.6	$ 981.4
Material	$ 2,618.3	$ 2,520.8	$ 2,628.0	$ 2,920.0	$ 3,111.0	$ 3,224.4	$ 4,748.9	$ 5,076.5	$ 5,336.3	$ 5,514.4	$ 5,701.5	$ 5,841.7	$ 5,971.8	$ 6,065.6	$ 6,168.2	$ 6,289.0	$ 6,404.5
Overhead	$ 314.0	$ 309.4	$ 329.7	$ 365.7	$ 388.9	$ 402.3	$ 392.9	$ 420.6	$ 442.4	$ 457.3	$ 472.8	$ 484.3	$ 494.9	$ 502.5	$ 510.9	$ 520.9	$ 530.2
Depreciation	$ 153.3	$ 148.1	$ 154.9	$ 172.0	$ 183.2	$ 189.8	$ 254.7	$ 272.2	$ 286.2	$ 295.7	$ 305.7	$ 313.3	$ 320.2	$ 325.3	$ 330.8	$ 337.2	$ 343.4
Stranded Assets	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,006.5	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Selling, General, & Administrative Expenses																	
Standard SG&A	$ 580.7	$ 560.9	$ 586.6	$ 651.6	$ 694.0	$ 719.1	$ 940.9	$ 1,005.8	$ 1,057.2	$ 1,092.5	$ 1,129.6	$ 1,157.4	$ 1,183.1	$ 1,201.8	$ 1,222.1	$ 1,246.0	$ 1,268.9
R&D	$ 102.2	$ 98.7	$ 103.2	$ 114.7	$ 122.1	$ 126.6	$ 165.6	$ 177.0	$ 186.1	$ 192.3	$ 198.8	$ 203.7	$ 208.2	$ 211.5	$ 215.1	$ 219.3	$ 223.3
Product Conversion Costs	$ -	$ -	$ -	$ 99.4	$ 139.2	$ 159.1	$ 8.1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Earnings Before Interest and Taxes (EBIT)	$ 275.7	$ 266.3	$ 278.5	$ 209.9	$ 190.3	$ 182.3	$ (718.1)	$ 316.5	$ 332.5	$ 343.5	$ 355.1	$ 364.0	$ 372.3	$ 378.2	$ 384.7	$ 392.3	$ 399.7
EBIT/Revenues	5.9%	5.9%	5.9%	4.0%	3.4%	3.2%	-9.5%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%
Taxes	$ 93.5	$ 90.3	$ 94.4	$ 71.2	$ 64.5	$ 61.8	$ -	$ 107.3	$ 112.7	$ 116.5	$ 120.4	$ 123.4	$ 126.2	$ 128.2	$ 130.4	$ 133.0	$ 135.5
Net Operating Profit after Taxes (NOPAT)	$ 182.3	$ 176.0	$ 184.1	$ 138.8	$ 125.8	$ 120.5	$ (718.1)	$ 209.2	$ 219.8	$ 227.1	$ 234.7	$ 240.6	$ 246.1	$ 250.0	$ 254.3	$ 259.3	$ 264.2
Cash Flow Statement (Base Case)																	
NOPAT	$ 182.3	$ 176.0	$ 184.1	$ 138.8	$ 125.8	$ 120.5	$ (718.1)	$ 209.2	$ 219.8	$ 227.1	$ 234.7	$ 240.6	$ 246.1	$ 250.0	$ 254.3	$ 259.3	$ 264.2
Depreciation	$ 153.3	$ 148.1	$ 154.9	$ 172.0	$ 183.2	$ 189.8	$ 1,261.1	$ 272.2	$ 286.2	$ 295.7	$ 305.7	$ 313.3	$ 320.2	$ 325.3	$ 330.8	$ 337.2	$ 343.4
Change in Working Capital	$ 134.7	$ 4.6	$ (6.0)	$ (15.1)	$ (9.8)	$ (5.8)	$ (51.5)	$ (15.0)	$ (11.9)	$ (8.2)	$ (8.6)	$ (6.4)	$ (6.0)	$ (4.3)	$ (4.7)	$ (5.6)	$ (5.3)
Cash Flow from Operations	$ 470.3	$ 328.7	$ 333.0	$ 295.7	$ 299.1	$ 304.5	$ 491.6	$ 466.4	$ 494.0	$ 514.6	$ 531.9	$ 547.4	$ 560.3	$ 570.9	$ 580.3	$ 591.0	$ 602.3
Ordinary Capital Expenditure	$ (167.2)	$ (161.5)	$ (168.9)	$ (187.6)	$ (199.9)	$ (207.1)	$ (271.0)	$ (289.7)	$ (304.5)	$ (314.6)	$ (325.3)	$ (333.3)	$ (340.7)	$ (346.1)	$ (352.0)	$ (358.9)	$ (365.5)
Capital Conversion Costs	$ -	$ -	$ -	$ (503.2)	$ (704.5)	$ (805.2)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Capital Investments	$ (167.2)	$ (161.5)	$ (168.9)	$ (690.9)	$ (904.4)	$ (1,012.3)	$ (271.0)	$ (289.7)	$ (304.5)	$ (314.6)	$ (325.3)	$ (333.3)	$ (340.7)	$ (346.1)	$ (352.0)	$ (358.9)	$ (365.5)
Federal Production Tax Benefit			$ 36.56														
Free Cash Flow	$ 303.0	$ 167.2	$ 200.6	$ (395.2)	$ (605.3)	$ (707.8)	$ 220.6	$ 176.7	$ 189.5	$ 199.9	$ 206.6	$ 214.1	$ 219.6	$ 224.8	$ 228.4	$ 232.1	$ 236.8
Terminal Value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Present Value Factor	0.00	0.00	1.00	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.53	0.50	0.47	0.43	0.41	0.38
Discounted Cash Flow	$ -	$ -	$ 200.6	$ (368.7)	$ (526.7)	$ (574.5)	$ 167.0	$ 124.8	$ 124.9	$ 122.9	$ 118.4	$ 114.5	$ 109.6	$ 104.6	$ 99.1	$ 94.0	$ 89.5
Industry Value through 2043 $ 1,018.29																	

APPENDIX 12-C. FEDERAL PRODUCTION TAX CREDIT

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APPENDIX 12-C. FEDERAL PRODUCTION TAX CREDIT

12-C.1 INTRODUCTION

The purpose of this appendix is to clarify how the Department of Energy (DOE) made its estimates of the Federal production tax credits ("tax credits") that would benefit residential refrigeration manufacturers. These tax credits have been made available to residential refrigeration manufacturers by the enactment of the Energy Improvement and Extension Act of 2008 (EIEA 2008), Pub. L. No. 110-343, Div. B, Sec. 305 (Oct. 3, 2008). To make its estimates, DOE relied primarily on market research and information provided by manufacturers.

12-C.2 ELIGIBILITY REQUIREMENTS

Multiple tax credit programs have been enacted in order to stimulate the adoption of higher efficiency products and equipment. The first to impact the residential refrigeration industry was the Energy Policy Act of 2005 (EPACT 2005), followed by EIEA 2008. Both programs share some eligibility requirements:

- EPACT 2005 included a $75 million cap on the total tax credit that any one manufacturer can receive across all eligible products and equipment it manufactures during the effective dates of the program. For refrigerators that consume at least 15 percent but not more than 20 percent less kilowatt hours per year than the 2001 energy conservation standards, the aggregate amount of the credit cannot exceed $20 million. EIEA 2008 also has a $75 million limit per taxpayer for all taxable years beginning after December 31, 2007. However, refrigerators qualifying for the highest tier are not counted towards the cap.

- Appliances or equipment that meet the efficiency requirements must be manufactured in the United States. The tax credit only applies to the original equipment manufacturer; *i.e.* tax-credits for private-labeled goods sourced from other domestic manufacturers accrue to the source, not the reseller.

- Tax credits accrue on the basis of how many additional eligible appliances the manufacturer has sold than in years past. The calculation is based on a rolling average of qualifying shipments, the length of which varies by the tax credit program.

- Products or equipment must meet certain efficiency metrics that vary by program. For refrigerators, targets were set based on a percentage reduction of energy usage of the 2001 energy conservation standards.

- Only residential model automatic defrost refrigerator-freezers with an internal volume of at least 16.5 cubic feet meet the definition of "refrigerator" for the purpose of these tax credits.

Some differences between the tax credits in EPACT 2005 and EIEA 2008 are shown in Table 12-C.2.1. Principal differences include the effective dates, the length of the rolling average period over which marginal qualifying units are calculated, the minimum efficiency requirements, and the per-unit tax credits that accrue to the original equipment manufacturer.

Table 12-C.2.1 Refrigerator Tax Credit Eligibility Requirements

Tax Credit Program	Effective Date		Rolling Average Basis	Efficiency Requirements	Tax Credit per Unit
	Start	End			
EPACT 2005	2006	2006	3 years	15%	$75
	2006	2007	3 years	20%	$125
	2006	2007	3 years	25%	$175
EIEA 2008	2008	2008	2 years	20%	$50
	2008	2009	2 years	23%	$75
	2008	2010	2 years	25%	$100
	2008	2010	2 years	30%	$200

12-C.3ELIGIBLE REFRIGERATION PRODUCTS

For the residential refrigeration products rulemaking, DOE sums the discounted annual cash flows from the base year through the end of the 30 year analysis period (2010 to 2043). Because 2010 is the base year to which industry cash flows are discounted, any Federal production tax credits prior to 2010 are not considered in the industry net present value (INPV) analysis that analyzes the impact of amended energy conservation standards on manufacturers. However, any tax benefit in 2010 falls within the timeframe that impacts INPV and hence increases industry value (potentially decreasing the impacts on manufacturers due to energy conservation standards). Therefore, DOE is only concerned with the tax benefit of EPACT 2005 and EIEA 2008 in 2010. In 2010, units that qualify for tax credits are those that meet efficiency levels of 25 percent and 30 percent, as shown in Table 12-C.2.1.

DOE used a Consortium for Energy Efficiency (CEE) database[a] to identify refrigerator models that are at least 25 percent and 30 percent more efficient than baseline efficiency levels, since these are the levels at which tax credits can be earned in 2010. CEE promotes energy-efficient refrigerators by identifying models that exist at certain tiers: Tier 1 designates models that are at least 20 percent more efficient than the federal minimum standard, Tier 2 designates models that are at least 25 percent more efficient, and Tier 3 designates models that are at least 30 percent more efficient. Therefore, DOE used the CEE database to identify models that meet CEE Tier 2 (25 percent efficiency improvement over baseline) and Tier 3 (30 percent efficiency improvement over baseline. DOE identified one qualifying model at the 25 percent efficiency level. Qualifying models must be manufactured in the U.S. and must have internal volume of at least 16.5 cubic feet. The CEE database also provided product specifications which DOE used to establish which models met the volume criteria. DOE used information it obtained during

[a] http://www.cee1.org/resid/seha/refrig/refrig-main.php3

manufacturer interviews to determine which models were manufactured domestically. Several models that meet these criteria exist on the market at the 25 percent efficiency level, but DOE assumed that all major U.S. manufacturers met their total tax benefit cap of $75 million prior to 2010. DOE identified only one manufacturer who had not met this cap and produced a qualifying model.

Using the same CEE database discussed above and information from manufacturer interviews, DOE also identified 63 qualifying models at the 30 percent efficiency level. Even though each of these models is made by a major U.S. manufacturer, these models all qualify for the tax credit under EIEA 2008 because the $75 million benefit cap does not apply to the highest efficiency tier.

12-C.4 ESTIMATED FEDERAL TAX CREDIT BENEFITS

DOE used several information sources to calculate the benefits received by residential refrigeration manufacturers from the tax credit programs in 2010. DOE first estimated the qualifying manufacturers' market shares for each product class for which they had qualifying models by using publicly available information and information obtained from manufacturer interviews. DOE then totaled the shipments estimated for each product class in 2010 in the NIA. Each manufacturer's 2010 shipments for a product class were calculated by multiplying its market share in that product class by total 2010 shipments.

DOE then estimated the percentage of qualifying shipments for each manufacturer by dividing the total number of qualifying models according to the CEE database of higher efficiency products by the total number of models offered by the manufacturer in that product class according to a Federal Trade Commission (FTC) product database[b]. DOE used the FTC product database to determine the total number of models for each product class for manufacturers that also produced qualifying products in 2010. DOE then calculated the total number of qualifying shipments for each manufacturer and product class by multiplying the manufacturer's total 2010 shipments by the percentage of qualifying shipments. Since each unit at the 25 percent efficiency level receives a $100 tax credit and each unit at the 30 percent efficiency level receives a $200 tax credit, DOE multiplied these values where appropriate by the total number of qualifying shipments to determine the total benefit of the tax credits for the industry. DOE's estimates suggest that manufacturers will collect approximately $36.6 million in Federal production tax credits in 2010 from the provisions of EIEA 2008.

12-C.5 IMPACTS ON INDUSTRY NET PRESENT VALUE

To determine the impacts of the tax credit on the INPV, DOE implemented the tax credit in the Government Regulatory Impact Model (GRIM). The calculated tax credit was added as a cash flow item in the base case and standards case. The impact of the Federal production tax credit is included in the main MIA results shown in Chapter 12 of the TSD. Of the $36.6 million

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[b] http://www.ftc.gov/bcp/conline/edcams/eande/appliances/fridge.htm

total tax benefit anticipated to be collected by the residential refrigeration industry, $36.566 million is expected to be earned by standard size refrigerator-freezer manufacturers from the 63 identified qualifying 30 percent models, and $0.042 million is expected to be earned by built-in refrigeration product manufacturers from the one identified qualifying 25 percent model. The tax credit does not apply to the remaining two subgroups of manufacturers, standard size freezer manufacturers and compact refrigeration product manufacturers. Table 12-C5.1 through Table 12-C5.8 provide the INPV estimates for the two manufacturer subgroups impacted by tax credits under the two markup scenarios analyzed with and without the incorporation of tax credits.

Table 12-C5.1 Industry Net Present Value for Standard Size Refrigerator-Freezers Including Federal Production Tax Credits (Flat Markup Scenario)

Flat Markup Scenario							
	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009 $ millions)*	3,779	3,738	3,662	3,570	3,313	3,228
Change in INPV	*(2009 $ millions)*	-	(41.0)	(117.0)	(209.7)	(466.4)	(551.4)
	(%)	-	-1.1%	-3.1%	-5.5%	-12.3%	-14.6%

Table 12-C5.2 Industry Net Present Value for Standard Size Refrigerator-Freezers Excluding Federal Production Tax Credits (Flat Markup Scenario)

Flat Markup Scenario							
	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009 $ millions)*	3,743	3,702	3,626	3,533	3,276	3,191
Change in INPV	*(2009 $ millions)*	-	(41.0)	(117.0)	(209.7)	(466.4)	(551.4)
	(%)	-	-1.1%	-3.1%	-5.6%	-12.5%	-14.7%

Table 12-C5.3 Industry Net Present Value for Standard Size Refrigerator-Freezers Including Federal Production Tax Credits (Preservation of Operating Profit Markup Scenario)

Preservation of Operating Profit Markup Scenario							
	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009 $ millions)*	3,779	3,470	3,310	3,105	2,257	1,585
Change in INPV	*(2009 $ millions)*	-	(309.1)	(469.2)	(674.0)	(1,521.9)	(2,194.0)
	(%)	-	-8.2%	-12.4%	-17.8%	-40.3%	-58.1%

Table 12-C5.4 Industry Net Present Value for Standard Size Refrigerator-Freezers Excluding Federal Production Tax Credits (Preservation of Operating Profit Markup Scenario)

Preservation of Operating Profit Markup Scenario							
	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009 $ millions)*	3,743	3,434	3,274	3,069	2,221	1,549
Change in INPV	*(2009 $ millions)*	-	(309.1)	(469.2)	(674.0)	(1,521.9)	(2,194.0)
	(%)	-	-8.3%	-12.5%	-18.0%	-40.7%	-58.6%

Table 12-C5.5 Industry Net Present Value for Built-In Refrigeration Products Including Federal Production Tax Credits (Flat Markup Scenario)

Flat Markup Scenario							
	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009 $ millions)*	790	738	736	727	715	712
Change in INPV	*(2009 $ millions)*	-	(51.5)	(54.2)	(62.8)	(75.0)	(77.8)
	(%)	-	-6.5%	-6.9%	-8.0%	-9.5%	-9.8%

Table 12-C5.6 Industry Net Present Value for Built-In Refrigeration Products Excluding Federal Production Tax Credits (Flat Markup Scenario)

Flat Markup Scenario							
	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009 $ millions)*	790	738	736	727	715	712
Change in INPV	*(2009 $ millions)*	-	(51.5)	(54.2)	(62.8)	(75.0)	(77.8)
	(%)	-	-6.5%	-6.9%	-8.0%	-9.5%	-9.8%

Table 12-C5.7 Industry Net Present Value for Built-In Refrigeration Products Including Federal Production Tax Credits (Preservation of Operating Profit Markup Scenario)

Preservation of Operating Profit Markup Scenario							
	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	*(2009 $ millions)*	790	737	733	709	686	668
Change in INPV	*(2009 $ millions)*	-	(53.0)	(57.1)	(81.1)	(104.2)	(122.1)
	(%)	-	-6.7%	-7.2%	-10.3%	-13.2%	-15.5%

Table 12-C5.8 Industry Net Present Value for Built-In Refrigeration Products Excluding Federal Production Tax Credits (Preservation of Operating Profit Markup Scenario)

Preservation of Operating Profit Markup Scenario							
	Units	**Base Case**	**Trial Standard Level**				
			1	**2**	**3**	**4**	**5**
INPV	***(2009 $ millions)***	790	737	733	709	686	668
Change in INPV	***(2009 $ millions)***	-	(53.0)	(57.1)	(81.1)	(104.2)	(122.1)
	(%)	-	-6.7%	-7.2%	-10.3%	-13.2%	-15.5%

The results from the GRIM show that the estimated Federal production tax credit has a minimal impact on residential refrigeration INPV impacts in the standards case. Depending on the markup scenario and product classes analyzed, the tax credit lowers the impacts of energy conservation standards by up to 0.5 percent. This small decrease is not enough to substantially mitigate the impacts on the residential refrigeration industry due to energy conservation standards.

APPENDIX 16-A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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Prepared by
Interagency Working Group on Social Cost of Carbon, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

16-A.1 EXECUTIVE SUMMARY

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Table 16-A.1.1 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

	Discount Rate			
	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

16-A.2 MONETIZING CARBON DIOXIDE EMISSIONS

The "social cost of carbon" (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. We report estimates of the social cost of carbon in dollars per metric ton of carbon dioxide throughout this document.[a]

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty,

[a] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020. See the Annex for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

16-A.3 SOCIAL COST OF CARBON VALUES USED IN PAST REGULATORY ANALYSES

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a "domestic" SCC value of \$2 per ton of CO_2 and a "global" SCC value of \$33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at \$80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of \$7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of \$0-\$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of \$0 to \$20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA's 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as "very preliminary" SCC estimates subject to revision. EPA's global mean values were \$68 and \$40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2. The $33 and $5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The $55 and $10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The $19 value was chosen as a central value between the $5 and $33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

16-A.4 APPROACH AND KEY ASSUMPTIONS

Since the release of the interim values, interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

16-A.4.1 Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[b] These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socio-economic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and

[b] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy. is now widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

economic processes (e.g. the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socio-economic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (e.g. the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in "natural capital." By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), "other vulnerable market sectors" (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact "catastrophic" climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function.

For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea's (2009) review concludes that "in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[c]

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (i.e., a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of

[c] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20%, and we re-calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection), ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on the absolute temperature change but also on the rate of temperature change and level of regional income.[d] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he characterizes several omitted impacts as "big unknowns": for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, "Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues."

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO_2 fertilization (damages are generally negative but diminishing to zero).

Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO_2 fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

Damage Functions

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[d] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

To generate revised SCC values, we rely on the IAM modelers' current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

The damage functions for the three IAMs are presented in Figures 16A.4.1 and 16A.4.2, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (figure 16A.4.2) and higher (figure 16A.4.1) increases in global-average temperature.

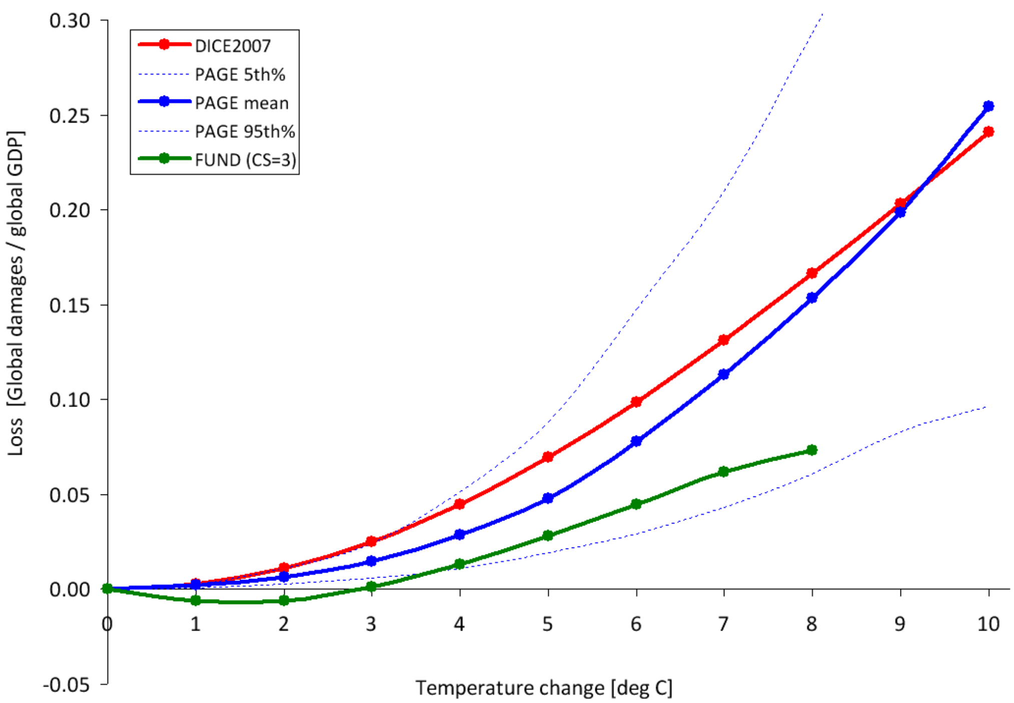

Figure 16-A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models[e]

[e] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socio-economic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

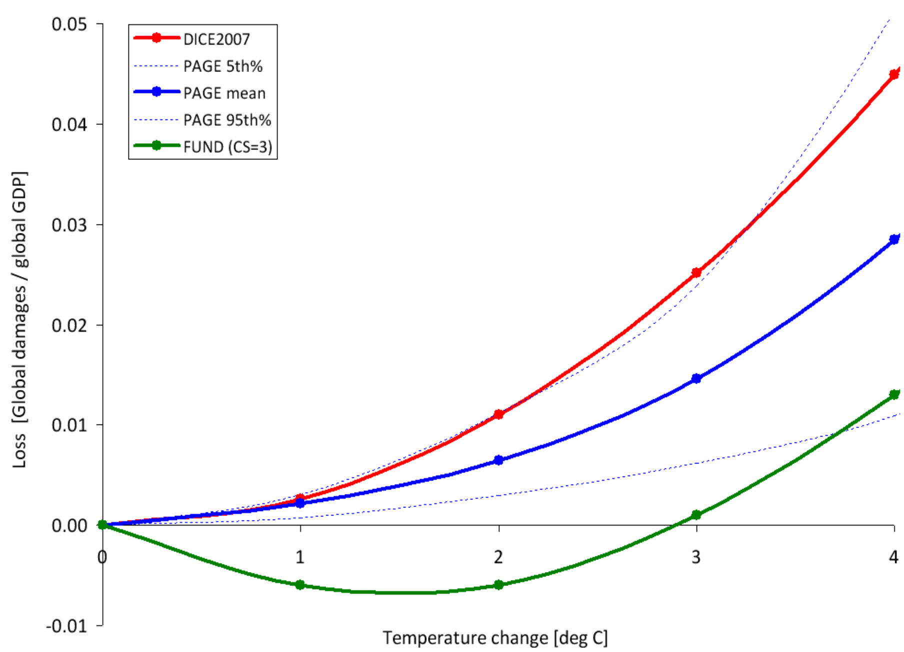

Figure 16-A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

16-A.4.2 Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[f]

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (e.g., Anthoff, et al. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[g] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

Domestic SCC

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[f] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

[g] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[h]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (e.g., global migration, economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

16-A.4.3 Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is

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[h] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

16-A.4.4 Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[i] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

> *Basing our assessment on a combination of several independent lines of evidence…including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or 'equilibrium climate sensitivity', is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C.* [j]
>
> *For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range.* (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 16A.4.1 included below gives summary statistics for the four calibrated distributions.

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[i] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (e.g. Hansen et al. 2007).

[j] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut et al.2007). "Very likely" indicates a greater than 90 percent probability.

Table 16-A.4.1 Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

(1) a median equal to 3°C, to reflect the judgment of "a most likely value of about 3 °C";[k]
(2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
(3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007, Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and

[k] Strictly speaking, "most likely" refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or "most likely" value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3°C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3°C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3°C than is the mode for the truncated distributions selected by the IPCC (Hegerl, et al., 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

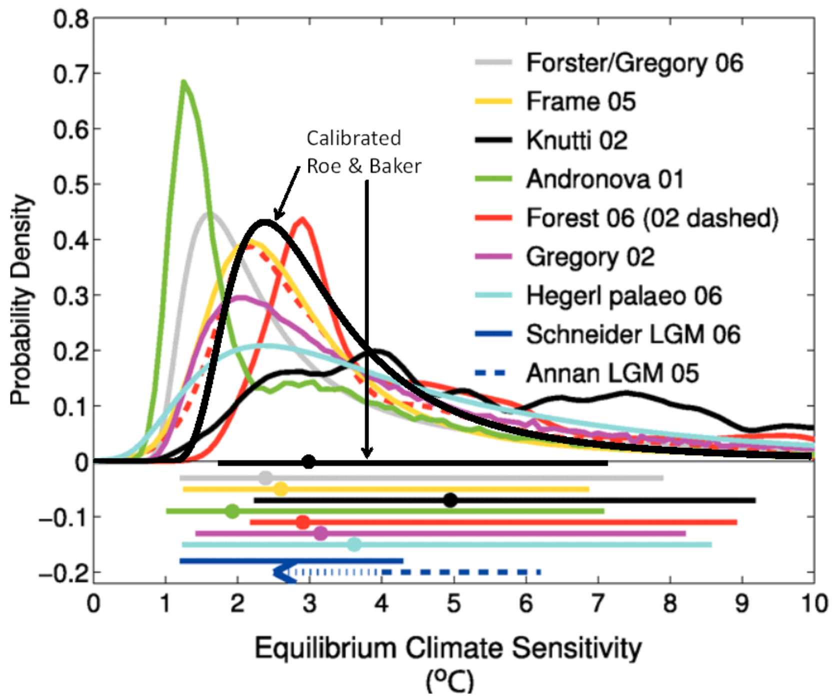

Figure 16-A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 16A.4.3 (above) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[1]

[1] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

16-A.4.5 Socio-Economic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socio-economic and emissions parameters for use in PAGE, DICE, and FUND. Socio-economic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (e.g., SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socio-economic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 16A.4.2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (i.e., CO_2-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[m] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

[m] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

Table 16-A.4.2 Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios

Reference Fossil and Industrial CO_2 Emissions ($GtCO_2$/yr)						
EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005$)[n]						
EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)						
EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socio-economic pathways.

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[n] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (e.g., Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (i.e., using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range, from the more optimistic (e.g. abundant low-cost, low-carbon energy) to more pessimistic (e.g. constraints on the availability of nuclear and renewables).[o] Second, the socio-economic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (e.g. MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[p] We chose not to include socio-economic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be \$51.8, \$71.0 and \$93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (e.g. aerosols and other gases). See the Annex for greater detail.

16-A.4.6 Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated

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[o] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.

[p] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, "If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent." For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled "descriptive" and "prescriptive." The descriptive approach reflects a positive (non-normative) perspective based on observations of people's actual choices—e.g., savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return "because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use" (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (e.g., Just et al. 2004). As some have noted, the word "potentially" is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—e.g., how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is "ethically indefensible" to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[q] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's recommendation to use 3 percent to represent the consumption rate of interest.[r] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity

[q] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

[r] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes yields a real rate of roughly 5 percent.[s]

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[t] These are then combined with g (growth rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[u] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta g$, will be equal to the rate of return to capital, i.e., the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning.[v] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, since η equal to 1 suggests savings rates that do not conform to observed behavior.

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[s] Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

[t] The parameter ρ measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.

[u] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

[v] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an intergenerational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socio-economic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed as an ethical choice linked to the value of an additional dollar in poorer countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of $\rho = 0.1$ percent per year, $\eta = 1$ and $g = 1.3$ percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[w]

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with $\eta = 1$). Using Stern's assumption that $\rho = 0.1$ percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate greater 2 percent.

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the

[w] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (e.g., Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate initially, but applies a graduated scale of lower discount rates further out in time.[x] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[y]

The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously

[x] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[y] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.[z] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

16-A.5 REVISED SCC ESTIMATES

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMS, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

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[z] Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.
c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3. Add an additional unit of carbon emissions in year *t*. (The exact unit varies by model.)

4. Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10 year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Annex.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no integrated assessment model or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socio-economic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95^{th} percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Annex.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 16A.5.1, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 16-A.5.1 Disaggregated Social Cost of CO_2 Values by Model, Socio-Economic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

Model	*Discount rate:* *Scenario*	**5%** Avg	**3%** Avg	**2.5%** Avg	**3%** 95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around \$9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around \$9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to \$8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[aa]

[aa] Nordhaus (2008) runs DICE2007 with $\rho = 1.5$ and $\eta = 2$. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ, and 0.5, 1, and 2 for η, respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of ρ = 0, 1, and 3 in many recent papers (e.g. Anthoff et al. 2009). The path of per-capita consumption growth, g, varies over time but is treated deterministically in two of the three models. In DICE, g is

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 16A.5.1 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

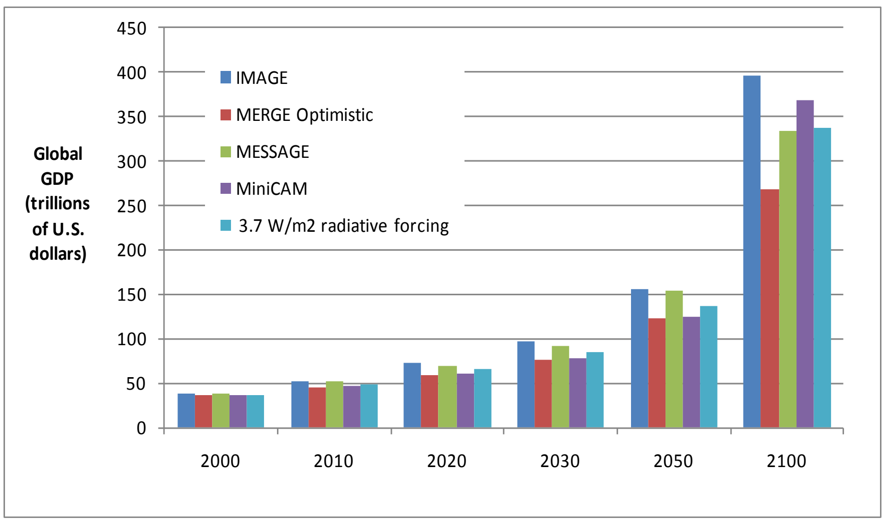

Figure 16-A.5.1 Level of Global GDP across EMF Scenarios

Table 16A.5.2 shows the four selected SCC values in five year increments from 2010 to 2050. Values for 2010, 2020, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

Table 16-A.5.2 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 16A.5.3 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 16-A.5.3 Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	**5%** Avg	**3%** Avg	**2.5%** Avg	**3.0%** 95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.[bb]

16-A.6 LIMITATIONS OF THE ANALYSIS

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold "are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-

[bb] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

impact low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning ; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[cc] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs under or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability but lower-impact damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

[cc] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in the results. Using FUND, Anthoff et al (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that "the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

16-A.7 A FURTHER DISCUSSION OF CATASTROPHIC IMPACTS AND DAMAGE FUNCTIONS

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models' functional forms may not adequately capture: (1) potentially discontinuous "tipping point" behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic "tipping points" at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (e.g., Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 16A.7.1. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (i.e., ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 16A.4.1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socio-economic and emission trajectories of \$113 per ton of CO_2 is almost double the value estimated by DICE, \$58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 16-A.7.1 Probabilities of Various Tipping Points from Expert Elicitation

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (e.g., Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

16-A.8 CONCLUSION

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

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16-A.9 ANNEX

Table 16-A.9.1 Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Annex also provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300, and shows the full distribution of 2010 SCC estimates by model and scenario combination.

16-A.9.1 Other (non-CO2) gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (e.g., aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[dd] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (e.g., DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_20, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

PAGE: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors[ee], decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_20, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

According to AR4, the RF in 2005 from CH_4, N_20, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was 0.48 + 0.16 + 0.34 = 0.98 W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be

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[dd] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

[ee] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

(1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter, and
(2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

> *Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.*[ff]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, Figure A1 shows that the sulfur dioxide emissions peak over the short-term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[gg] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[hh] The lower bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

[ff] AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[gg] See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

[hh] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. Environmental Science and Technology, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. Science, 294(5548): 1835-1837.

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m^2; forcing due to other non-CO_2 gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m^2.

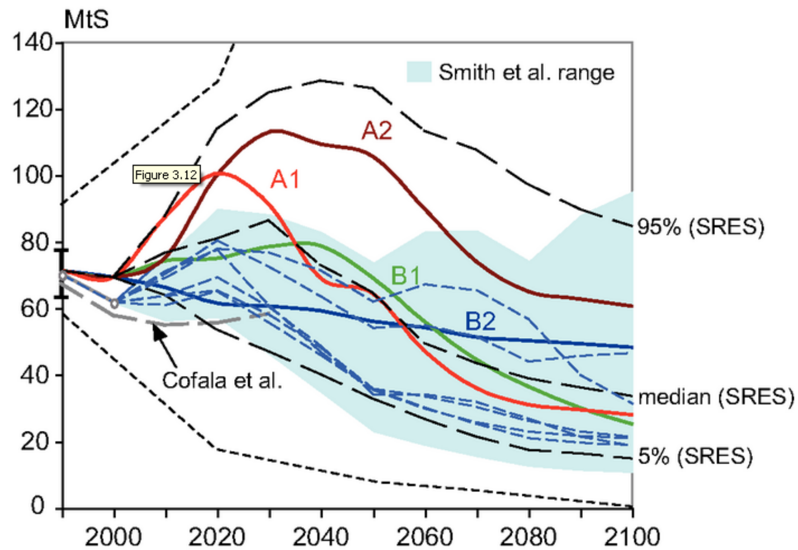

Figure 16-A.9.1 Sulphur Dioxide Emission Scenarios

Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES.
Source: IPCC (2007), AR4 WGIII 3.2, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or $0.50-$3)–depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

16-A.9.2 Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/ per capita growth rate declines linearly, reaching zero in the year 2300.
3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[ii] The resulting range of EMF population trajectories (Figure A2) also encompass the UN medium scenario forecasts through 2300 – global population of 8.5 billion by 2200, and 9 billion by 2300.

Maintaining the decline in the 2090-2100 carbon intensity growth rate (i.e., CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

[ii] United Nations. 2004. *World Population to 2300*. http://www.un.org/esa/population/publications/longrange2/worldpop2300final.pdf

Figures A2-A7 show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

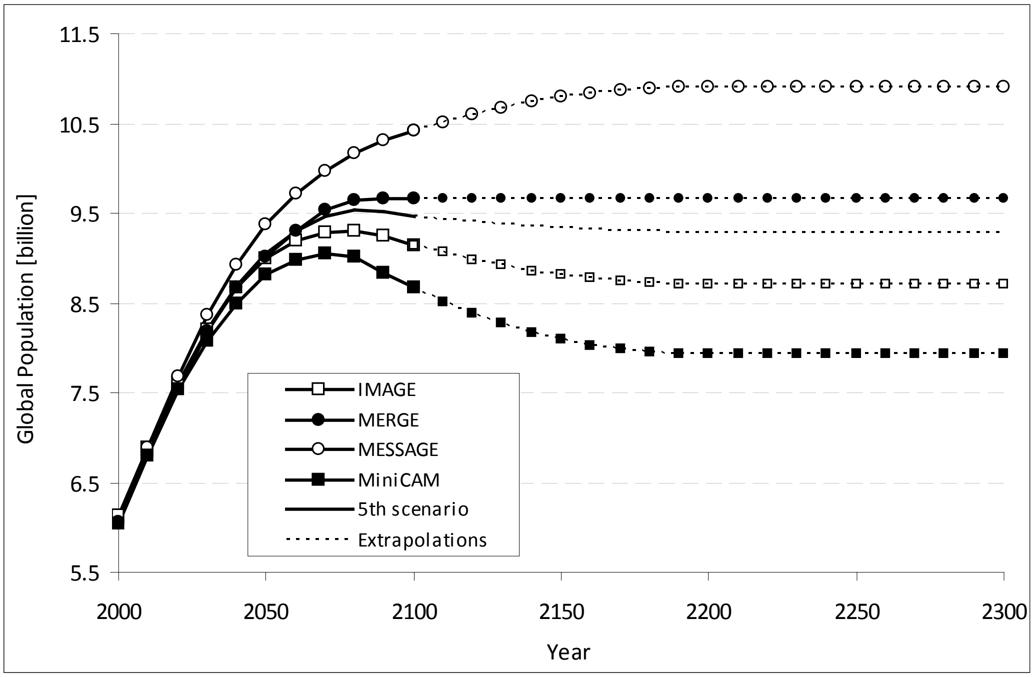

Figure 16-A.9.2 Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200.)

Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

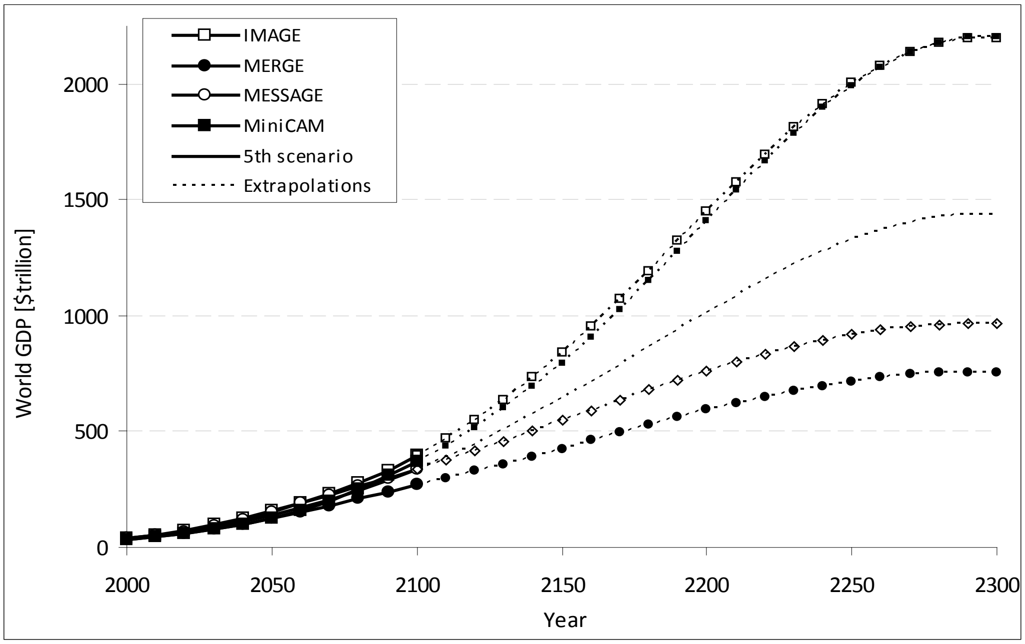

Figure 16-A.9.3 World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)

Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

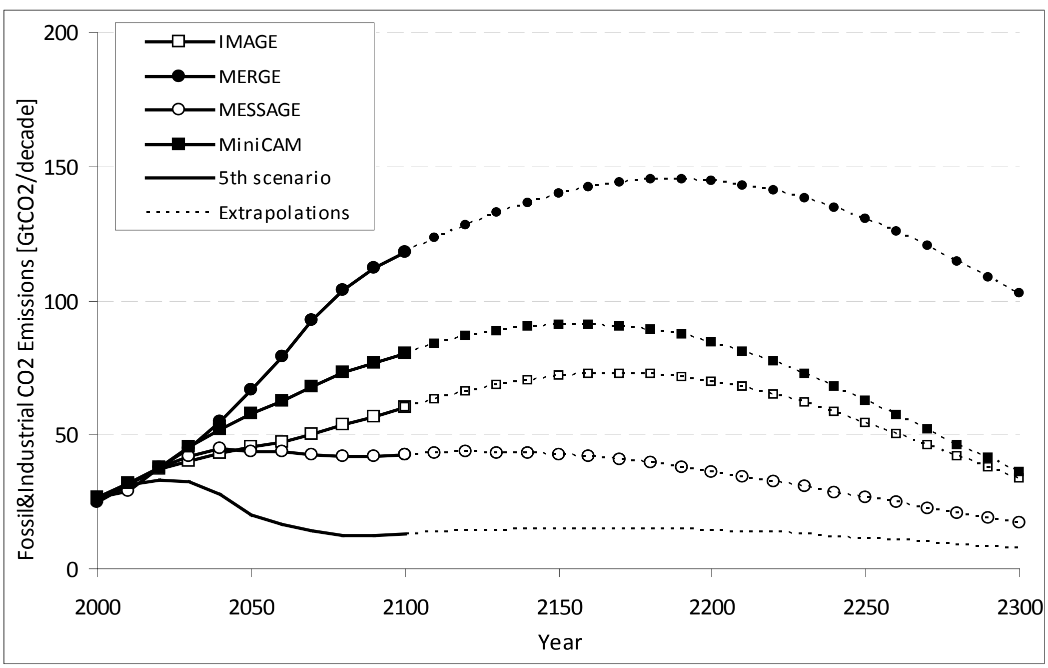

Figure 16-A.9.4 Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300.)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

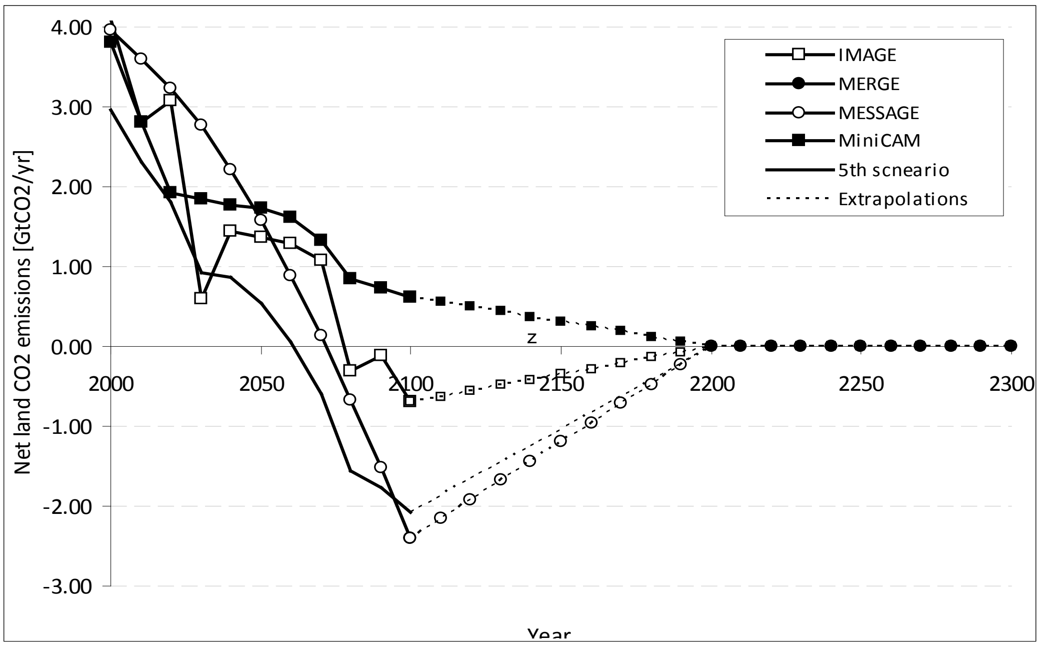

Figure 16-A.9.5 Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[jj]

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

[jj] MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

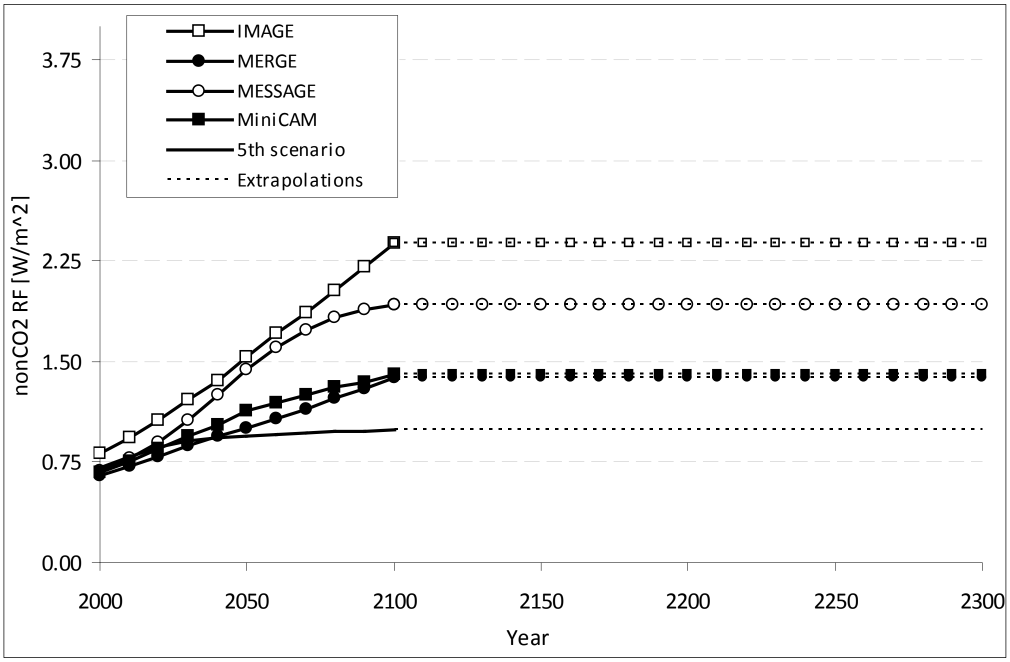

Figure 16-A.9.6 Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

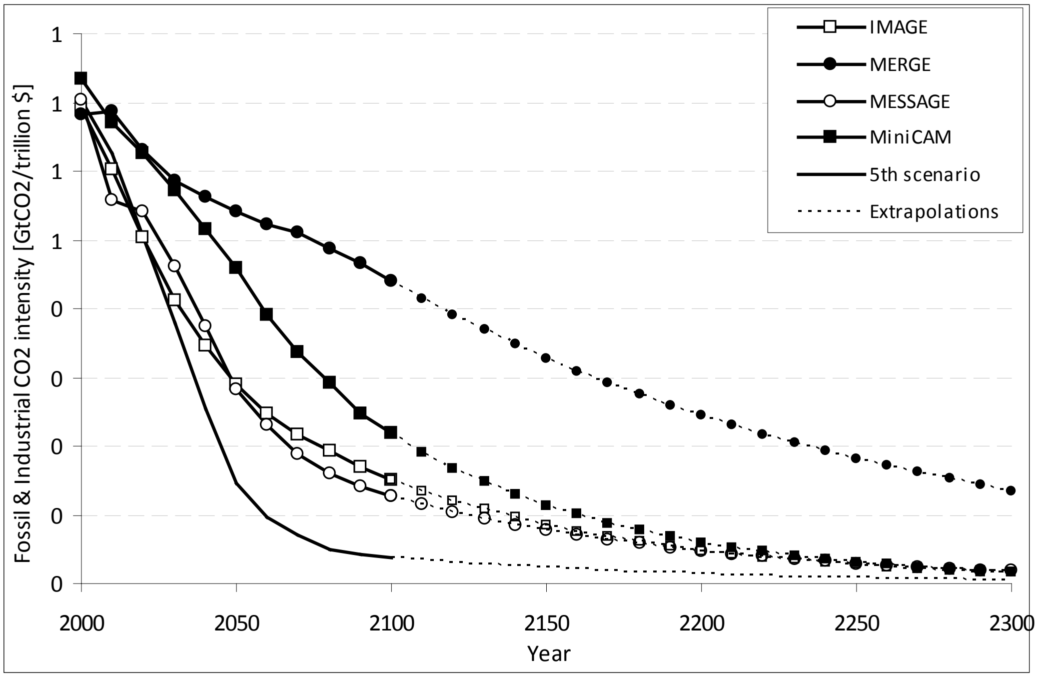

Figure 16-A.9.7 Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table 16-A.9.2 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9

Scenario	**DICE**									
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8

Scenario	**FUND**									
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table 16-A.9.3 2010 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					**PAGE**					
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5

Scenario					**DICE**					
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6

Scenario					**FUND**					
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table 16-A.9.4 2010 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					**PAGE**					
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7
Scenario					**DICE**					
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0
Scenario					**FUND**					
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

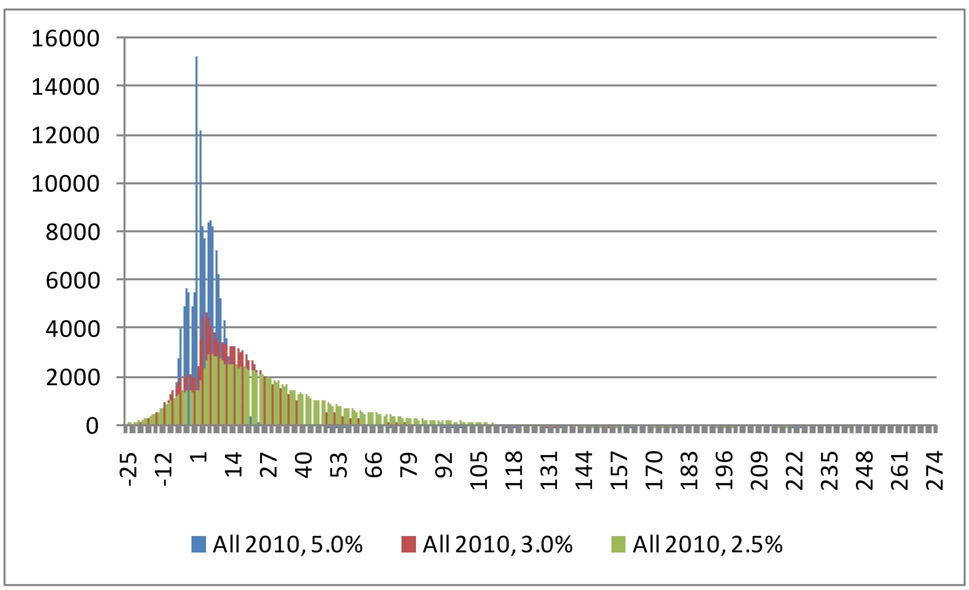

Figure 16-A.9.8 Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by discount rate

* The distribution of SCC values ranges from -$5,192 to $66,116 but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table 16-A.9.5 Additional Summary Statistics of 2010 Global SCC Estimates

Discount Rate		Scenario		
		DICE	PAGE	FUND
5%	Mean	9	6.5	-1.3
	Variance	13.1	136	70.1
	Skewness	0.8	6.3	28.2
	Kurtosis	0.2	72.4	1,479.00
3%	Mean	28.3	29.8	6
	Variance	209.8	3,383.70	16,382.50
	Skewness	1.1	8.6	128
	Kurtosis	0.9	151	18,976.50
2.50%	Mean	42.2	49.3	13.6
	Variance	534.9	9,546.00	#######
	Skewness	1.2	8.7	149
	Kurtosis	1.1	143.8	23,558.30

APPENDIX 17-A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

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APPENDIX 17-A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

17-A.1 INTRODUCTION

This appendix contains sections discussing the following topics:

- NIA-RIA Integrated Models
- XENERGY penetration curves used to analyze consumer rebates, including:
  - Background material,
  - DOE's adjustment of these curves for this analysis,
  - DOE's new method for interpolating the curves, and
  - Presentation of the interpolated curves by product class
- Projections of annual market share increases for the six alternative policies
- Detailed tables of rebates offered for the considered products
- Background material on Federal and state tax credits for appliances

17-A.2 NIA-RIA INTEGRATED MODEL

For this analysis, DOE developed an integrated NIA-RIA[a] model approach that built on the NIA models discussed in chapter 10 and documented in Appendix 10-A.The resulting four NIA-RIA models (one for each product group)[b] featured both the NIA analysis inputs and results and the RIA inputs with capability to generate results for each of the RIA policies. A separate module produced summaries of inputs for the rebate policy, generated their penetration curves (discussed in section 17-A.3.3 below), reported shipment and market share increase data by product class, and produced summary tables for the national energy savings and net present value results reported in chapter 17, sections 17.4 and 17.5. This module also generated tables of market share increases for each policy reported in section 17-A.4 of this Appendix.

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[a] NIA = national impact analysis; RIA = regulatory impact analysis

[b] The four product groups are Standard-Size Refrigerator-Freezers, Standard-Size Freezers, Compact Refrigeration Products, and Built-in Refrigeration Products.

17-A.3 CONSUMER REBATE POLICY MARKET PENETRATION CURVES

This section first discusses the theoretical basis for the market penetration curves that DOE used to analyze the Consumer Rebates policy. Next it discusses the adjustments it made to the maximum penetration rates. It then presents the method it developed to create interpolated penetration curves for each specific product class and efficiency level in the analysis. Examples of the resulting curves for standard-size refrigerator-freezer product classes are in chapter 17, section 17.3.2.1. The curves for the product classes in the remaining product groups: standard-size freezers, compact refrigeration products, and built-in refrigeration products — are in section 17-A.3.4 below.

17-A.3.1 Introduction

XENERGY, Inc.[c], developed a re-parameterized, mixed-source information diffusion model to estimate market impacts induced by financial incentives for purchasing energy efficient appliances.[1] The basic premise of the mixed-source model is that information diffusion drives the adoption of technology.

Extensive economic literature describes the diffusion of new products as technologies evolve. Some research focuses primarily on developing analytical models of diffusion patterns applicable to individual consumers or to technologies from competing firms.[2],[3],[4] One study records researchers' attempts to investigate the factors that drive diffusion processes.[5] Because a new product generally has its own distinct characteristics, few studies have been able conclusively to conclusively develop a universally applicable model. Some key findings, however, generally are accepted in academia and industry.

One accepted finding is that, regardless of their economic benefits and technological merits, new technologies are unlikely to be adopted by all potential users. For many products, a ceiling must be placed on the adoption rate. A second conclusion is that not all adopters purchase new products at the same time: some act quickly after a new product is introduced; others wait for the product to mature. Third, diffusion processes can be characterized approximately by asymmetric S-curves that depict three stages of diffusion: starting, accelerating, and decreasing (as the adoption ceiling is approached).

A so-called epidemic model of diffusion is used widely in marketing and social studies. The epidemic model assumes that (1) all consumers place identical value on the benefits of a new product, and (2) the cost of a new product is constant or declines monotonically over time. What induces a consumer to purchase a new product is information about the availability and benefits of the product. In other words, information diffusion drives consumers' adoption of a new product.[3] The model incorporates information diffusion from both internal sources (spread by word of mouth from early adopters to prospective adopters) and external sources (the "announcement effect" produced by government agencies, institutions, or commercial

[c] XENERGY is now owned by KEMA, Inc. (www.kema.com)

advertising). The model incorporates both internal and external sources by combining a logistic function with an exponential function.[4],[5]

The relative degree of influence from the internal and external sources determines the general shape of the diffusion curve for a specific product.[4],[5] If adoption of a product is influenced primarily by external sources of information (the announcement effect), for instance, a high rate of diffusion occurs at the beginning of the process. In this scenario, external sources provide immediate information exposure to a significant number of prospective adopters. In contrast, internal sources (such as a network of prospective adopters) are relatively small in size and reach, producing a more gradual exposure to prospective adopters. Graphically speaking, information diffusion dominated by external sources is represented by a concave curve (the exponential curve in Figure 17-A.3.1). If adoption of a new product is influenced most strongly by internal sources of information, the number of adopters increases gradually, forming a convex curve (the logistic curve in Figure 17-A.3.1).

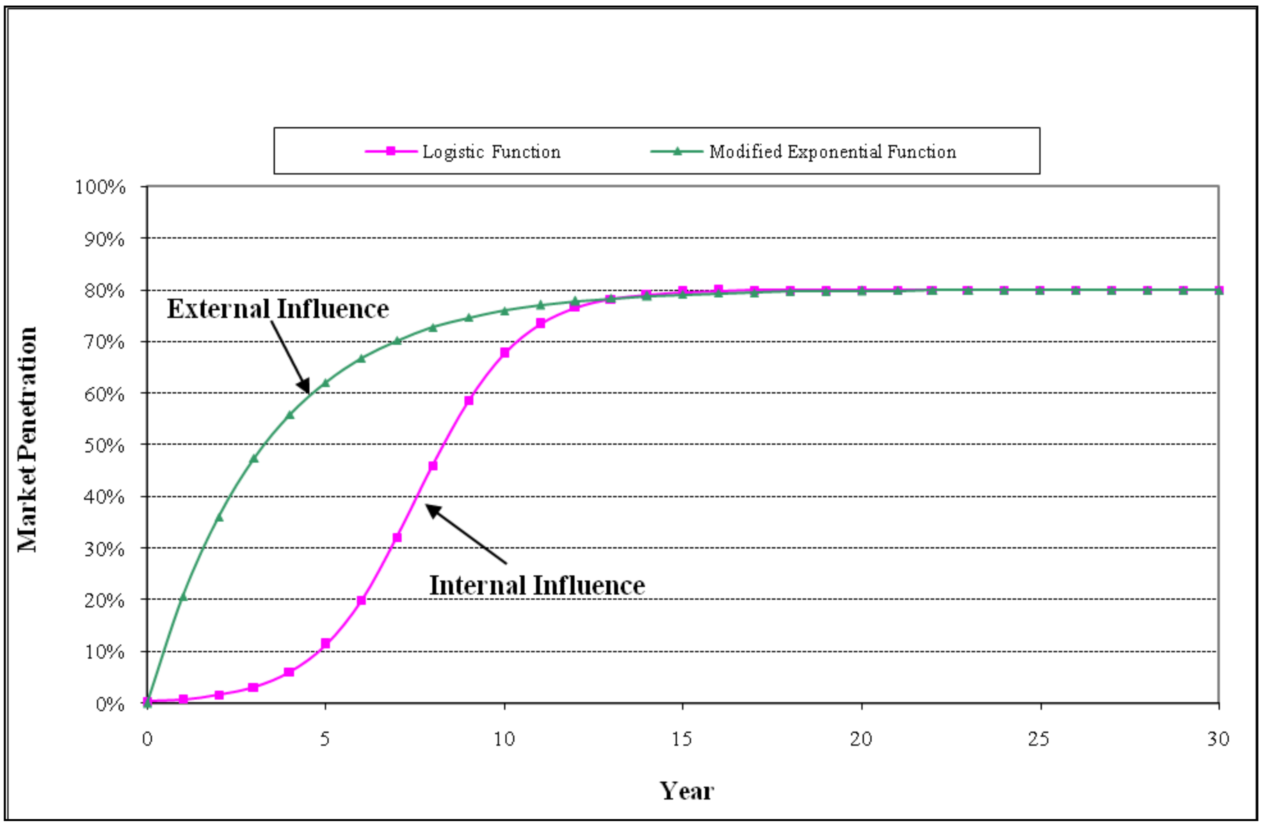

Figure 17-A.3.1 S-Curves Showing Effects of External and Internal Sources on Adoption of New Technologies

17-A.3.2 Adjustment of XENERGY Penetration Curves

In consultation with the primary authors of the 2002 XENERGY study who later conducted similar California studies, DOE made some adjustments to XENERGY's original implementation (penetration) curves.[6] The experiences with utility programs since the

XENERGY study indicate that incentive programs have difficulty achieving penetration rates as high as 80 percent. Consumer response is limited by barriers created by consumer utility issues and other non-economic factors. DOE therefore adjusted the maximum penetration parameters for some of the curves from 80 percent to the following levels:

Moderate Barriers:	70%
High Barriers:	60%
Extremely High Barriers:	50%

The *low barriers* and *no barriers* curves (the latter used only when a product has a very high base-case-market share) remained, respectively, with 80 percent and 100 percent as their maximum penetration rates. For the interpolated penetration curves (discussed below), DOE set the *no barriers* and *extremely high barriers* curves as the upper and lower bounds, respectively, for any benefit/cost ratio points higher or lower than the curves. It set another constraint such that the policy case market share cannot be great than 100 percent, as might occur for products with high base case market shares of the target-level technology.

17-A.3.3 Interpolation of Penetration Curves

As discussed above, the XENERGY penetration (implementation) curves followed a functional form to estimate the market implementation rate caused by energy efficiency measures such as consumer rebates.[d] The XENERGY report presents five reference market implementation curves that vary according to the level of market barriers to technology penetration.[1] Such curves have been used by DOE in the Regulatory Impact Analyses for rulemakings for appliance energy efficiency standards to estimate market share increases in response to rebate programs.[e] They provide a framework for evaluating technology penetration, yet require matching the studied market to the curve that best represents it. This approximate matching can introduce some inaccuracy to the analysis.

This section presents an alternative approach to such evaluation: a method to estimate market implementation rates more accurately by performing interpolations of the reference curves. The following describes the market implementation rate function and the reference curves, the method to calibrate the function to a given market, and the limitations of the method.

[d] The RIA chapter refers to these curves as *penetration curves*. This section, in references to the original source, uses the term *implementation curve*.
[e] DOE has also used this method to estimate market share increases resulting from consumer tax credit and manufacturer tax credit programs, since the effects of tax credits on markets can be considered proportional to the rebate impacts.

17-A.3.3.1 Market Implementation Rate Function and Curves

The XENERGY curves employ the following functional form to estimate the percentage of the informed market[f] that will accept each energy-efficiency measure based on the participant's benefit/cost ratio:

$$\mathrm{imp(bc)} = \frac{\mathrm{max}}{\left(1+\mathrm{e}^{-\ln\left(\frac{\mathrm{bc}}{4}\right)}\right)\cdot\left(1+\mathrm{e}^{-\mathrm{fit}\cdot\ln(\mathrm{mid}\cdot\mathrm{bc})}\right)} \qquad [1]$$

where:

imp implementation rate
bc benefit/cost ratio
max maximum annual acceptance rate for the technology
mid inflection point of the curve
fit parameter that determines the general shape (slope) of the curve.

In recent efficiency standards rulemakings, DOE has been adopting a slightly different functional form of Equation [1], where the constant value 1/4 is replaced by a parameter *r*. By introducing this parameter in Equation [1] and rewriting it without the exponential and logarithmic operators, the market implementation rate of rebate programs can be evaluated using the following equation:

$$imp(bc) = \frac{max}{\left(1+\frac{1}{r\cdot bc}\right)\cdot\left(1+(mid\cdot bc)^{-fit}\right)} \qquad [2]$$

In XENERGY's report, Equation [1] is used to generate five primary (reference) curves. These curves produce initial theoretical results that are calibrated to actual measure implementation results associated with the first year of major utility energy efficiency programs. Different curves, generated using distinct values of the parameters *max*, *mid*, *fit* and *r*, reflect different levels of market barriers for different efficiency measures.

DOE has been using similar curves in the appliance efficiency standards rulemaking. The curves characterize market implementation rates for five reference levels of market barriers: *No Barriers*, *Low Barriers*, *Moderate Barriers*, *High Barriers,* and *Extremely High Barriers*. Figure 17-A.3.2 presents the five reference curves.

[f] The *informed market* refers to the portion of the market aware and informed about the energy efficiency measure.

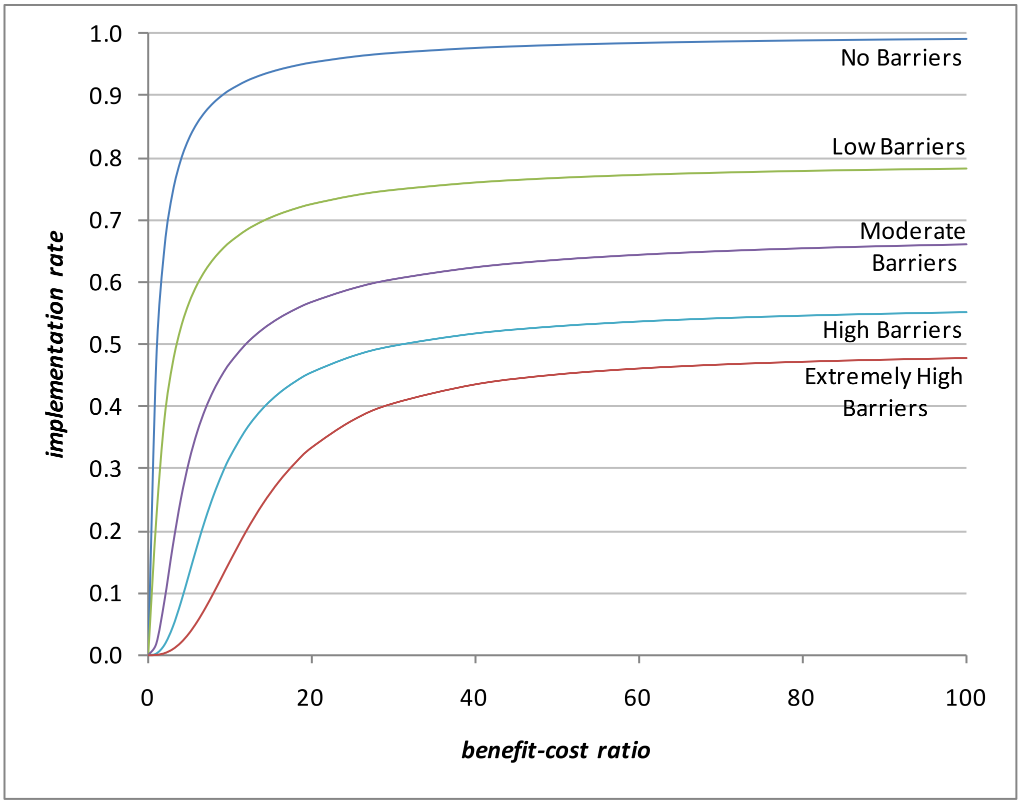

Figure 17-A.3.2 Market Implementation Curves for Five Market Barriers Reference Levels

The reference curves build on the following functional form:

$$imp(b_d, bc) = \frac{max_d(b_d)}{(1 + r_d(b_d) \cdot bc) \cdot (1 + (mid_d(b_d) \cdot bc)^{-fit_d(b_d)})} \qquad [3]$$

where:

b_d = [barrier type]

and $max_d(b_d)$, $mid_d(b_d)$, $fit_d(b_d)$ and $r_d(b_d)$ are as shown in Table 17-A.3.1. The four parameters are also presented in Figure 17-A.3.3 as discrete-value functions.

Table 17-A.3.1 Parameter Values for Reference Curves

	Market Barriers Level				
	No Barriers	*Low Barriers*	*Moderate Barriers*	*High Barriers*	*Extremely High Barriers*
max_d	1.0	0.8	0.7[g]	0.6[g]	0.5 [g]
mid_d	10	2	0.3	0.1	0.04
fit_d	1	1.7	1.7	1.7	1.7
r_d	1	0.5	0.25	0.25	0.25

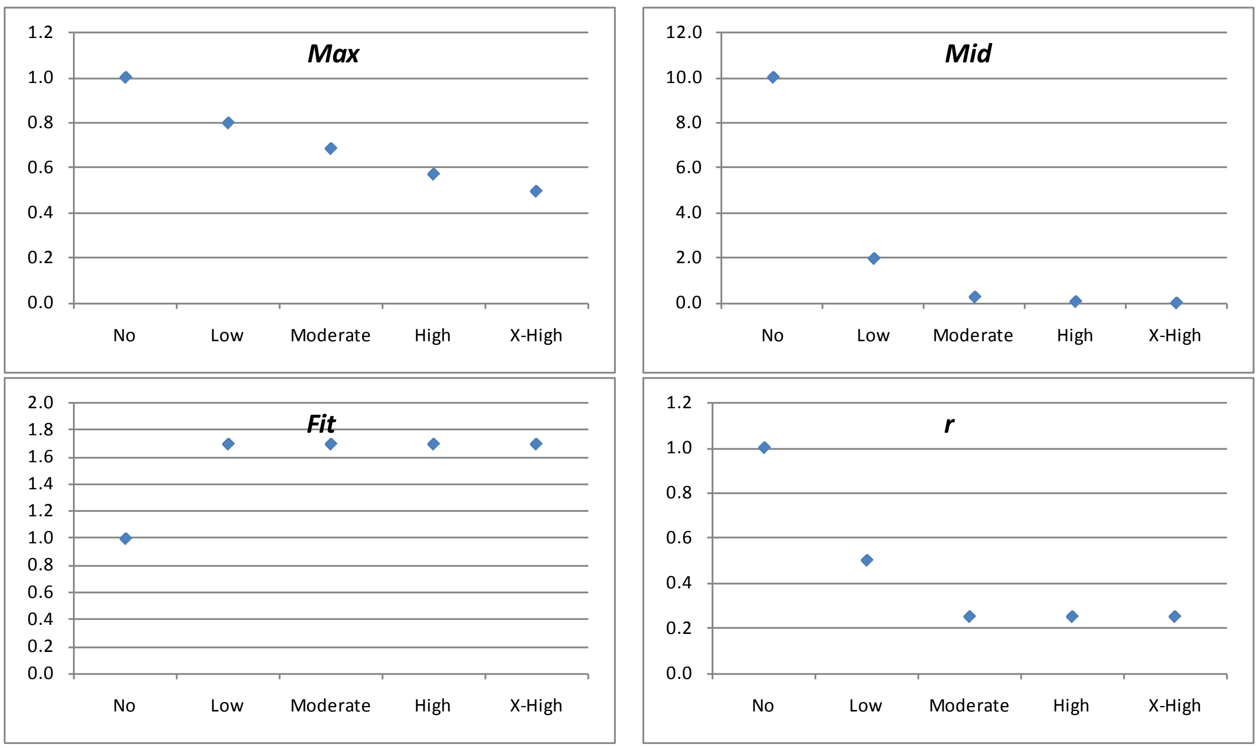

Figure 17-A.3.3 Discrete-value Functions of Parameters Driving Implementation Curve Shape

To estimate the barrier level of a given market, in the past DOE sought the reference curve that most closely represented the pair (base case market share, benefit/cost ratio) of the technology corresponding to the mandatory standard's chosen efficiency level. It then estimated

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[g] DOE adopted these parameters for the Refrigeration Products RIA, as discussed in section 17-A.3.2, after consultation with the implementation curve authors. For the RIAs for the rulemakings for Cooking Products and Commercial Clothes Washers the *max* value adopted for the *moderate barriers* and *high barriers* market barrier levels was 0.5. RIAs developed during prior rulemakings for Furnaces and Boilers, Commercial Unitary Air Conditioners and Heat Pumps, and Distribution Transformers used a *max* value of 0.8 for all but the *no barriers* curve, based on the original penetration curve values from XENERGY's report.

the effect of a rebate program on the technology market penetration using that curve. For this estimation, DOE calculated the increase in market share that an increase in the benefit/cost ratio – driven by a rebate program – would produce. It then assumed that the relative increase in market share calculated from the reference curve was a *proxy* to the effects of a rebate program on the studied market.

17-A.3.3.2 Calibrating the Market Implementation Rate Function

The procedure previously described lacks accuracy when the studied market penetration point based on the actual benefit/cost ratio does not lie close to one of the reference curves. This section presents an interpolation approach to eliminate such inaccuracy. The interpolation process provides intermediate, continuous values for the four parameters (*max*, *mid*, *fit* and *r*) driving the market implementation curves. These intermediate values are obtained after linear interpolation of their corresponding reference values.

The four parameters (*max*, *mid*, *fit* and *r*) were previously defined as discrete-value functions ($max_d(b_d)$, $mid_d(b_d)$, $fit_d(b_d)$ and $r_d(b_d)$) of the market barriers level (Table 17-A.3.1, Figure 17-A.3.2). To facilitate the interpolation, it is necessary to transform the four discrete-value functions into continuous functions, the latter being thus capable of associating each of the four parameters to a real number denoting the market barrier level ($b_c \in \mathbf{R}$). A numeric, continuous scale for the market barriers level is proposed, ranging from 0 to 5 ($b_c \in [0,5]$). The correspondence between the discrete-values of market barrier levels and b_c are shown in Table 17-A.3.2.

Based on the continuous-value market barriers level, the parameters *max*, *mid*, *fit* and *r* are interpolated using the following functions:

$$max_c(b_c) = \propto_{max}(b_c) \cdot b_c + \beta_{max}(b_c) \quad [4]$$

$$mid_c(b_c) = \propto_{mid}(b_c) \cdot b_c + \beta_{mid}(b_c) \quad [5]$$

$$fit_c(b_c) = \propto_{fit}(b_c) \cdot b_c + \beta_{fit}(b_c) \quad [6]$$

$$r_c(b_c) = \propto_{r}(b_c) \cdot b_c + \beta_{r}(b_c) \quad [7]$$

where $\propto_x(b_c)$ and $\beta_x(b_c)$ are shown in Table 17-A.3.3.

The continuous-value functions defined for *max*, *mid*, *fit* and *r*, as expressed by Equations [4]-[7], are then substituted in Equation [3], leading to the following functional form for the market implementation rate of rebate programs:

$$imp(b_c, bc) = \frac{max_c(b_c)}{(1 + r_c(b_c) \cdot bc) \cdot (1 + (mid_c(b_c) \cdot bc)^{-fit_c(b_c)})} \quad [8]$$

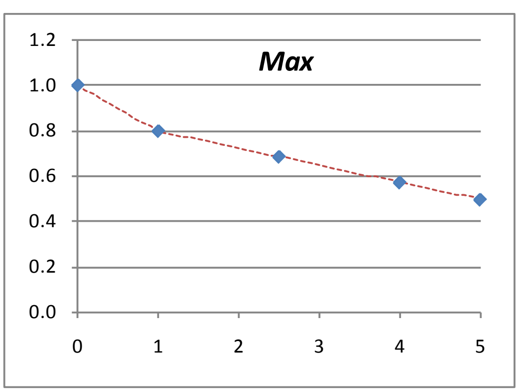
Table 17-A.3.2 Correspondence between Discrete and Continuous Values of Market Barrier Levels

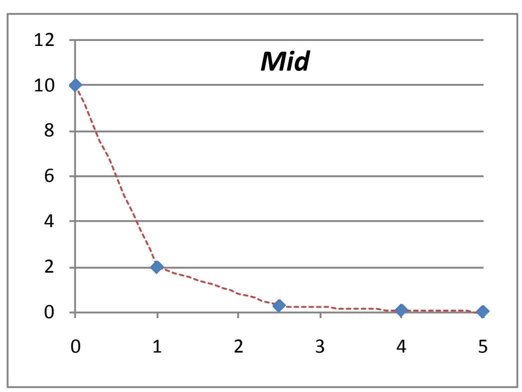
	Market Barriers Level				
	No Barriers	*Low Barriers*	*Moderate Barriers*	*High Barriers*	*Extremely High Barriers*
b_c	0.0	1.0	2.5	4.0	5.0

Table 17-A.3.3 Coefficients of Continuous-value Functions of *max*, *mid*, *fit* and *r*

	Market Barriers Level Intervals			
	No-Low Barriers $b \in [0,1]$	*Low-Moderate Barriers* $b \in [1,2.5]$	*Moderate-High Barriers* $b \in [2.5,4]$	*High-Extremely High Barriers* $b \in [4,5]$
Max				
$\propto_{max}(b_c)$	-0.200	-0.075	-0.075	-0.075
$\beta_{max}(b_c)$	1.000	0.875	0.875	0.875
Mid				
$\propto_{mid}(b_c)$	-8.000	-1.133	-0.133	-0.060
$\beta_{mid}(b_c)$	10.000	3.133	0.633	0.340
Fit				
$\propto_{fit}(b_c)$	0.700	0.000	0.000	0.000
$\beta_{fit}(b_c)$	1.000	1.700	1.700	1.700
R				
$\propto_{r}(b_c)$	-0.500	-0.167	0.000	0.000
$\beta_{r}(b_c)$	1.000	0.667	0.250	0.250

Figure 17-A.3.4 presents the four continuous-value functions.





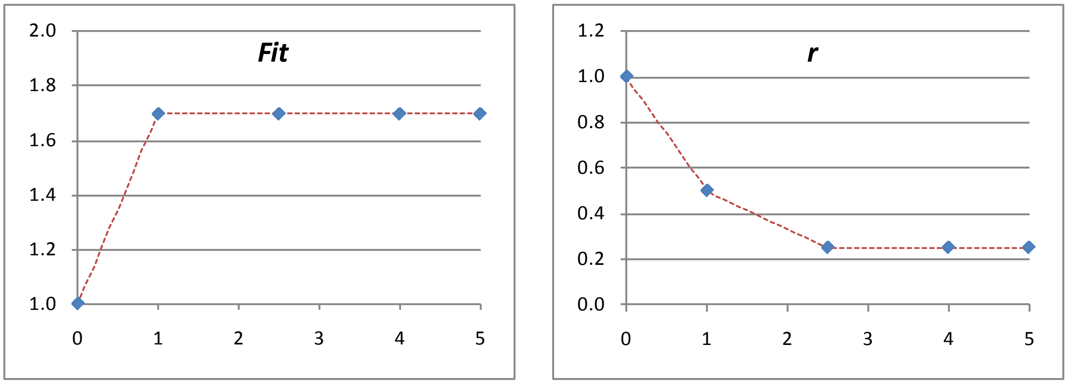


Figure 17-A.3.4 Continuous-value Functions of Parameters Driving Implementation Curve Shape

Hence, estimating the market effects of a rebate program relies on finding the interpolated implementation curve that best represents the studied market. In other words, it involves finding b_c such that the pair $(imp(b_c, bc), bc)$ equals the pair (base case market share, benefit/cost ratio) of the technology corresponding to the mandatory standard's efficiency level. Once the appropriate value of b_c is found (e.g. $b_c = \mathrm{b}_\mathrm{c}^*$), the market penetration of the technology under a rebate program can be calculated by the following equation:

$$imp(\mathrm{b}_\mathrm{c}^*, \mathrm{bc}^*) = \frac{max_c(\mathrm{b}_\mathrm{c}^*)}{(1 + r_c(\mathrm{b}_\mathrm{c}^*) \cdot \mathrm{bc}^*) \cdot (1 + (mid_c(\mathrm{b}_\mathrm{c}^*) \cdot \mathrm{bc}^*)^{-fit_c(\mathrm{b}_\mathrm{c}^*)})} \qquad [9]$$

where:

b_c^* market barriers level corresponding to the studied market

bc^* benefit/cost ratio with rebate.

17-A.3.3.3 Limits to the Interpolation Approach

The approach presented above increases the accuracy of the estimate of the market implementation rate resulting from a rebate program. Consequently, it improves the analysis of the market effects of rebate programs. However, whereas it is feasible to develop interpolated implementation curves between the reference ones, there is no empirical support to extrapolate them beyond the *No Barriers* and the *Extremely High Barriers* curves. In fact, the theoretical boundaries for the market barriers level would be:

(a) Zero Barriers (b_0): With the assumption of the rational consumer, a tiny increase in the benefit/cost ratio of a technology with that ratio greater than 1 would be sufficient to make the technology widely adopted.[h] This would result in the following implementation rate function:

[h] When the benefit/cost ratio is 1 the participant is indifferent to adopting the technology or not, and the implementation rate, in this case, would be undetermined.

$$imp(b_0, bc) = \begin{cases} 0, & bc < 1 \\ 1, & bc > 1 \end{cases}$$

(b) Infinite Barriers (b_∞): In this case, even an extremely high benefit/cost ratio would not be sufficient to cause the market to adopt a technology. This would result in the following implementation rate function:

$$imp(b_\infty, bc) = 0, \forall bc$$

However, notwithstanding the existence of such theoretical boundaries, the analysis of market implementation rates in cases of markets where the base case market share is either higher than the market share in the *No Barriers* curve (for the corresponding benefit/cost ratio), or lower than the one in the *Extremely High Barriers* curve (idem), should follow the former analysis approach (as described at the end of section 17-A.3.3.2). It should rely, respectively, on the *No Barriers* or the *Extremely High Barriers* curves to estimate a relative market increase due to the rebate program.

17-A.3.4 Interpolated Penetration Curves for Standard-Size Freezers, Compact Refrigeration Products, and Built-in Refrigeration Products

Figures 17-A.3.5 through 17-A.3.13 show the interpolated penetration curves for the product classes in the product groups of Standard-Size Freezers, Compact Refrigeration Products, and Built-in Refrigeration Products. Chapter 17, Figures 17.3.1 through 17.3.3, show the interpolated penetration curves for the product classes of Standard-Size Refrigerator-Freezers.

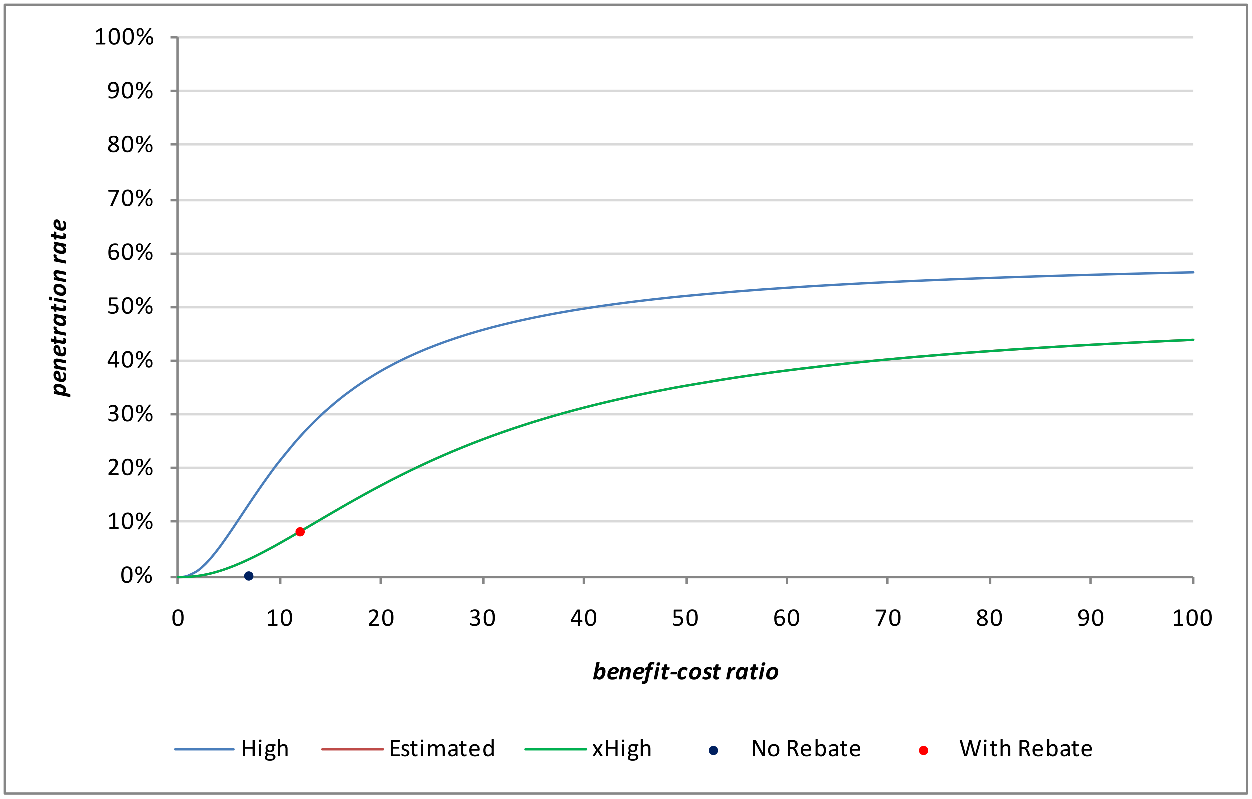


Figure 17-A.3.5 Market Penetration Curve for Upright Freezers

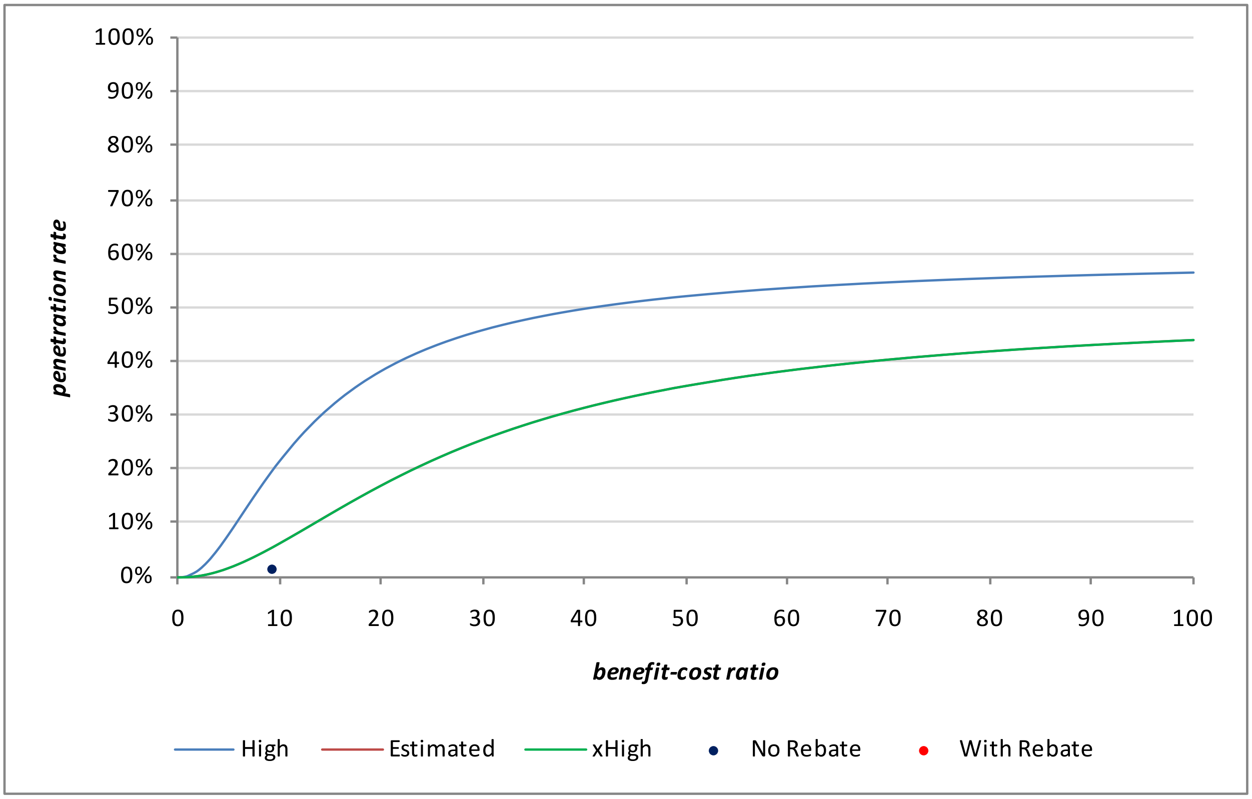


Figure 17-A.3.6 Market Penetration Curve for Chest Freezers

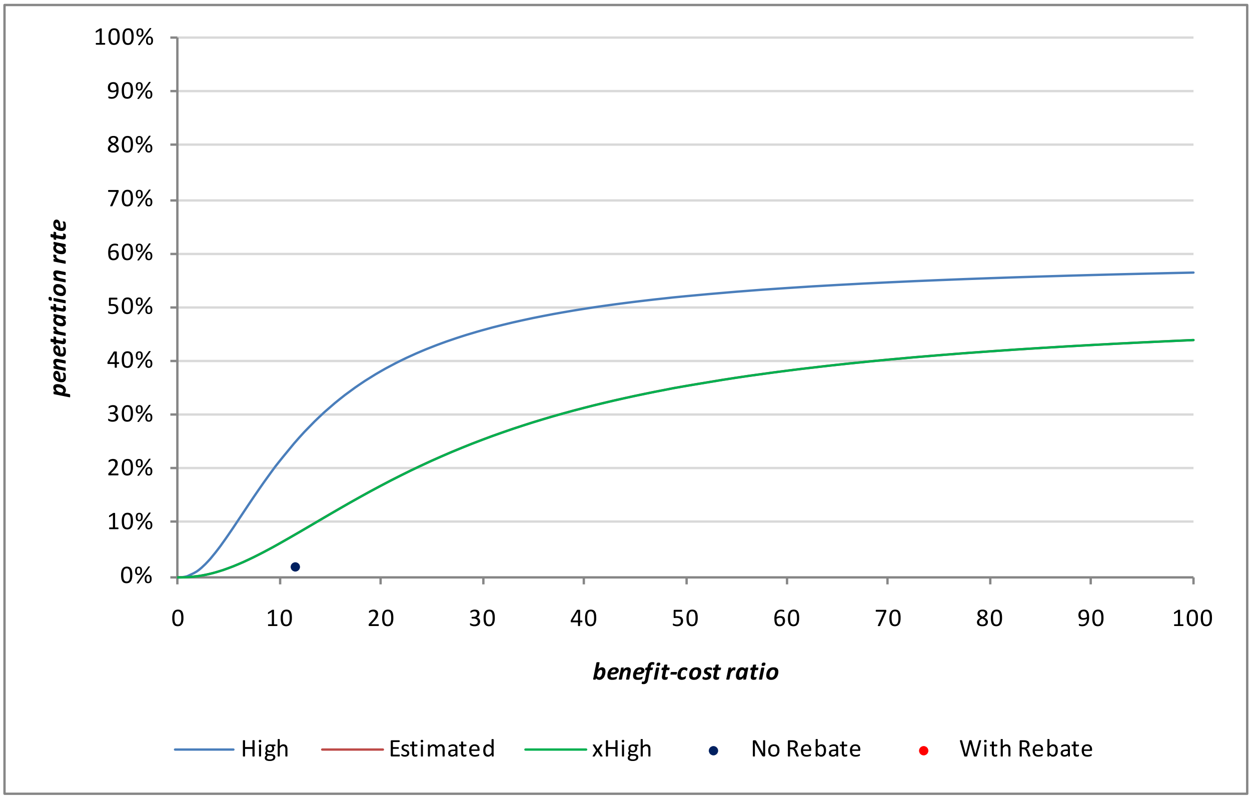


Figure 17-A.3.7 Market Penetration Curve for Compact Refrigerators (PC11)

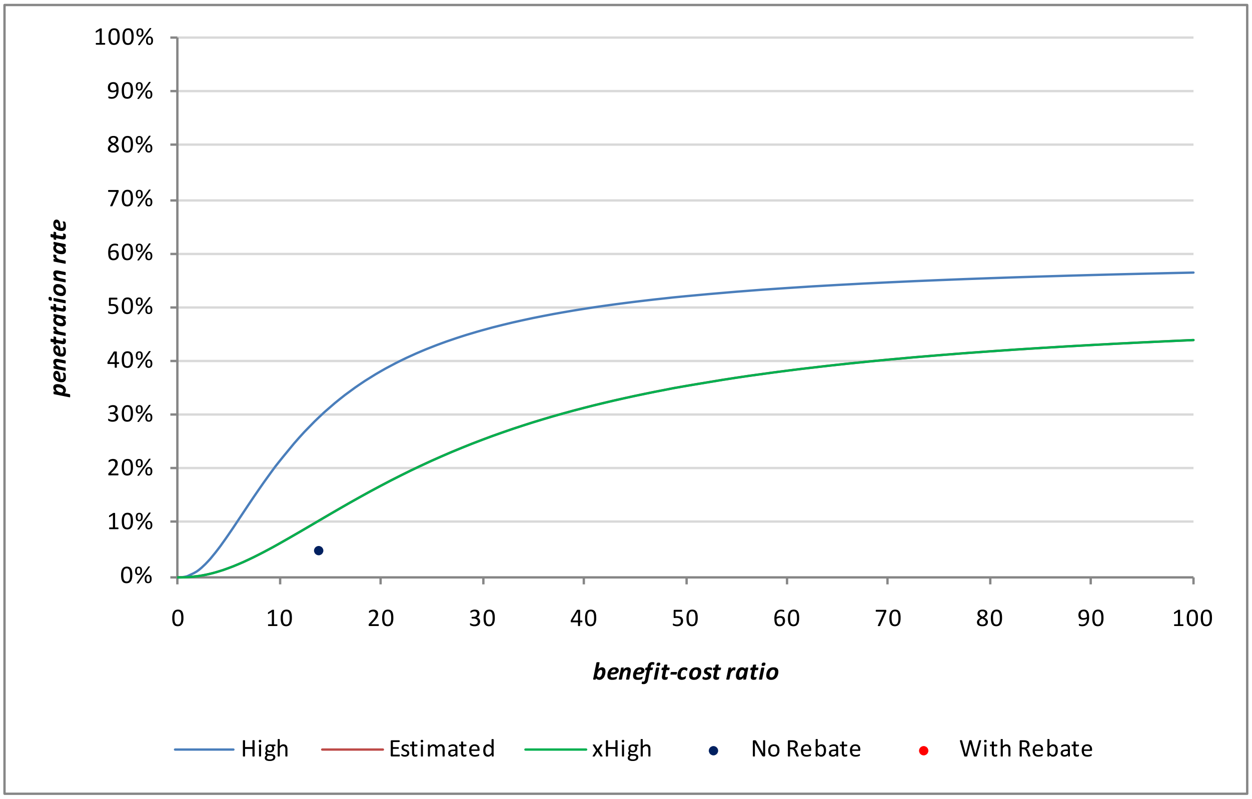


Figure 17-A.3.8 Market Penetration Curve for Compact Refrigerators (PC13, PC13A, and PC14)

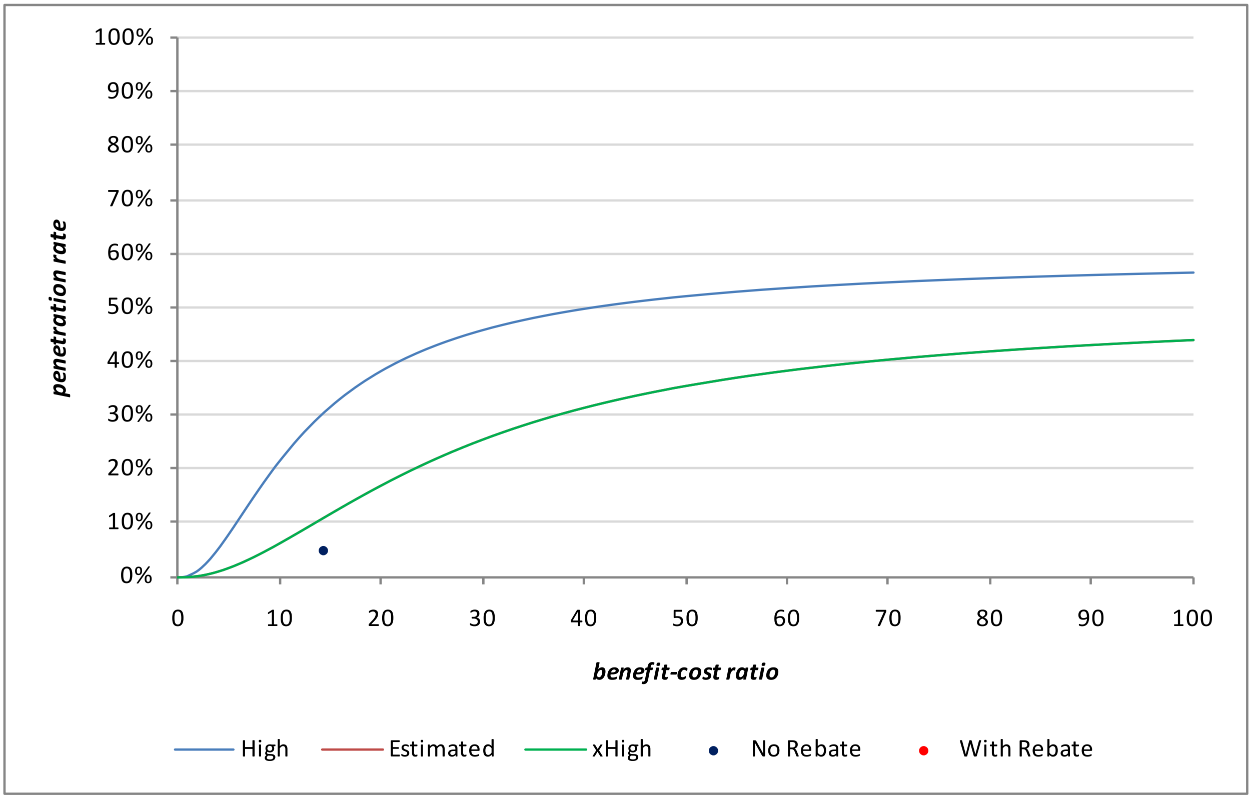


Figure 17-A.3.9 Market Penetration Curve for Compact Freezers

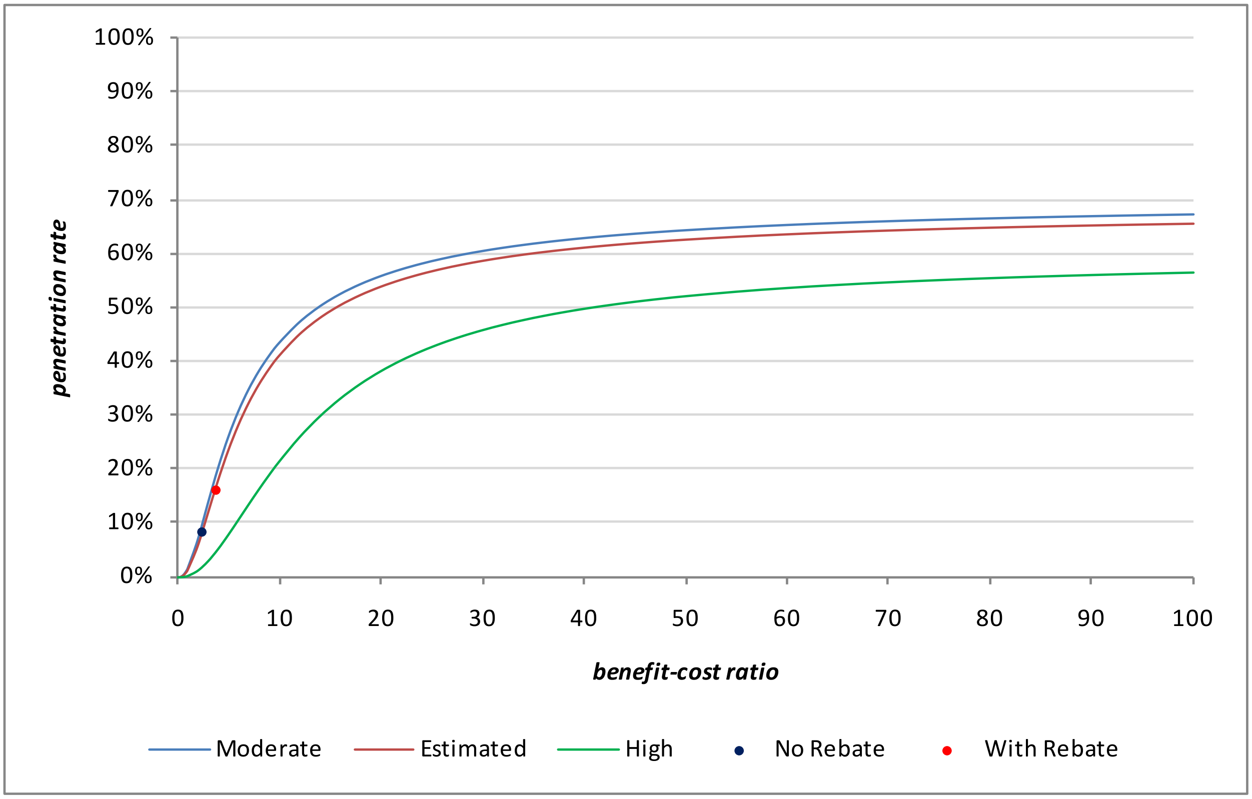


Figure 17-A.3.10 Market Penetration Curve for Built-in All Refrigerators

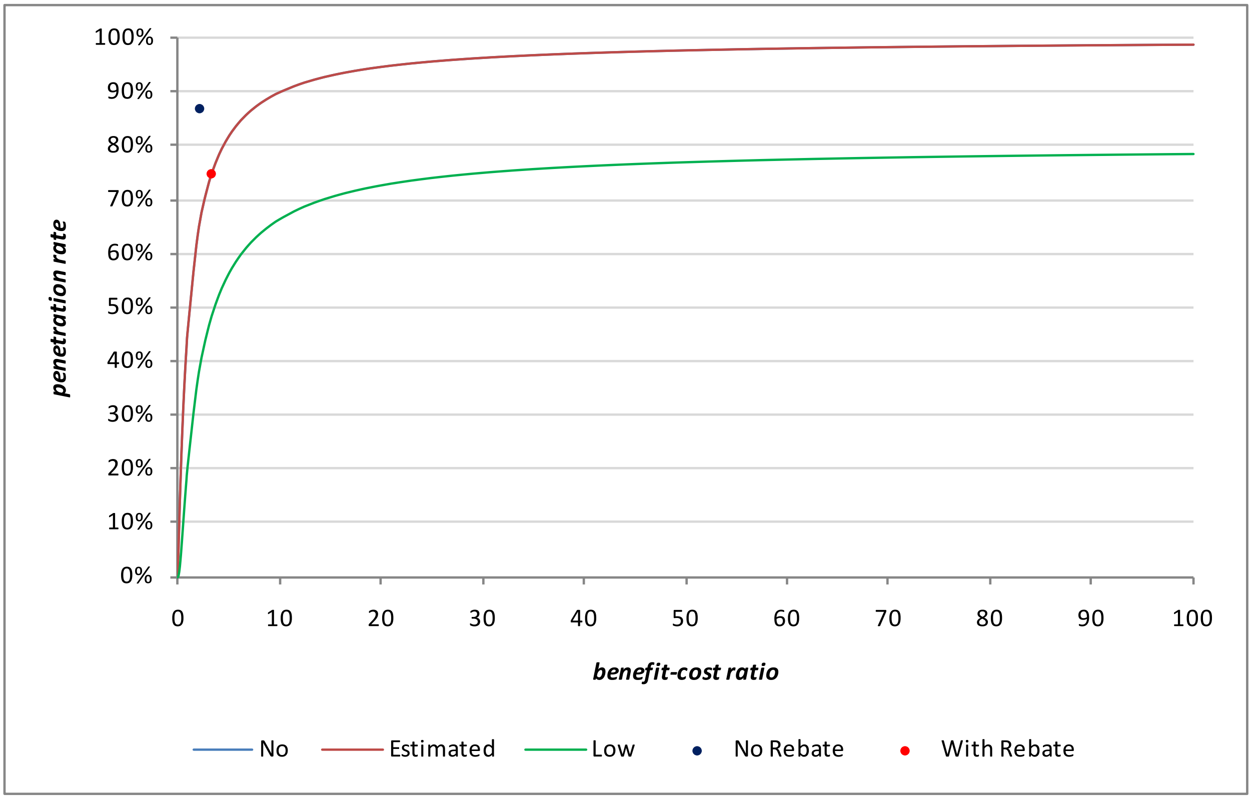


Figure 17-A.3.11 Market Penetration Curve for Built-in Bottom-Mount Refrigerator-Freezers

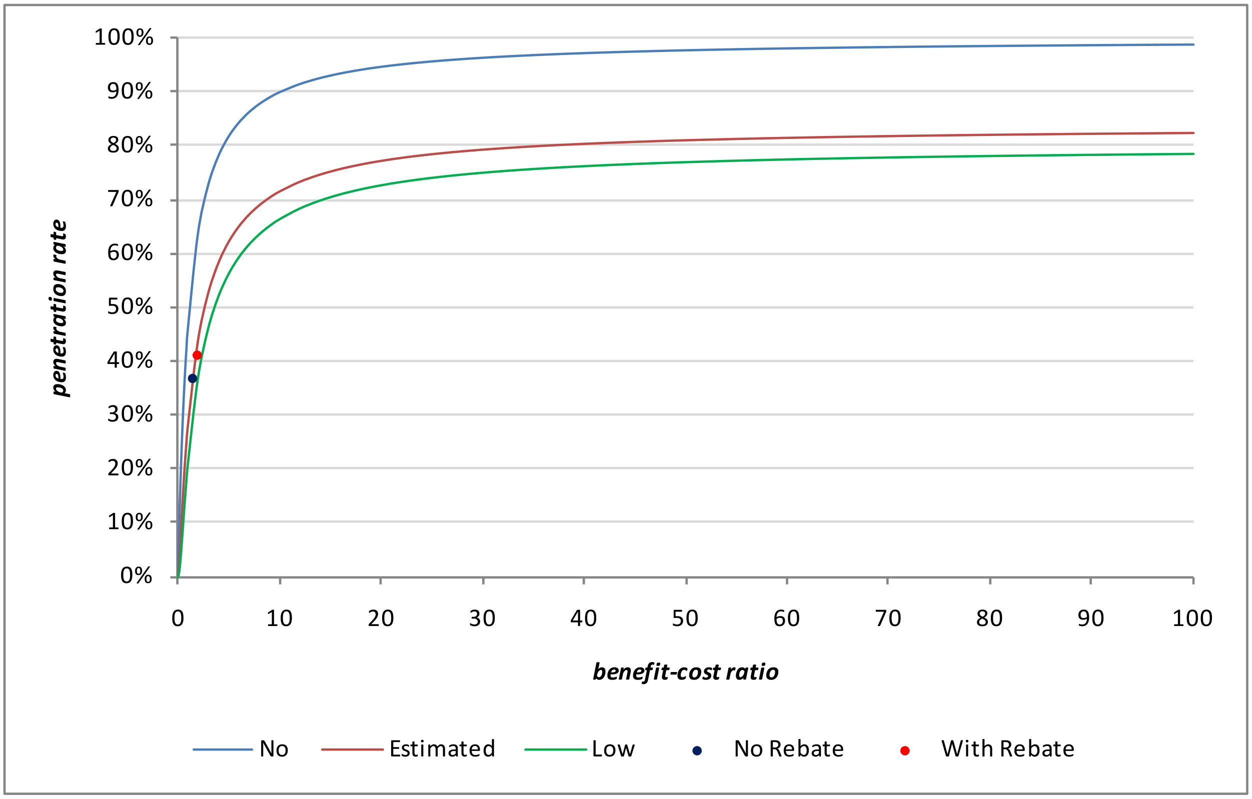


Figure 17-A.3.12 Market Penetration Curve for Built-in Side-by-Side Refrigerator-Freezers

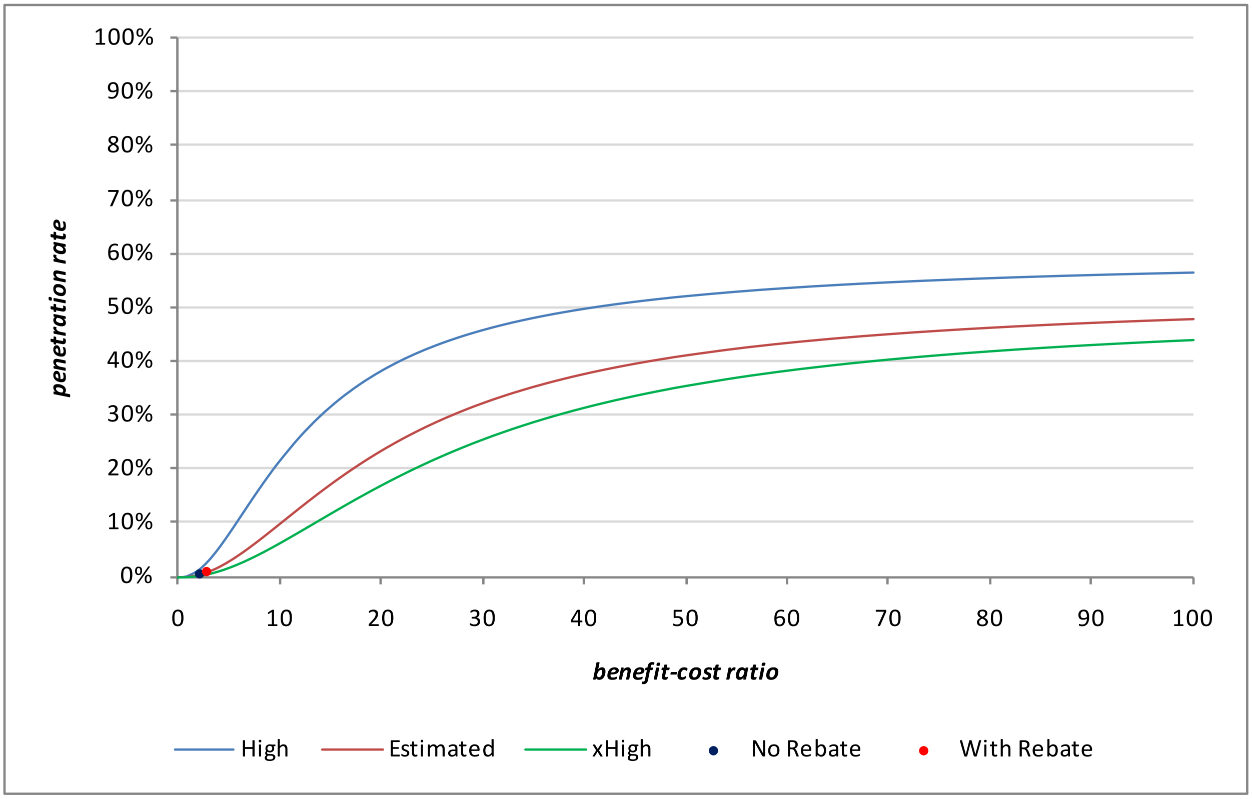


Figure 17-A.3.13 Market Penetration Curve for Built-in Upright Freezer

17-A.4 MARKET SHARE ANNUAL INCREASES BY POLICY

For the consumer rebate, consumer tax credit, and manufacturer tax credit policies, Table 17-A.4.1 shows the annual increases in market shares for refrigeration products meeting target efficiency levels. DOE used these market share increases as inputs to the NIA-RIA spreadsheet model.

Table 17-A.4.1 Annual Increases in Market Shares Attributable to Rebate and Tax Credit Policies for Refrigeration Products

Year	Consumer Rebates				Consumer Tax Credits				Manufacturer Tax Credits			
	Std-Size R/F %	Std-Size Frz %	Com-pact %	Built-in %	Std-Size R/F %	Std-Size Frz %	Com-pact %	Built-in %	Std-Size R/F %	Std-Size Frz %	Com-pact %	Built-in %
2014	21	25	41	6	13	15	25	3	6	8	12	2
2015	21	25	41	6	13	15	25	3	6	8	12	2
2016	21	25	41	6	13	15	25	3	6	8	12	2
2017	21	25	41	6	13	15	25	3	6	8	12	2
2018	21	25	41	6	13	15	25	3	6	8	12	2
2019	21	25	41	6	13	15	25	3	6	8	12	2
2020	21	25	41	6	13	15	25	3	6	8	12	2
2021	21	25	41	6	13	15	25	3	6	8	12	2
2022	21	25	41	6	13	15	25	3	6	8	12	2
2023	21	25	41	6	13	15	25	3	6	8	12	2
2024	21	25	41	6	13	15	25	3	6	8	12	2
2025	21	25	41	6	13	15	25	3	6	8	12	2
2026	21	25	41	6	13	15	25	3	6	8	12	2
2027	21	25	41	6	13	15	25	3	6	8	12	2
2028	21	25	41	6	13	15	25	3	6	8	12	2
2029	21	25	41	6	13	15	25	3	6	8	12	2
2030	21	25	41	6	13	15	25	3	6	8	12	2
2031	21	25	41	6	13	15	25	3	6	8	12	2
2032	21	25	41	6	13	15	25	3	6	8	12	2
2033	21	25	41	6	13	15	25	3	6	8	12	2
2034	21	25	41	6	13	15	25	3	6	8	12	2
2035	21	25	41	6	13	15	25	3	6	8	12	2
2036	21	25	41	6	13	15	25	3	6	8	12	2
2037	21	25	41	6	13	15	25	3	6	8	12	2
2038	21	25	41	6	13	15	25	3	6	8	12	2
2039	21	25	41	6	13	15	25	3	6	8	12	2
2040	21	25	41	6	13	15	25	3	6	8	12	2
2041	21	25	41	6	13	15	25	3	6	8	12	2
2042	21	25	41	6	13	15	25	3	6	8	12	2
2043	21	25	41	6	13	15	25	3	6	8	12	2

For the voluntary efficiency targets, early replacement and bulk government purchases policies, Table 17-A.4.2 shows the annual increases in market shares for refrigeration products meeting target efficiency levels. DOE did not consider the voluntary efficiency targets policy for compact refrigeration products nor for built-in refrigeration products. It did not consider the bulk government purchases policy for standard-size freezers nor for built-in refrigeration products. DOE used these market share increases as inputs to the NIA-RIA spreadsheet model.

Table 17-A.4.2 Annual Increases in Market Shares Attributable to Voluntary Energy Efficiency Targets, Early Replacement, and Bulk Government Purchases Policies for Refrigeration Products

Year	Voluntary Energy Efficiency Targets				Early Replacement				Bulk Government Purchases			
	Std-Size R/F %	Std-Size Frz %	Com-pact %	Built-in %	Std-Size R/F %	Std-Size Frz %	Com-pact %	Built-in %	Std-Size R/F %	Std-Size Frz %	Com-pact %	Built-in %
2014	4	4			3	2	0	2	0		1	
2015	4	5			3	2	0	1	0		1	
2016	5	5			2	1	0	1	0		2	
2017	5	5			2	1	0	1	0		2	
2018	6	5			2	1	0	1	0		3	
2019	6	6			2	1	0	1	1		3	
2020	7	6			1	1	0	1	1		4	
2021	7	6			1	1	0	1	1		4	
2022	8	7			1	1	0	0	1		5	
2023	8	7			0	1	0	0	1		6	
2024	9	7			0	1	0	0	1		6	
2025	9	7			0	0	0	0	1		6	
2026	10	7			0	0	0	0	1		6	
2027	10	7			0	0	0	0	1		6	
2028	11	7			0	0	0	0	1		6	
2029	11	7			0	0	0	0	1		6	
2030	12	7			0	0	0	0	1		6	
2031	12	7			0	0	0	0	1		6	
2032	12	7			0	0	0	0	1		6	
2033	12	7			0	0	0	0	1		6	
2034	12	7			0	0	0	0	1		6	
2035	12	7			0	0	0	0	1		6	
2036	12	7			0	0	0	0	1		6	
2037	12	7			0	0	0	0	1		6	
2038	12	7			0	0	0	0	1		6	
2039	12	7			0	0	0	0	1		6	
2040	12	7			0	0	0	0	1		6	
2041	12	7			0	0	0	0	1		6	
2042	12	7			0	0	0	0	1		6	
2043	12	7			0	0	0	0	1		6	

17-A.5 UTILITY REBATE PROGRAMS

This section presents data on rebate programs in effect nationwide for refrigeration products. The two tables organize the data for the rebates offered for refrigerators/refrigerator-freezers and for freezers.

17-A.5.1 Rebate Programs for Standard-Size Refrigerator-Freezers and Compact Refrigerator-Freezers

DOE found 115 organizations, comprising electric utilities and municipal and regional agencies, that have rebate programs for refrigerator-freezers. The organizations offer more than 127 rebates for models that meet various efficiency criteria. Table 17-A.5.1 provides the organizations' names, states, rebate amounts, whether the rebate applies to standard-size or compact units, efficiency levels, and program websites. If there is more than one entry for an organization, that organization offers different rebate amounts depending on efficiency level. Some rebate programs include both standard-size and compact refrigerators, as shown in the table. The average rebate amounts for standard-size refrigerators and for compact refrigerators, given in 2009$ at the end of the table, are simple averages of the individual amounts (rather than being population-weighted).

Table 17-A.5.1 Rebates for Standard-Size and Compact Refrigerator-Freezers

Utility or Agency	State	Amount 2009$	Std	Cpct	Effic	Website
LADWP	CA	65	√		E*	http://www.ladwp.com/ladwp/cms/ladwp000478.jsp
SCE	CA	50	√		E*	http://www.sce.com/residential/rebates-savings/appliance/fridge-freezer-recycling.htm
SDG&E	CA	25	√		E*	http://www.sdge.com/residential/refrigerators.shtml
Alameda Municipal Power	CA	100	√		E*	http://www.alamedamp.com/index.php?option=com_content&view=article&id=52:refrigerator-rebate-program&catid=18:save-energy-at-home-&Itemid=46
Anaheim Public Utilities	CA	50	√		E*	http://www.anaheim.net/utilities/adv_svc_prog/nrg_star/flyer.pdf
Burbank Water & Power	CA	150	√		E*	http://www.burbankwaterandpower.com/download/Home-Rewards-Rebate-Form-Web.pdf
Burbank Water & Power	CA	100	√		E*	http://www.burbankwaterandpower.com/download/Home-Rewards-Rebate-Form-Web.pdf
City of Palo Alto Utilities	CA	50	√		E*	http://www.cityofpaloalto.org/civica/filebank/blobdload.asp?BlobID=4365
Glendale Water and Power	CA	60	√		E*	http://www.glendalewaterandpower.com/save_money/residential/sh_energy_saving_rebates.aspx
Glendale Water and Power	CA	80	√		E*	http://www.glendalewaterandpower.com/save_money/residential/sh_energy_saving_rebates.aspx
Hercules Municipal Utility	CA	100	√		E*	http://www.ci.hercules.ca.us/index.aspx?page=157
IID Energy	CA	80	√		E*	http://www.iid.com/Media/rewards_instruct_residential10_Eng.pdf
Lassen Municipal Utility District	CA	50	√		E*	http://www.lmud.org/documents/appliancerebate.pdf
Lodi Electric Utility	CA	50	√		E*	http://lodielectric.com/residential/rebateoffer.asp?id=2
Pacific Power	CA	20	√		E*	http://www.homeenergysavings.net/Downloads/CA_ApplianceForm2010a.pdf
Pasadena Water and Power	CA	150	√		E*	http://ww2.cityofpasadena.net/waterandpower/EnergyStar/default.asp
Plumas-Sierra REC	CA	125	√		E*	http://www.psrec.coop/energy_rebates.php?sec=enersol&pag=enerreb
Redding Electric	CA	75	√		E*	http://www.reupower.com/energysvc/documents/2010/Jan10EnergyStar.pdf
Redding Electric	CA	35	√		E*	http://www.reupower.com/energysvc/documents/2010/Jan10EnergyStar.pdf
Riverside Public Utilities	CA	200	√		E*	http://www.riversideca.gov/utilities/resi-energystar.asp
Roseville Electric	CA	100	√		E*	http://www.roseville.ca.us/electric/home/rebates/appliances.asp
Silicon Valley Power	CA	85	√		E*	http://www.siliconvalleypower.com/pdf/res_rebates_09.pdf
Truckee Donner Public Utility District	CA	100	√		E*	http://www.tdpud.org/pdf/Rebate%20program%20pamphlet,5-09.pdf
Turlock Irrigation District	CA	35	√		E*	http://www.tid.org/stellentdmz/groups/public/documents/tidweb_content/tidweb

Utility or Agency	State	Amount 2009$	Std	Cpct	Effic	Website
						_energy_efficiency_broch.pdf
Delta-Montrose Electric Association	CO	40	√		E*	http://www.dmea.com/Portals/0/refrigeratorrebate1-20-2010.pdf
Gunnison County Electric	CO	20	√		E*	http://www.gcea.coop/EE/rebate_program.cfm
Holy Cross Energy	CO	75	√		E*	http://www.holycross.com/green-programs/appliance-rebates
La Plata Electric Association	CO	40	√		E*	http://www.lpea.coop/programs_services/ApplianceRebate.pdf
Morgan County REA	CO	75	√		E*	http://www.mcrea.org/Services/Electric_Appliances.html
United Power	CO	40	√	√	E*	http://www.unitedpower.com/ApplianceRebate.aspx#recycle
Groton Utilities	CT	60	√		E*	http://www.grotonutilities.com/files/conservation_forms/Appliance_Rebate.pdf
Norwich Public Utilities	CT	60	√		E*	http://www.norwichpublicutilities.com/energyefficiency/efficiency-res.html#res-electric
City of Tallahassee Utilities	FL	75	√		E*	http://www.talgov.com/you/energy/energy_programs.cfm#appl
Lake Worth Utilities	FL	100	√		E*	http://www.lakeworth.org/vertical/Sites/%7B5E6FE119-0228-4C9B-B2DB-067168049C16%7D/uploads/%7B5348F2F5-5F25-464C-873C-87948A60D480%7D.PDF
Ames Electric Department	IA	100	√		E*	http://www.cityofames.org/SmartEnergy/Documents/EfficientApplianceClaimForm%207.9.09.pdf
Ames Electric Department	IA	50	√		E*	http://www.cityofames.org/SmartEnergy/Documents/EfficientApplianceClaimForm%207.9.09.pdf
Ames Electric Department	IA	25	√	√	E*	http://www.cityofames.org/SmartEnergy/Documents/EfficientApplianceClaimForm%207.9.09.pdf
Interstate Power and Light	IA	50	√		E*	http://alliantenergy.com/wcm/groups/wcm_internet/@int/documents/contentpage/022811.pdf
Linn County REC	IA	25	√		E*	http://www.linncountyrec.com/cgi-script/csarticles/uploads/334/Energy%20Star%20Appliances%20LCREC.pdf
MidAmerican Energy	IA	50	√		E*	http://www.midamericanenergy.com/ee/include/pdf/ia_res_equip_brochure.pdf
Muscatine Power and Water	IA	75	√		E*	http://www.mpw.org/residential_rebates.aspx
Waverly Light & Power	IA	150	√	√	E*	http://wlp.waverlyia.com/appliance_programs.asp
Idaho Falls Power	ID	25	√		E*	http://www.idahofallsidaho.gov/city/city-departments/idaho-falls-power/energy-efficiency/energy-star-appliance-program.html
Idaho Power	ID	30	√	√	E*	http://www.idahopower.com/EnergyEfficiency/Residential/Programs/HomeProducts/default.cfm
Kootenai Electric Cooperative	ID	25	√	√	E*	http://www.kec.com/rebates.php
Rocky Mountain Power	ID	20	√		E*	http://www.homeenergysavings.net/Downloads/ID_ApplianceForm2010.pdf

Utility or Agency	State	Amount 2009$	Std	Cpct	Effic	Website
City Water Light and Power	IL	50	√			http://www.cwlp.com/energy_services/ESO_services_programs/refrigerator_rebate.htm
Commonwealth Edison	IL	50	√		E*	https://www.comed.com/sites/HomeSavings/Pages/appliancerecycling.aspx; http://www.cee1.org/files/CEEApplianceProgramSummaryApril2010.pdf
Munihelps	MA	50	√		E*	http://www.munihelps.org/2010%20rebate%20forms/MailinformAshburnham.pdf
Belmont Municipal Light Department	MA	100	√		E*	http://www.town.belmont.ma.us/public_documents/BelmontMA_LightNews/Announcements/2010%20Appliance%20Rebate%20Program%20&%20Form%20Brochure.pdf
Concord Municipal Light Plant	MA	100	√		E*	http://www.concordma.gov/Pages/ConcordMA_LightPlant/appliance
Mansfield Municipal Electric	MA	100	√		E*	http://www.mansfieldelectric.com/consumerforms/Appliance-Rebate-App.pdf
Marblehead Light Department	MA	100	√		E*	http://www.marbleheadelectric.com/9-6_Rebate_guide_for_MMLD.pdf
NSTAR (part of Cape Light Compact)	MA	50	√		E*	http://www.nstaronline.com/docs3/ee-rebate-forms/fridge.pdf?unique=20100402200503
Reading Municipal Light	MA	50	√		E*	http://www.rmld.com/Pages/rmldma_residential/rebate.pdf
Shrewsbury Electric & Cable Operations	MA	50	√		E*	http://www.shrewsbury-ma.gov/egov/docs/1263402562_742065.pdf
Wakefield Municipal Gas & Light Department	MA	50	√		E*	http://www.wakefield.ma.us/Public_Documents/WakefieldMA_MGLD/WMGLDRebateForm.pdf
Allegheny Power	MD	50	√		E*	http://www.nxtbook.com/nxtbooks/garrisonhughes/empowermaryland2010/#/4
Baltimore Gas & Electric Company	MD	50	√		E*	http://conservation.bgesmartenergy.com/residential/lighting-appliances/appliance-rebates
Delmarva Power	MD	50	√		E*	http://www.delmarva.com/energy/conservation/appliance/default.aspx
PEPCO	MD	50	√	√	E*	http://homeenergysavings.pepco.com/dc/appliance-rebate
Efficiency Maine	ME	75	√		E*	http://www.efficiencymaine.com/at-home/appliance_rebate_program
Anoka Municipal Utility	MN	25	√		E*	http://www.ci.anoka.mn.us/index.asp?Type=B_BASIC&SEC={03DDAD7B-EC66-4214-97D8-EB42DA396059}
Southern Minnesota Municipal Power Agency	MN	25	√		E*	http://www.smmpa.org/upload/Res%202010%20Rebate%20Program%20Fact%20Sheet-BP.pdf
City of North St. Paul Electric Utility	MN	25	√		E*	http://www.ci.north-saint-paul.mn.us/index.asp?Type=B_BASIC&SEC={F5C1E5FE-1ADD-49AF-ACD8-59C3FB4192FF}
Crow Wing Power	MN	100	√		E*	http://www.cwpower.com/heatingcoolingoptions.shtml
Minnesota Power	MN	25	√		E*	http://www.mnpower.com/powerofone/one_home/energystar/special_offers/index.php

Utility or Agency	State	Amount 2009$	Std	Cpct	Effic	Website
Shakopee Public Utilities	MN	35	√		E*	http://www.shakopeeutilities.com/Residential_Rebate_Packet.pdf
Stearns Electric	MN	50	√		E*	https://www.stearnselectric.org/energystarres.htm
Stearns Electric	MN	75	√		E*	https://www.stearnselectric.org/energystarres.htm
New Ulm Public Utilities	MN	30	√		E*	http://www.ci.new-ulm.mn.us/index.asp?Type=B_BASIC&SEC={743A5650-3018-4B6E-B7B0-662834287912}&DE={89E00F68-1EF5-4A75-BECE-E3DE07703621}
New Ulm Public Utilities	MN	10	√	√	E*	http://www.ci.new-ulm.mn.us/index.asp?Type=B_BASIC&SEC={743A5650-3018-4B6E-B7B0-662834287912}&DE={89E00F68-1EF5-4A75-BECE-E3DE07703621}
White River Valley Electric Cooperative	MO	75	√		E*	http://whiteriver.org/residential_rebate_program.aspx
Flathead Electric	MT	25	√		E*	http://www.flatheadelectric.com/energy/Rebates.html
Yellowstone Valley Electric Cooperative	MT	25	√		E*	http://www.yvec.com/UserFiles/File/Energy%20Star%20Rebate.pdf
Four-County EMC	NC	150	√		E*	http://www.fourcty.org/news.php?id=39&p=7
South River EMC	NC	25	√		E*	http://www.sremc.com/ESRebates.aspx
Central New Mexico Electric Cooperative	NM	80	√		E*	http://www.cnmec.org/pdfs/waterheater_rebate_guidelines.pdf
Long Island Power Authority	NY	75	√		E*	http://www.lipower.org/residential/efficiency/rebates/rebates-refrigerators.html
Ashland Electric Utility	OR	25	√		E*	http://www.ashland.or.us/Files/RefridgeratorRebateForm.pdf
Ashland Electric Utility	OR	35	√		CEE Tier 3	http://www.ashland.or.us/Files/RefridgeratorRebateForm.pdf
Central Electric Cooperative	OR	25	√		E*	http://www.cec-co.com/custserv/energy_info/brochures/energy_star.pdf
Central Lincoln People's Utility District	OR	70	√		E*	http://www.clpud.org/pdf/Rebate%20Forms/CLPUD%20Applnc%20Rebate%20form%2005-09.pdf
Columbia River PUD	OR	25	√		E*	http://www.crpud.net/residential/efficiency/appliances
Consumers Power, Inc	OR	25	√		E*	http://www.cpi.coop/rebates/appliance.php
Douglas Electric Cooperative	OR	25	√		E*	http://www.douglaselectric.com/programs/Rebate_Form.pdf
Emerald P.U.D.	OR	25	√		E*	http://www.epud.org/documents/ApplianceRebate_000.pdf
Energy Trust of Oregon	OR	50	√		E*	http://energytrust.org/residential/incentives/Appliances/NewRefrigeratorsandFreezers
Eugene Water & Electric Board	OR	25	√		E*	http://www.eweb.org/public/documents/energy/home_appliance_rebate.pdf
Forest Grove L&P	OR	50	√		E*	http://www.forestgrove-

Utility or Agency	State	Amount 2009$	Std	Cpct	Effic	Website
						or.gov/images/stories/services/lightandpower/pdf/mar2010appliancerebateform.pdf
Idaho Power	OR	30	√		E*	http://www.idahopower.com/EnergyEfficiency/Residential/Programs/HomeProducts/default.cfm
McMinnville Water and Light	OR	25	√		E*	http://www.mc-power.com/rebates.aspx
Midstate Electric Cooperative	OR	25	√		E*	http://www.midstateelectric.coop/Refrig%20Rebate%20Form.pdf
Monmouth Power & Light	OR	25	√		E*	http://www.ci.monmouth.or.us/vertical/Sites/%7BCE78EAE1-6CA4-4610-BDB0-A9B3B0A8BB71%7D/uploads/%7BF66F3203-CD45-406C-89BF-ADE93D1D975D%7D.PDF
OTEEC	OR	25	√		E*	http://www.otecc.com/residentialprograms.aspx
Salem Electric	OR	60	√		E*	http://www.salemelectric.com/residential/pdfs/rebates_programs/ApplianceBrochure.pdf
Springfield Utility Board	OR	25	√		E*	http://www.subutil.com/files/static_page_files/E3DD085D-078B-420B-267070C0638CD317/RebateForm10.pdf
Tillamook County PUD	OR	50	√		E*	http://www.tpud.org/nrg_appliance.html
Allegheny Power	PA	50	√		E*	http://www.alleghenypower.com/EngConserv/PA/WattWatchers/RebateREF.asp
Duquesne Light	PA	10	√		E*	http://www.duquesnelight.com/wattchoices/#RE
PPL Electric Utilities	PA	50	√		E*	http://www.rebate-zone.com/ppl/pdf/PEJ.pdf
National Grid	RI	50	√		E*	https://www.powerofaction.com/rirefridge/
Guadalupe Valley Electric Cooperative	TX	100	√		E*	http://www.gvec.org/safety_con/Home%20Improvement.pdf
City of St. George	UT	20	√		E*	http://www.sgcity.org/energyservices/ES%20Appliance%20Rebate%20Application.pdf
Rocky Mountain Power	UT	20	√	√	E*	http://www.homeenergysavings.net/Downloads/UT_ApplianceForm2010.pdf
Efficiency Vermont	VT	25	√	√	E*	http://efficiencyvermont.com/pages/Residential/Lightingandappliances/ENERGYSTARAppliances/RefrigeratorsandFreezers/
Efficiency Vermont	VT	50	√	√	CEE Tier 2	http://efficiencyvermont.com/pages/Residential/Lightingandappliances/ENERGYSTARAppliances/RefrigeratorsandFreezers/
Avista Utilities	WA	25	√		E*	https://www.avistautilities.com/savings/rebates/Documents/HighEfficiencyRebate_OREnergyStar-R2.1.5.2009.pdf
Benton PUD	WA	25	√		E*	http://www.bentonpud.org/pdf/CRC/REEP/October%201,%202009/Appliance%20Rebate%20Application%209-1-09.pdf
Clallam PUD	WA	50	√		E*	http://www.clallampud.net/uploadedFiles/conservation/documents/energy_star_

Utility or Agency	State	Amount 2009$	Std	Cpct	Effic	Website
						appliance_rebate.pdf
Clark Public Utilities	WA	25	√		E*	http://www.clarkpublicutilities.com/yourhome/conservation/rebates
Columbia Rural Electric Association	WA	25	√		E*	http://www.columbiarea.com/programs/Res%20Rebate%20Application.pdf
Cowlitz County PUD	WA	25	√		E*	http://www.cowlitzpud.org/pdf/RebateBrochureRevised10-6-08.pdf
Franklin PUD	WA	25	√		E*	http://www.franklinpud.com/pdfs/REBATE_PROGRAM_V_10.2.pdf
Grant County Public Utility District	WA	25	√		E*	http://www.gcpud.org/conservation/rebates/index.htm
Grays Harbor PUD	WA	25	√		E*	https://www.ghpud.org/index.php?option=com_content&task=view&id=89&Itemid=113
Inland Power and Light Co	WA	25	√		E*	http://www.inlandpower.com/pdf/appliancerebateform.pdf
Mason PUD	WA	25	√		E*	http://www.masonpud3.org/powerSupply/applianceRebates.aspx
Okanogan PUD	WA	25	√		E*	http://www.okanoganpud.org/consrebates.htm
Orcas Power and Light Cooperative	WA	25	√		E*	http://www.opalco.com/energy-efficiency/rebates/
Pacific Power	WA	20	√	√	E*	http://www.homeenergysavings.net/Washington/appliances/refrigerators.html
City of Port Angeles	WA	100	√		E*	https://www.cityofpa.us/pwConserv.htm
Richland Energy Services	WA	25	√		E*	http://www.ci.richland.wa.us/RICHLAND/Electric/index.cfm?PageNum=89
Snohomish County Public Utility District No. 1	WA	50	√		E*	http://www.snopud.com/conservation/appliances.ashx?p=1139
Barron Electric Cooperative	WI	25	√	√	E*	http://www.barronelectric.com/Appliance%20&%20Lighting%20Program.pdf
Eau Claire Energy Cooperative	WI	25	√		E*	http://www.ecec.com/programs/incentives
Riverland Energy Cooperative	WI	25	√		E*	http://riverlandenergy.com/RIVERLAND%20HOMEPAGE/rebates.htm
Montana-Dakota Utilities	WY	10	√		E*	http://www.montana-dakota.com/Wyoming/Conservation/Pages/ElectricIncentivePrograms.aspx
Rocky Mountain Power	WY	20	√	√	E*	http://www.homeenergysavings.net/Wyoming/appliances/refrigerators.html
Average Rebate Amount (2009$)			**52**	**34**		

17-A.5.2 Rebate Programs for Standard-Size Freezers and Compact Freezers

DOE found 59 organizations, comprising electric utilities and municipal and regional agencies that offered 62 rebate programs for standard-size and compact freezers. The organizations offer rebates for units that meet a range of efficiency criteria. Table 17-A.5.2 lists the organizations' names, states, rebate amounts, whether the rebate applies to standard-size or compact units, efficiency levels, and program websites. Some rebate programs include both standard-size and compact refrigerators, as shown in the table. If there is more than one entry for an organization, that organization offers different rebates based on efficiency level. The average rebate amounts, given in 2009$ at the end of the table, are simple averages of the individual amounts (rather than being population-weighted). The table also shows the adjusted rebate amount for compact freezers, as discussed in chapter 17, section 17.3.2.3.

Table 17-A.5.2 Rebates for Standard-Size and Compact Freezers

Utility	State	Rebate Amount 2009$	Std	Cpct	Effic	Website
Montana-Dakota Utilities	WY	10	√		E*	http://www.montana-dakota.com/Wyoming/Conservation/Pages/ElectricIncentivePrograms.aspx
Barron Electric Cooperative	WI	25	√		E*	http://www.barronelectric.com/Appliance%20&%20Lighting%20Program.pdf
Eau Claire Energy Cooperative	WI	25	√		E*	http://www.ecec.com/programs/incentives
Riverland Energy Cooperative	WI	25	√		E*	http://riverlandenergy.com/RIVERLAND%20HOMEPAGE/rebates.htm
Avista Utilities	WA	20	√		E*	https://www.avistautilities.com/savings/rebates/Documents/HighEfficiencyRebate_OREnergyStar-R2.1.5.2009.pdf
Clallam PUD	WA	25	√		E*	http://www.clallampud.net/uploadedFiles/conservation/documents/energy_star_appliance_rebate.pdf
Clark Public Utilities	WA	25	√		E*	http://www.clarkpublicutilities.com/yourhome/conservation/rebates
Columbia Rural Electric Association	WA	25	√		E*	http://www.columbiarea.com/programs/Res%20Rebate%20Application.pdf
Cowlitz County PUD	WA	25	√		E*	http://www.cowlitzpud.org/pdf/RebateBrochureRevised10-6-08.pdf
Franklin PUD	WA	25	√		E*	http://www.franklinpud.com/pdfs/REBATE_PROGRAM_V_10.2.pdf
Grant County Public Utility District	WA	25	√		E*	http://www.gcpud.org/conservation/rebates/index.htm
Grays Harbor PUD	WA	25	√		E*	https://www.ghpud.org/index.php?option=com_content&task=view&id=89&Itemid=113
Inland Power and Light Co	WA	25	√		E*	http://www.inlandpower.com/pdf/appliancerebateform.pdf
Mason PUD	WA	25	√		E*	http://www.masonpud3.org/powerSupply/applianceRebates.aspx
Orcas Power and Light Cooperative	WA	25	√		E*	http://www.opalco.com/energy-efficiency/rebates/
Guadalupe Valley Electric Cooperative	TX	100	√		E*	http://www.gvec.org/safety_con/Home%20Improvement.pdf
National Grid	RI	50	√		E*	https://www.powerofaction.com/rirefridge/
Allegheny Power	PA	25	√		E*	http://www.alleghenypower.com/EngConserv/PA/WattWatchers/RebateFR.asp
Duquesne Light	PA	11	√		E*	http://www.duquesnelight.com/wattchoices/#RE
Central Electric Cooperative	OR	25	√		E*	http://www.cec-co.com/custserv/energy_info/brochures/energy_star.pdf
Central Lincoln People's Utility District	OR	70	√		E*	http://www.clpud.org/pdf/Rebate%20Forms/CLPUD%20Applnc%20Rebate%20form%2005-09.pdf
Columbia River PUD	OR	25	√		E*	http://www.crpud.net/residential/efficiency/appliances

Utility	State	Rebate Amount 2009$	Std	Cpct	Effic	Website
Consumers Power, Inc	OR	25	√		E*	http://www.cpi.coop/rebates/appliance.php
Emerald P.U.D.	OR	25	√		E*	http://www.epud.org/documents/ApplianceRebate_000.pdf
Energy Trust of Oregon	OR	50	√	√	E*	http://energytrust.org/residential/incentives/Appliances/NewRefrigeratorsandFreezers
Eugene Water & Electric Board	OR	25	√		E*	http://www.eweb.org/public/documents/energy/home_appliance_rebate.pdf
Forest Grove L&P	OR	50	√		E*	http://www.forestgrove-or.gov/images/stories/services/lightandpower/pdf/mar2010appliancerebateform.pdf
McMinnville Water and Light	OR	25	√		E*	http://www.mc-power.com/rebates.aspx
Monmouth Power & Light	OR	25	√		E*	http://www.ci.monmouth.or.us/vertical/Sites/%7BCE78EAE1-6CA4-4610-BDB0-A9B3B0A8BB71%7D/uploads/%7BF66F3203-CD45-406C-89BF-ADE93D1D975D%7D.PDF
OTEEC	OR	25	√		E*	http://www.otecc.com/residentialprograms.aspx
Salem Electric	OR	60	√		E*	http://www.salemelectric.com/residential/pdfs/rebates_programs/ApplianceBrochure.pdf
Springfield Utility Board	OR	25	√		E*	http://www.subutil.com/files/static_page_files/E3DD085D-078B-420B-267070C0638CD317/RebateForm10.pdf
Tillamook County PUD	OR	50	√		E*	http://www.tpud.org/nrg_appliance.html
Four-County EMC	NC	150	√		E*	http://www.fourcty.org/news.php?id=39&p=7
South River EMC	NC	25	√		E*	http://www.sremc.com/ESRebates.aspx
Central New Mexico Electric Cooperative	NY	80	√		E*	http://www.cnmec.org/pdfs/waterheater_rebate_guidelines.pdf
Flathead Electric	MT	25	√		E*	http://www.flatheadelectric.com/energy/Rebates.html
Yellowstone Valley Electric Cooperative	MT	25	√		E*	http://www.yvec.com/UserFiles/File/Energy%20Star%20Rebate.pdf
Anoka Municipal Utility	MN	50	√		E*	http://www.ci.anoka.mn.us/index.asp?Type=B_BASIC&SEC={03DDAD7B-EC66-4214-97D8-EB42DA396059}
Southern Minnesota Municipal Power Agency	MN	26	√			http://www.smmpa.org/upload/Res%202010%20Rebate%20Program%20Fact%20Sheet-BP.pdf
Crow Wing Power	MN	100	√		E*	http://www.cwpower.com/heatingcoolingoptions.shtml
Shakopee Public Utilities	MN	35	√		E*	http://www.shakopeeutilities.com/Residential_Rebate_Packet.pdf
Stearns Electric	MN	50	√		E*	https://www.stearnselectric.org/energystarres.htm
Stearns Electric	MN	75	√		E*	https://www.stearnselectric.org/energystarres.htm

Utility	State	Rebate Amount 2009$	Std	Cpct	Effic	Website
Cape Light Compact	MA	50	√		E*	http://myenergystar.com/documents/RebateForms/2010/MA_FridgeFreezer_Rebate_CLC.pdf
Concord Municipal Light Plant	MA	100	√		E*	http://www.concordma.gov/Pages/ConcordMA_LightPlant/appliance
Allegheny Power	MD	25	√		E*	http://www.nxtbook.com/nxtbooks/garrisonhughes/empowermaryland2010/#/4
Ames Electric Department	IA	50	√	√	E*	http://www.cityofames.org/SmartEnergy/Documents/EfficientApplianceClaimForm%207.9.09.pdf
Interstate Power and Light	IA	50	√		E*	http://alliantenergy.com/wcm/groups/wcm_internet/@int/documents/contentpage/022811.pdf
Linn County REC	IA	25	√		E*	http://www.linncountyrec.com/cgi-script/csarticles/uploads/334/Energy%20Star%20Appliances%20LCREC.pdf
MidAmerican Energy	IA	25	√		E*	http://www.midamericanenergy.com/ee/include/pdf/ia_res_equip_brochure.pdf
Idaho Falls Power	ID	25	√		E*	http://www.idahofallsidaho.gov/city/city-departments/idaho-falls-power/energy-efficiency/energy-star-appliance-program.html
Kootenai Electric Cooperative	ID	25	√		E*	http://www.kec.com/rebates.php
City of Tallahassee Utilities	FL	40	√		E*	http://www.talgov.com/you/energy/energy_programs.cfm#appl
Groton Utilities	CT	60	√		E*	http://www.grotonutilities.com/files/conservation_forms/Appliance_Rebate.pdf
Norwich Public Utilities	CT	60	√		E*	http://www.norwichpublicutilities.com/energyefficiency/efficiency-res.html#res-electric
Delta-Montrose Electric Association	CO	40	√		E*	http://www.dmea.com/Portals/0/refrigeratorrebate1-20-2010.pdf
Gunnison County Electric	CO	20	√		E*	http://www.gcea.coop/EE/rebate_program.cfm
Morgan County REA	CO	75	√		E*	http://www.mcrea.org/miscellaneous/pdf/APPLIANCE.pdf
United Power	CO	40	√		E*	http://www.unitedpower.com/ApplianceRebate.aspx#recycle
Burbank Water & Power	CA	150	√		E*	http://www.burbankwaterandpower.com/download/Home-Rewards-Rebate-Form-Web.pdf
Burbank Water & Power	CA	100	√		E*	http://www.burbankwaterandpower.com/download/Home-Rewards-Rebate-Form-Web.pdf
Averages (2009$)			**43**	50		
Adjusted Average (2009$)				**28**		

17-A.6 FEDERAL AND STATE TAX CREDITS

This section summarizes the Federal and State tax credits available to consumers who purchase energy efficient appliances. This section also describes tax credits available to manufacturers who produce certain energy efficient appliances.

17-A.6.1 Federal Tax Credits for Consumers of Residential Appliances

EPACT 2005 included Federal tax credits for consumers who installed efficient air conditioners or heat pumps; gas or oil furnaces; furnace fans; and/or gas, oil, or electric heat pump water heaters in new or existing homes.[7],[8] These tax credits were in effect in 2006 and 2007, expired in 2008, and were reinstated for 2009–2010 by the American Recovery and Reinvestment Act (ARRA).[9] These tax credits did not apply to consumers who purchased energy efficient refrigerators or freezers.

Although this tax credit did not include efficient refrigeration products, in an effort to evaluate the potential impact of a Federal appliance tax credit program, DOE reviewed Internal Revenue Service (IRS) data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. It estimated the percentage of taxpayers who filed Form 5695, Residential Energy Credits.[10] It also estimated the percentage of taxpayers with entries under Form 5695's Line 3, Residential energy property costs, which included (3a) energy-efficient building property (including water heaters), (3b) qualified natural gas, propane, or oil furnace or hot water boiler, and (3c) advanced main air circulating fan used in a natural gas, propane, or oil furnace. While none of these three items corresponds exactly to refrigeration products, DOE reasoned that the percentage of taxpayers with at least one entry under Line 3 could serve as a rough indication of the potential of taxpayer participation in a Federal tax credit program for an efficient appliance during the initial program years. It found that of all residential taxpayers filing tax returns in 2006 and 2007, 2.1 percent each year claimed at least one credit under Line 3. DOE further found that the percentages of those filing Form 5695 for any qualifying energy property expenditure (which also included installation of efficient windows, doors and roofs) were 3.1 and 3.2 percent in 2006 and 2007 respectively.

DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. While this tax credit was available from 1979 through 1985, DOE located data for only the first three years of the program.[11],[12],[13] For those three years -1979, 1980, and 1981 - the percentages of taxpayers filing Form 5695 were 6.4 percent, 5.2 percent, and 4.9 percent.. Given that the data from this earlier tax credit program were not disaggregated by type of energy property, this data series served only to indicate a possible trend of greater participation in the initial program year, followed by slightly smaller participation in subsequent years. However, DOE did not find detailed analysis of this program to indicate the possible reasons for such a trend. Also, this trend varies from the more stable trend shown in the EPAct 2005 energy tax credit program data for its first two program years.

As discussed in chapter 17, section 17.3.3, DOE analyzed the percentage of participation in consumer tax credit programs using its estimates of consumer participation in rebate programs that was based on benefit/cost data specific to each refrigeration product class. Hence it was difficult to compare these detailed estimates to the more general data analysis described above from the existing Federal tax credit program, or to use the IRS data analysis in its consumer tax credit analysis.

17-A.6.2 Federal Tax Credits for Manufacturers

EPACT 2005 provided Federal Energy Efficient Appliance Credits to manufacturers that produced high-efficiency refrigerators, clothes washers, and dishwashers in 2006 and 2007.[14] The Emergency Economic Stabilization Act of 2008[15] amended the credits and extended them through 2010. Manufacturers receive the credits for increasing their production of qualifying appliances relative to a two-year rolling baseline. Each manufacturer is limited to a certain amount for all credits. Manufacturers were eligible for Energy Efficient Appliance Credits for qualifying models of residential refrigerators, residential and commercial clothes washers, and residential dishwashers. The credits listed below were available for refrigerator models produced in 2008, 2009, and 2010. These credit amounts and criteria applied to manufacturers who produce these appliances. The amounts listed are for each unit manufactured. However, the maximum credit that a manufacturer could receive for qualifying equipment was $75 million for 2008–2010, with the exceptions that the most efficient refrigerator (30 percent) models were not subject to the cap.[16]

- $50 for models manufactured in 2008 that consume at least 20 percent but not more than 22.9 percent fewer kilowatt hours per year than the 2001 energy conservation standards.
- $75 for models manufactured in 2008 or 2009 that consume at least 23 percent but no more than 24.9 percent fewer kilowatt hours per year than the 2001 energy conservation standards.
- $100 for models manufactured in 2008, 2009, or 2010 that consume at least 25 percent but not more than 29.9 percent fewer kilowatt hours per year than the 2001 energy conservation standards.
- $200 for models manufactured in 2008, 2009, or 2010 that consume at least 30 percent less energy than the 2001 energy conservation standards.

17-A.6.3 State Tax Credits

The States of Oregon and Montana have offered consumer tax credits for efficient appliances for several years, and the States of Indiana, Kentucky and Michigan began offering such credits in 2009. The Oregon Department of Energy (ODOE) has disaggregated data on taxpayer participation in credits for eligible products. (See the discussion in chapter 17, section 17.3.3, on tax credit data for refrigerators and clothes washers.) Montana’s Department of Revenue does not disaggregate participation data by appliance, although DOE reviewed Montana's overall participation trend that were congruent with its analysis of Oregon's clothes washer tax credits. DOE was unable to obtain state tax credit data from Indiana, Kentucky or Michigan.

Oregon’s Residential Energy Tax Credit (RETC) was created in 1977. After the Oregon legislature expanded the RETC program in 1997 to include residential refrigerators, clothes washers, and dishwashers, participation in the program increased significantly. For standard-sized refrigerators the program offers two levels of rebates for units between 12 and 30 ft.[3] The required efficiency levels are 20 percent above Federal standard (ENERGY STAR) and 30 percent above Federal standard (CEE Tier 3). The program subsequently added credits for high-efficiency heat pump systems, air conditioners, and water heaters (2001); furnaces and boilers (2002); and duct/air sealing, fuel cells, heat recovery, and renewable energy equipment. For heating, ventilating, and air conditioning equipment; residential appliances; and water heaters, the credit is $0.40 per kilowatt saved in the first year, or 25 percent of the net purchase price, whichever is less. The credit limit for energy efficient appliances and heating and cooling systems is $1,000 per calendar year; excess credit may be carried forward for 5 years.[17]

Montana has had an Energy Conservation Tax Credit for residential measures since 1998.[18] The tax credit covers various residential energy and water efficient products, including ENERGY STAR heating/cooling equipment, water heaters, low-flow showerheads and faucets, and light fixtures and controls. In 2002 the amount of the credit was increased from 5 percent of product costs (up to $150) to 25 percent (up to $500) per taxpayer. The credit can be used for products installed in new construction or remodeling projects. The tax credit covers only that part of the cost and materials that exceed established standards of construction.

Beginning in 2009 Indiana offered a tax credit to individuals and small businesses for costs associated with purchasing ENERGY STAR-qualified central air conditioners, room air conditioners, furnaces, programmable thermostats, and water heaters. The credit may be claimed against state income tax, insurance premium tax, or financial institutions tax. The amount of the credit is 20 percent of the expenditure for qualified heating and cooling equipment, to a maximum of $100 per taxable year. The credit applies to expenditures made in 2009 and 2010; there is no carryover.[19],[20]

Beginning in 2009 Kentucky offered a 30 percent state income tax credit for taxpayers who install certain energy efficiency measures in their principal residence or residential rental property. The qualifying products include water heaters, heat pumps, central air conditioners, and advanced main air circulating fans. A product must meet the same energy efficiency guidelines as specified for the Federal tax credit for that residential product. The tax credit may not exceed $250. The credit, which applies to products purchased in taxable years 2009–2015, may be carried forward for 1 year.[21],[22]

Beginning in 2009, certain Michigan low-income taxpayers became eligible for a tax credit for the purchase and installation of qualifying energy efficient home improvements. The definition of qualifying home improvements is limited to the following categories: insulation, water heaters, furnaces, windows, refrigerators, clothes washers, and dishwashers. All equipment must meet the EPA Energy Star efficiency criteria. The amount of the credit is 10% of the installed cost of each improvement, up to $75 for single filers and $150 for joint filers. A taxpayer may not make more than one claim under each equipment category during a single tax year. The credit only applies to equipment purchased in 2009 - 2011. If the amount of the credit exceeds a taxpayer's tax liability for a given year, the balance is refunded.[23],[24]

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