PRELIMINARY TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR COMMERCIAL EQUIPMENT:

ENERGY CONSERVATION STANDARDS FOR ELECTRIC MOTORS

July 23, 2012

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CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 DOCUMENT PURPOSE

This preliminary technical support document (TSD) is a stand-alone report that presents the technical analyses that the U.S. Department of Energy (DOE or Department) has conducted in preparation for amending energy conservation standards for electric motors. The public is invited to comment on these analyses, either in writing or orally at a public meeting on August 21st, 2012. Details about the public meeting and instructions for submitting written comments are contained in the notice of public meeting (NOPM) published in the *Federal Register* before the date of the public meeting. DOE will review the comments it receives and revise and update these analyses prior to publishing a notice of proposed rulemaking (NOPR) in the *Federal Register*.

1.2 HISTORY OF ELECTRIC MOTOR RULEMAKINGS

The Energy Policy and Conservation Act (EPCA), 42 U.S.C. § 6311, *et seq*, as amended by the Energy Policy Act of 1992 (EPACT) established energy conservation standards and test procedures for certain commercial and industrial electric motors manufactured (alone or as a component of another piece of equipment) after October 24, 1997. Then, in December 2007, Congress passed into law the Energy Independence and Security Act of 2007 (EISA 2007) (Pub. L. No. 110–140) Section 313(b)(1) of EISA 2007 updated the energy conservation standards for those electric motors already covered by EPCA and established energy conservation standards for a larger scope of motors not previously covered. (42 U.S.C. 6313(b)(2))

EPCA also directs that the Secretary of Energy shall publish a final rule no later than 24 months after the effective date of the previous final rule to determine whether to amend the standards in effect for such product. Any such amendment shall apply to electric motors manufactured after a date which is five years after –

(i) the effective date of the previous amendment; or
(ii) if the previous final rule did not amend the standards, the earliest date by which a previous amendment could have been effective. (42 U.S.C. 6313(b)(4))

As described previously, EISA 2007 constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. Because these amendments went into effect December 19, 2010, DOE is required by statute to publish a final rule determining whether to amend the EISA 2007 energy conservation standards for electric motors by December 19, 2012. DOE will determine whether to promulgate amended energy conservation standards for electric motors and, if so, what level the new standards should be set at based on an in-depth consideration of the technological feasibility, economic justification, and energy savings of candidate standards levels, as required by section 325 of EPCA. (42 U.S.C. 6295(o)-(p), 6316(a)) Any such amended standards that DOE establishes would require compliance as of December 19, 2015.

1.3 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

Under EPCA, when DOE studies new or amended standards, it must consider, to the greatest extent practicable, the following seven factors:

(1) the economic impact of the standard on the manufacturers and consumers of the products subject to the standard;

(2) the savings in operating costs throughout the estimated average life of the products compared to any increase in the prices, initial costs, or maintenance expenses for the products that are likely to result from the imposition of the standard;

(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 covered 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. (42 U.S.C. 6295(o)(2)(B)(i))

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

DOE considers the participation of interested parties a very important part of the process for setting energy conservation standards. Through formal public notifications (*i.e., Federal Register* notices), DOE encourages the participation of all interested parties during the comment period in each stage of the rulemaking. Beginning with the preliminary analysis for this rulemaking and during subsequent comment periods, interactions among interested parties provide a balanced discussion of the information that is required for the standards rulemaking.

Before DOE determines whether to adopt an amended 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 preliminary analysis and a NOPM, the energy conservation standards rulemaking process involves two additional public notices that DOE publishes in the *Federal Register*. This first step 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 next 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 new or amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts; and the proposed energy conservation standards for each product. The last 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.

The analytical framework presented in this NOPM presents the different analyses, such as the engineering analysis and the consumer economic analyses (*e.g.*, the life-cycle cost (LCC) and payback period (PBP) analyses), the methods used for conducting them, and the relationships among the various analyses. Table 1.3.1 outlines the analyses DOE conducts for each stage of the rulemaking.

Table 1.3.1 Analyses by Rulemaking Stage

	Preliminary	**NOPR**	**Final Rule**
Market and technology assessment	✓	✓	✓
Screening analysis	✓	✓	✓
Engineering analysis	✓	✓	✓
Energy use characterization	✓	✓	✓
Product price determination	✓	✓	✓
Life-cycle cost and payback period analyses	✓	✓	✓
Life-cycle cost subgroup analysis		✓	✓
Shipments analysis	✓	✓	✓
National impact analysis	✓	✓	✓
Preliminary manufacturer impact analysis	✓		
Manufacturer impact analysis		✓	✓
Utility impact analysis		✓	✓
Employment impact analysis		✓	✓
Emissions Analysis		✓	✓
Regulatory impact analysis		✓	✓

DOE developed spreadsheets for the engineering, LCC, PBP, and national impact analyses (NIA) for each equipment class. The LCC workbook calculates the LCC and PBP at various energy efficiency levels. The NIA workbook does the same for national energy savings (NES) and national net present values (NPVs). All of these spreadsheets are available on the DOE website for electric motors:

http://www1.eere.energy.gov/buildings/appliance_standards/commercial/electric_motors.html

1.3.1 Manufacturer Interviews

As part of the information gathering and sharing process, DOE interviewed electric motor manufacturers. DOE selected companies that represented production of all types of equipment, ranging from small to large manufacturers. 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, for manufacturers to express their concerns to DOE; and (4) foster cooperation between manufacturers and DOE.

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

1.4 STRUCTURE OF THE DOCUMENT

The preliminary TSD describes the analytical approaches used in the preliminary analysis and presents preliminary results. The TSD consists of 17 chapters, an executive summary, and several appendices.

Executive Summary	Describes the rulemaking process, identifies the key results of the preliminary analyses, and identifies the key issues for which DOE seeks public comment that resulted from the preliminary analyses.
Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to the electric motor rulemaking, and outlines the structure of the document.
Chapter 2	Analytical Framework: describes the methodology, the analytical tools, and relationships among the various analyses, summarizes issues and comments DOE received from its preliminary interviews with manufacturers, and explains DOE's responses to those comments.
Chapter 3	Market and Technology Assessment: provides DOE's definition of an electric motor, lists the proposed equipment classes, and names the major industry players. This chapter also provides an overview of electric motor technology, including techniques employed to improve motor efficiency.
Chapter 4	Screening Analysis: identifies all the design options that improve electric motor efficiency, and determines which of these DOE evaluated and which DOE screened out of its analysis.
Chapter 5	Engineering Analysis: discusses the methods used for developing the relationship between increased manufacturer price and increased efficiency. Presents detailed cost and efficiency information for the units of analysis.

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 standard levels.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: discusses the effects of standards on individual customers and users of the products and compares the LCC and PBP of equipment with and without higher energy conservation standards.
Chapter 9	Shipments Analysis: discusses the methods used for forecasting the total number of electric motors that would be affected by standards.
Chapter 10	National Impact Analysis: discusses the methods used for forecasting national energy consumption and national consumer economic impacts in the absence and presence of standards.
Chapter 11	Life-Cycle Cost Subgroup Analysis: discusses the effects of standards on any identifiable subgroups of consumers who may be disproportionately affected by any proposed standard level. This chapter compares the LCC and PBP of products with and without higher energy conservation standards for these consumers.
Chapter 12	Manufacturer Impact Analysis: discusses the effects of standards on the finances and profitability of electric motor manufacturers.
Chapter 13	Employment Impact Analysis: discusses the effects of standards on national employment.
Chapter 14	Utility Impact Analysis: discusses the effects of standards on the electric utility industry.
Chapter 15	Emissions Analysis: discusses the effects of standards on three pollutants – sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury – as well as carbon emissions.
Chapter 16	Monetization of Emission Reductions Benefits: discusses the effects of standards on the monetary benefits likely to result from the reduced emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_X).
Chapter 17	Regulatory Impact Analysis for Electric Motors: discusses the impact of non-regulatory alternatives to efficiency standards.

Appendices:

App.5-A	Engineering Data
App.5-B	Sample Teardown Bill of Materials
App.7-A	Energy Use Scenario for Electric Motors with Higher Operating Speeds
App.8-A	User Instructions for Life-Cycle Cost and Payback Period Spreadsheets
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CHAPTER 2 ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

This chapter describes the general analytical framework that the U.S. Department of Energy (DOE or the Department) is using to develop amended energy conservation standards for certain electric motors. This chapter describes the methodology, analytical tools, and relationships among the various analyses that are part of the preliminary analysis performed in support of DOE's potential rulemaking.

The analyses presented in this preliminary Technical Support Document (TSD) include:

- a market and technology assessment to characterize the market for electric motors and review the techniques and approaches used to produce more efficient electric motors;

- a screening analysis to identify design options that improve electric motor efficiency and to determine which ones DOE should evaluate;

- an engineering analysis to estimate the relationship between the manufacturer's selling price of an electric motor and its efficiency level;

- an analysis of the energy use and end-use load profiles of electric motors;

- a markups analysis to develop distribution channel markups to convert manufacturer selling prices to customer installed prices;

- a life-cycle cost (LCC) and payback period (PBP) analysis to calculate, at the user level, the discounted savings in operating costs (minus maintenance and repair costs) throughout the estimated average lifetime of the covered equipment, compared to any increase in purchase and installation cost likely to result directly from imposition of a given standard;

- a shipments analysis to estimate shipments of electric motors during the period examined in the analysis;

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

- a preliminary manufacturer impact analysis (MIA) 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 analyses DOE will perform for the subsequent Notice of Proposed Rulemaking (NOPR) include those listed below. DOE plans to revise these analyses based on comments and new information received in preparing the NOPR.

- an consumer subgroup analysis to evaluate variations in customer characteristics that might cause a standard to affect particular customer subpopulations, such as small businesses, differently from the overall population
- an MIA to estimate the financial impacts of standards on manufacturers and to calculate impacts on competition, employment, and manufacturing capacity
- an employment impact analysis to assess the aggregate impacts on national employment
- a utility impact analysis to estimate the effects of proposed standards on the generation capacity and electricity generation of electric utilities
- an emissions analysis to estimate the effects of amended energy conservation standards on emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury (Hg)
- a monetization of emission reduction benefits resulting from reduced emissions associated with potential amended standards
- a regulatory impact analysis to evaluate alternatives to proposed amended energy conservation standards that could achieve substantially the same regulatory goal

2.2 BACKGROUND

The Energy Policy and Conservation Act (EPCA), 42 U.S.C. §§ 6291-6317, as amended by the Energy Policy Act of 1992 (EPACT 1992), established energy conservation standards and test procedures for certain commercial and industrial electric motors manufactured (alone or as a component of another piece of equipment) after October 24, 1997. Then, in December 2007, Congress enacted the Energy Independence and Security Act of 2007 (EISA 2007) (Pub. L. No. 110–140). Among other things, that law removed the statutory definition for the term "electric motor," updated the energy conservation standards for those electric motors already covered by EPCA, and established energy conservation standards for additional electric motors not previously covered. (42 U.S.C. § 6313(b)(2))

In May 2012, DOE published an electric motors test procedure final rule primarily focused on updating various definitions and incorporations by reference related to the current test procedure. A regulatory definition of "electric motor" was promulgated in light of EISA 2007's removal of the statutory definition of "electric motor." DOE also clarified definitions related to those motors that EISA 2007 added for standards coverage which were not previously regulated.

EPCA also directs the Secretary of Energy to publish a final rule no later than 24 months after the effective date of the previous final rule to determine whether to amend the standards in effect for such equipment. Any such amendment shall apply to electric motors manufactured after a date which is five years after –

(i) the effective date of the previous amendment; or
(ii) if the previous final rule did not amend the standards, the earliest date by which a previous amendment could have been effective. (42 U.S.C. § 6313(b)(4))

As described previously, EISA 2007 constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. Because these amendments went into effect on December 19, 2010, DOE is required by statute to publish a final rule determining whether to amend the EISA 2007 energy conservation standards for electric motors. DOE will determine whether to promulgate amended energy conservation standards for electric motors and, if so, the appropriate level for those new standards based on an in-depth consideration of the technological feasibility, economic justification, and energy savings of candidate standards levels as required by section 325 of EPCA. (42 U.S.C. §§ 6295(o)-(p), 6316(a)) Any such amended standards that DOE establishes would go into effect three years after publication of the final rule. This technical support document describes how DOE conducted the in-depth analysis for this rulemaking process.

2.2.1 Test Procedure

On May 4, 2012, DOE published a test procedure final rule for electric motors. 77 FR 26608 The final rule clarifies the scope of regulatory coverage for electric motors and ensures the accurate and consistent measurement of energy efficiency through changes to the current test procedures. These changes clarify certain terms and language in Title 10 of the Code of Federal Regulations (CFR), part 431 by revising the definitions of certain terms related to electric motors, clarifying the scope of energy conservation standards for electric motors, and updating references to several industry and testing standards for electric motors. DOE's final rule incorporates by reference portions of test procedures and definitions from relevant sources, including the Institute of Electrical and Electronics Engineers, Inc. (IEEE), National Electrical Manufacturers Association (NEMA), Canadian Standards Association (CSA), and the International Electrotechnical Commission (IEC).

During the course of both the test procedure and energy conservation standard rulemakings, DOE received comment on the use of updated industry standards and testing procedures. Baldor suggested that DOE incorporate the most recent version of the NEMA industry standard, MG1-2009, because it represents the current practices and performance guidelines that electric motor manufacturers use in the United States.[a] (Baldor, Public Meeting

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[a] One of the key documents that relates to the scope of coverage for electric motors is the National Electrical Manufacturers Association (NEMA) Standards Publication MG1, "Motors and Generators." NEMA drafted and maintains the MG1 document, most recently revised in 2011. MG1 assists users in the correct selection and application of electric motors and generators. MG1 provides practical information to electric motor manufacturers

Transcript, No. 14 at pp. 31, 57) [b] As discussed in the test procedure final rule, (77 FR 26608) DOE believed it was prudent to update its references to the relevant standards to be consistent with the electric motor industry. The final rule on test procedures adopted the updated MG1-2009 standard because it was, at the time, the most recent version of MG1.

Baldor and NEMA inquired if the newest version of Canadian Standards Association (CSA) Standard C390-10, “Test methods, marking requirements, and energy efficiency levels for three-phase induction motors,” Test Method 1, would be adopted by DOE as an acceptable test procedure. Commenters noted that the newest version is not technically equivalent to IEEE Standard 112-2004 Test Method B (IEEE 112B) because efficiency is calculated from the collected data using a different method. (Baldor, Public Meeting Transcript, No. 14 at p. 30; NEMA, No. 13 at p. 2) DOE also received input from Advanced Energy, who provided comments based upon its own testing experience that cited data from LTEE Hydro-Quebec in Canada. The comments from Advanced Energy indicated that the differences between the two standards were shown to be negligible. [c] In view of these comments, DOE reviewed the studies cited by the independent testing laboratory, Advanced Energy, and conferred with other independent experts about IEEE 112B and CSA Standard C390-10 (Test Method 1). DOE understands that the test methods are not identical, but DOE believes that the differences are minimal and both tests will result in an accurate and similar measurement of efficiency. For further discussion on this topic and how DOE made its decisions, please see the electric motors test procedure final rule at 77 FR 26622.

2.3 MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment (see chapter 3 of the preliminary TSD) characterizes the electric motor markets and existing technology options to improve electric motor efficiency. When DOE begins an energy conservation standards rulemaking, it develops information that provides an overall picture of the market for the equipment considered, including definitions, the nature of the equipment, market characteristics, and industry structure. This activity consists of both quantitative and qualitative efforts, based primarily on publicly available information.

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and users concerning the construction, testing, performance, and safety of alternating current (AC) and direct current (DC) motors and generators.

[b] “Baldor, Public Meeting Transcript, No. 14 at pp. 31, 57,” refers to the transcript of the “Public Meeting to Address Rulemaking Process Framework for Electric Motor Efficiency Standards,” held in Washington, DC, October 18, 2010. The elements of the footnote respectively refer to the company whose representative is making a comment, the docket number of the public meeting transcript, and the page(s) where the comment appears. For example, “(Baldor, Public Meeting Transcript, No. 14 at pp. 31, 57)” refers to (1) a statement made by Baldor at the Framework Public Meeting and recorded in the DOE Appliance Standards Program docket under “Energy Conservation Program for Certain Commercial and Industrial Equipment: Framework Document for Commercial and Industrial Electric Motors,” Docket Number EERE–2010–BT–STD–0027, as document number 14; and (2) the passage that appears on page 31 and 57 of that document.

[c] Report from Advanced Energy is available at http://www.regulations.gov/#!documentDetail;D=EERE-2007-BT-TP-0008-0023

The discussion following this paragraph summarizes the analytical approach to the market assessment and key issues highlighted during DOE's preliminary interviews with manufacturers. The manufacturer interviews were conducted to gather feedback on DOE's engineering and market analysis approach, as well as to gather data on pricing, market behavior, electric motor shipments, and key concerns of manufacturers. A more detailed discussion on DOE's approach can be found in the market and technology assessment (chapter 3 of the preliminary TSD).

2.3.1 Current Definitions and Scope of Energy Conservation Standards for Electric Motors

EISA 2007 amended EPCA to establish energy conservation standards for four sets of electric motors: general purpose electric motors (subtype I), general purpose electric motors (subtype II), fire pump electric motors, and NEMA Design B general purpose electric motors (from 200 horsepower through 500 horsepower). The test procedure final rule codified certain definitions of general purpose electric motors (subtype I and subtype II) that helped clarify the application of the efficiency levels mandated under EISA 2007. As background, the following subsections provide some additional details about the four sets of electric motors as defined in the test procedure final rule.

Manufacturers expressed confusion over DOE's proposed definitions and interpretations of the statutory language under section 313(a) of EISA 2007. Baldor stated that it was difficult to understand what electric motors are covered under the general purpose subtype I heading and what efficiency levels apply to NEMA Design B electric motors under EISA 2007. (Baldor, Public Meeting Transcript, No. 14 at pp. 26, 46, 49, 54) Additionally, Baldor expressed concern over a *Federal Register* notice from March 23, 2009 (74 FR 12058) that codified EISA 2007 by striking the long-standing definition of the term "electric motor" from 10 CFR Part 431. (Baldor, Public Meeting Transcript, No. 14 at p. 34) That notice adopted the approach established by EISA 2007, which removed the previous EPACT 1992 definition for the term "electric motor" and inserted in its place two new categories of types of electric motors, general purpose electric motor (subtype I) and general purpose electric motor (subtype II). *See* 42 U.S.C. § 6313(b)(2). As a result of this removal by EISA 2007, DOE addressed this gap by defining the term "electric motor" through its regulations. See 77 FR at 2663 (defining the term "electric motor" as "a machine that converts electrical power into rotational mechanical power.")

General Purpose Electric Motors (Subtype I) Definition

As a result of the recent electric motors test procedure final rule, 10 CFR 431.12 now defines a general purpose electric motor (subtype I) as a general purpose electric motor that:

(1) Is a single-speed, induction motor;
(2) Is rated for continuous duty (MG1) operation or for duty type S1 (IEC);
(3) Contains a squirrel-cage (MG1) or cage (IEC) rotor;
(4) Has foot-mounting that may include foot-mounting with flanges or detachable feet;

(5) Is built in accordance with NEMA T-frame dimensions or their IEC metric equivalents, including a frame size that is between two consecutive NEMA frame sizes or their IEC metric equivalents;
(6) Has performance in accordance with NEMA Design A (MG1) or B (MG1) characteristics or equivalent designs such as IEC Design N (IEC);
(7) Operates on polyphase alternating current 60-hertz sinusoidal power, and:
(i) Is rated at 230 or 460 volts (or both) including motors rated at multiple voltages that include 230 or 460 volts (or both), or
(ii) Can be operated on 230 or 460 volts (or both); and
(8) Includes, but is not limited to, explosion-proof construction.

This definition fills in the statutory gap left by EISA 2007 when it removed the prior definition for "electric motor." The new definition includes updated references to International Electrotechnical Commission (IEC) and MG1 standards. This definition is functionally equivalent to the definition of "electric motor" that was codified in the CFR prior to EISA 2007. In effect, EISA 2007 renamed the electric motors that were, at that time, required to meet energy conservation standards as "general purpose electric motor (subtype I)." EISA 2007 also increased the efficiency requirements for most of those motors (the lone exception being fire pump electric motors, which are discussed later in this section, to levels equivalent to the NEMA Premium industry standard, which is found in Table 12-12 of NEMA MG1-2006 (now Table 12-12 of NEMA MG1-2011). These levels have been codified as part of DOE's regulations. *See* 10 CFR 431.25(c).

General Purpose Electric Motors (Subtype II) Definition

Further, the recent electric motors test procedure final rule amended 10 CFR 431.12 and defined a general purpose electric motor (subtype II) as any general purpose electric motor that incorporates design elements of a general purpose electric motor (subtype I). Unlike a general purpose electric motor (subtype I), a subtype II motor is configured in one or more of the following ways:

(1) Is built in accordance with NEMA U-frame dimensions as described in NEMA MG1–1967 (incorporated by reference, see § 431.15) or in accordance with the IEC metric equivalents, including a frame size that is between two consecutive NEMA frame sizes or their IEC metric equivalents;
(2) Has performance in accordance with NEMA Design C characteristics as described in MG1 or an equivalent IEC design(s) such as IEC Design H;
(3) Is a close-coupled pump motor;
(4) Is a footless motor;
(5) Is a vertical solid shaft normal thrust motor (as tested in a horizontal configuration) built and designed in a manner consistent with MG1;
(6) Is an eight-pole motor (900 rpm); or
(7) Is a polyphase motor with a voltage rating of not more than 600 volts, is not rated at 230 or 460 volts (or both), and cannot be operated on 230 or 460 volts (or both).

This definition provides greater clarity to the definition in EISA 2007. This definition, as with the general purpose electric motor (subtype I) definition, includes references to the most recent IEC and NEMA standards publications. Additionally, general purpose electric motors (subtype II) constituted the greatest expansion of motors covered as a result of EISA 2007. EISA 2007 required subtype II electric motors to meet energy conservation standard levels equivalent to those established by EPACT 1992, which can be found at Table 12-11 of NEMA MG1-2006 (now Table 12-11 of NEMA MG1-2011). These levels have been codified as part of DOE's regulations. *See* 10 CFR 431.25(e).

NEMA Design B Electric Motor Definition

Also, as a result of the electric motors test procedure final rule, 10 CFR 431.12 defines a NEMA Design B electric motor as a squirrel-cage motor that is:

(1) Designed to withstand full-voltage starting;
(2) Develops locked-rotor, breakdown, and pull-up torques adequate for general application as specified in sections 12.38, 12.39 and 12.40 of NEMA MG1– 2009 (incorporated by reference, see § 431.15);
(3) Draws locked-rotor current not to exceed the values shown in section 12.35.1 for 60 hertz and 12.35.2 for 50 hertz of NEMA MG1–2009; and
(4) Has a slip at rated load of less than 5 percent for motors with fewer than 10 poles.

NEMA MG1-2009 establishes the same torque requirements for both NEMA Design A and NEMA Design B electric motors. However, NEMA Design B electric motors must be designed such that their locked-rotor (or starting) current is less than that established for NEMA Design A electric motors. Unless the application specifically requires a NEMA Design A[d] electric motor design, NEMA Design B electric motors are often used instead of Design A electric motors because of the smaller spike in startup current. NEMA Design B electric motors are designed for continuous-duty operation and are commonly used in pumps, fans, blowers, and compressors.

During the framework document public meeting, the Appliance Standards Awareness Project (ASAP) stated that it did not want "legal" definitions (i.e., DOE adopted) to be in conflict with those that are used by the industry. ASAP continued, stating that NEMA Design B electric motors should not be defined within a certain horsepower range. (ASAP, Public Meeting Transcript, No. 14 at p. 52) DOE understands ASAP's concern and notes that the Design B definition noted above does not explicitly limit the horsepower rating of an electric motor. Additionally, DOE's definition is consistent with the industry version of the definition found in NEMA MG1-2009. The only difference between the definition in 10 CFR 431.12 and the

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[d] Locked-rotor current, sometimes called in-rush current, is the spike in current occurring when power is first applied to the motor and lasting until a certain rotor speed is reached. NEMA Design B motors have limits on locked-rotor current (specified in NEMA MG1-2011 Section 12.35.1). NEMA Design A are not subject to locked-rotor current limits and the ensuing larger locked-rotor current spike may require special hardware, such as larger-gauge power connections or larger electrical system fuses.

definition from MG1 is that the DOE definition corrects minor typographical errors that appear in that industry-based document. 77 FR 26616-17

As clarified in the DOE test procedure (77 FR 26616-17), DOE interprets EISA 2007 as establishing energy conservation standards for NEMA Design B motors (greater than 200 horsepower, but less than or equal to 500 horsepower) that also meet the definition of either subtype I or II. These motors would then be required to meet the energy conservation standard levels found in Table 12-11 of NEMA MG1-2006 (now Table 12-11 of NEMA MG1-2011).

Fire Pump Electric Motors Definition

Finally, the electric motors test procedure final rule, amended 10 CFR 431.12 by defining a fire pump electric motor in the following manner:

Fire pump electric motor means an electric motor, including any IEC-equivalent, that meets the requirements of section 9.5 of National Fire Protection Association (NFPA) Standard 20 (incorporated by reference, see §431.15).

Before the test procedure final rule was published, Baldor expressed concern about a potential conflict between the long-standing industry definition of fire pump electric motors and a new definition for the purpose of establishing energy conservation standards. (Baldor, Public Meeting Transcript, No. 14 at pp. 54-55) In the test procedure final rule, DOE considered these comments and adopted a definition incorporating NFPA 20-2010 in an effort to clarify the definition. NEMA noted that while DOE has identified fire pump electric motors as polyphase motors with NEMA Design B performance characteristics, these electric motors are not simply NEMA Design B electric motors because fire pump motors have additional performance requirements, such as being able to start a minimum of 12 times per hour. (NEMA, No. 13 at p. 6) NEMA noted this concern because the additional requirements for fire pump motors affect a motor's utility and ability to meet the same efficiency standards when compared to the more typical NEMA Design B electric motors, which have no additional performance requirements. DOE is aware of the similarity in performance requirements between these two types of electric motors and, as will be discussed, DOE has separated fire pump electric motors from other general purpose electric motors into separate equipment class groups for this rulemaking. Finally, as mentioned, fire pump electric motors were covered by energy conservation standards for electric motors prior to the enactment of EISA 2007. However, unlike the rest of the electric motors that were previously required to meet energy conservation standards, the efficiency levels for fire pump motors were not raised above their pre-EISA 2007 levels, although DOE did modify the horsepower range of covered motors from 1 through 200 to 1 through 500. (77 FR 26636)

2.3.2 Expanded Scope of Coverage

The four categories of electric motors discussed in the previous section represent the entire scope of coverage for current electric motor energy conservation standards in subpart B of 10 CFR part 431. For purposes of this document, DOE's discussion of expanding the scope of coverage refers to the proposal to analyze energy conservation standards for electric motor types that currently do not have such standards. DOE has the statutory authority to establish such standards without first promulgating a coverage determination rulemaking based on the lack of a statutory definition for “electric motors.” When DOE began updating standards for these electric motors it held a public meeting to discuss its framework document on October 18, 2010. During that meeting, DOE received comments regarding the energy saving potential from expanding the scope of coverage beyond subtype I, subtype II, and fire pump electric motors.

In response to the September 28, 2010, framework document, NEMA, ASAP, Baldor, and the American Council for an Energy-Efficient Economy (ACEEE) suggested that DOE expand its regulatory coverage to include other electric motors besides those that have already been specifically enumerated in EPCA. These commenters believed that excluding only certain definite and special purpose electric motors -- and including all others -- would simplify compliance and enforcement. The commenters also stated that such an approach could save more energy than simply increasing the stringency of those electric motors that are already covered by specific energy conservation standards. (ASAP and NEMA, No. 12 at p. 1; ACEEE, Public Meeting Transcript, No. 14 at p. 62; ACEEE, No. 4 at p.2; Baldor, Public Meeting Transcript, No. 14 at pp. 65-66) ASAP and NEMA calculated that establishing standards for other electric motors beyond the four groupings already addressed would save more energy than increasing the required efficiency levels of currently regulated motors because it would expand the number of motors that would be subject to the NEMA Premium[e] levels and would increase the efficiency of unregulated motors by 2.2 percent to 5 percent. (ASAP and NEMA, No. 12 at pp. 1, 4) Baldor, ASAP and NEMA all supported this approach along with the adoption of a standard level equivalent to NEMA Premium levels. In their view, this approach avoids imposing unmanageable costs and marketplace disruptions on manufacturers because they already have the tooling to reach these levels. (ASAP and NEMA, No. 12 at pp. 1-2; Baldor, No. 8 at p. 2) ACEEE commented that this move would be in the best interest of consumers, domestic manufacturers, and the economy. (ACEEE, Public Meeting Transcript, No. 14 at p. 22)

Utility companies also supported this approach. California Investor-Owned Utilities (IOUs), consisting of Pacific Gas and Electric Company, Southern California Gas Company, the San Diego Gas and Electric Company, and Southern California Edison submitted a joint comment supporting an expanded scope that would require most electric motors to meet NEMA Premium efficiency levels and require a compliance date to commence 18 months after the issuance of the final rule for new electric motors standards. (IOUs, No. 11 at pp.1-2)

On March 30, 2011, DOE published a Request for Information (RFI) in the *Federal Register* seeking additional public comments about an increased scope of coverage for the electric motors listed in Table 2.1. (76 FR 17577 (March 30, 2011)) DOE compiled the list based on submitted comments, manufacturer interviews, and discussions with subject matter experts. Many of these electric motors have similar electromechanical properties to those general purpose electric motors currently subject to regulation. Therefore, many interested parties believed that many of these motors could be incorporated into the current scope of coverage without a major overhaul of the electric motor test procedure.

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[e] NEMA Premium efficiency levels refer to the efficiency values in NEMA MG1-2011 Table 12-12.

Table 2.1 Unregulated Electric Motors Addressed in the Request for Information

Electric Motor Description	
NEMA Design A from 201 to 500 horsepower	Inverter duty
Brake	Totally enclosed, air-over
Integral shafted partial and-partial ¾	Totally enclosed, non-ventilated
Vertical hollow shaft and vertical motors of all thrust configurations	Multispeed
Integral gear	Direct current
Single phase	Liquid cooled
Electronically commutated	Switched reluctance
Interior permanent magnet	Intermittent-duty
Submersible	Immersible

DOE received comments responding to the RFI advocating that DOE regulate many of the electric motors discussed in the RFI as well as many additional motor types and devices. The Copper Development Association (CDA) suggested setting standards for gearboxes[f] included in integral gear electric motor sets. (Copper Development Association, No. 18 at pp. 1-2) ASAP and NEMA recommended that DOE regulate many of the motors in Table 2.1 and all of the electric motors listed in Table 2.2, which are motors not addressed in the RFI (ASAP and NEMA, No. 20 at pp. 2-3).

Table 2.2 Unregulated Electric Motors Not Addressed in the Request for Information

Electric Motor Description	
Customer-defined endshields	Special flanged endshields
Shaft of non-standard dimension or additions	Special base or mounting feet
Double Shaft	Electric motors with thrust or sleeve bearings
Encapsulated	All Mounting Configurations

DOE agrees that many of the electric motors in Table 2.1 and Table 2.2 have electromechanical similarities relative to those motors that are already regulated. Additionally, DOE recognizes the energy savings potential of expanding the scope of regulated electric motors and has preliminarily decided to adopt this approach. DOE plans to set energy conservation standards for all of the NEMA Design A, B, or C motors[g] discussed below. Historically, DOE has not covered motors deemed "definite purpose" or "special purpose" (as defined by EPCA) from energy conservation standards. These motor types were excluded from coverage under the "electric motor" energy conservation standards established in EPACT 1992. However, with the elimination of the prior statutory definition of the term "electric motor" and the required new energy conservation standards mandated by EISA 2007, coupled with the continued national interest to seek greater national energy savings, DOE is contemplating applying minimum efficiency standards to any electric motor type exhibiting all of the characteristics listed in Table 2.3.

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[f] The electric motors currently subject to energy conservation standards are constant speed electric motors. The speed depends on pole configuration, slip, and operating frequency. Gearboxes allow users to run equipment at a speed that is different from the nameplate.

[g] Including IEC equivalents.

Table 2.3 Characteristics of Motors Regulated Under Expanded Scope of Coverage

Motor Characteristic
Is a single-speed, induction motor,
Is rated for continuous duty (MG1) operation or for duty type S1 (IEC),
Contains a squirrel-cage (MG1) or cage (IEC) rotor,
Operates on polyphase alternating current 60-hertz sinusoidal power,
Is rated 600 volts or less,
Has a 2-, 4-, 6-, or 8-pole configuration,
Has a three-digit NEMA frame size and is less than 500 horsepower, and
Is a NEMA Design A, B, or C motor (or an IEC equivalent)

Some motor types with all characteristics listed in Table 2.3 may be considered "special purpose" or "definite purpose" motors. However, should DOE expand its scope of coverage, it would no longer be excluding such motor types from energy conservation standards. Assuming that DOE decides to set minimum standards for all electric motor types with the characteristics listed in Table 2.3, their standards would likely be based on their respective equipment class groups. For a discussion of which characteristics determine a motor's equipment class group, see section 2.3.5. Motor types that exhibit all characteristics shown in Table 2.3, but which DOE does not believe should be subject to efficiency regulations at this time, either because of testing difficulty or other reasons, are addressed in section 2.3.3.

ASAP and NEMA suggested that DOE use the NEMA definitions of electric motors whenever possible and offered to work with DOE "to develop new, clear definitions to help characterize exempt motors." (ASAP and NEMA, No. 20 at p. 5) In an attempt to harmonize relevant terminology, DOE has provided definitions that are based at least in part on the applicable industry-developed definitions. These motors, and their definitions, are listed in chapter 3 of the preliminary TSD. DOE attempted to define certain motors that may be regulated because there is no formal industry-based definition for them (e.g., partial motors and inverter-duty motors). DOE requests feedback on the preliminary definitions outlined in chapter 3 of the preliminary TSD.

Finally, for those motor types that DOE has not previously regulated but is now considering regulating as part of this rulemaking, DOE is not proposing at this time to make changes to the underlying test methods used to determine these motors' efficiencies. In other words, DOE currently believes that all of these new motor types would still be tested using either IEEE 112B or CSA C390. In some instances, additional preparatory steps may be needed to test a motor using either test procedure. DOE believes that this is an appropriate approach because all of the motors that DOE is considering expanding coverage to are single-speed, polyphase induction motors like those currently subject to energy conservation standards, and they all function using the same general principles. DOE has provided a preliminary discussion of some of the modifications and preparatory steps that it believes will be necessary for some of these motor types and requests commenter feedback on each approach. Additionally, DOE plans to conduct a separate test procedure rulemaking in which it will incorporate such feedback and seek to codify the additional steps necessary to test all of these additional motors.

Motors with Encapsulated Stator Windings

Encapsulated motors have special insulation protecting the stator winding from condensation, moisture, dirt, and debris. This insulation typically consists of a special material coating that completely seals off the stator's copper windings. Encapsulation is generally found on open-frame motors, such as open dripproof (ODP) motors, where the possibility of contaminants getting inside the motor is higher than on an enclosed-frame motor, such as a totally enclosed, fan-cooled (TEFC) motor.

DOE received comment regarding motors with encapsulated windings. NEMA and ASAP commented that, with the exception of designs for submersible applications, encapsulated motors should be subjected to minimum standards. (ASAP and NEMA, No. 20 at p. 4; ASAP and NEMA, No. 12 at p. 9) DOE further discussed encapsulation with industry and subject matter experts to determine if encapsulated stator windings affect the efficiency of a motor and determined that encapsulated motors could be included in the list of regulated motors.

DOE previously categorized encapsulated motors as "special purpose" because of their special construction and excluded them from standards because the EPACT 1992 electric motor standards explicitly did not apply to definite- or special-purpose motors. 62 FR 59978, 59984 (November 5, 1997) However, DOE does not believe that whether or not a motor has encapsulated stator windings affects the efficiency of a motor because the encapsulation does not significantly inhibit heat dissipation from the stator windings. (Heat dissipation plays a significant role in affecting the overall efficiency of an electric motor. Excessive heat build-up can reduce the efficiency of a motor while good dissipation of heat can help improve it.) Therefore, DOE is considering setting standards for motors with encapsulated windings, unless covering them would not be warranted because of other criteria (e.g., a submersible motor with encapsulated windings, see section 2.3.3). DOE also believes that encapsulated windings do not interfere with the DOE test procedures[h] because the encapsulated windings do not prevent the motor from being attached to a dynamometer and running like a typical general purpose motor. Therefore, DOE has no plans at this time to alter the current test procedure to specifically address these types of motors.

DOE requests comment on its tentative plan to include motors with encapsulated windings as part of its efforts to more broadly address efficiency levels for electric motors generally, and its preliminary view that encapsulated motors can be tested using the existing DOE test methods.

Single- and Double-Shaft Motors of Non-Standard Shaft Dimensions or Additions

DOE understands that NEMA Standard MG1-2011 and IEC Standard 60072-1 (1991) specify tolerances for the shaft extension diameter and keyseat that relate to the fit between the shaft and the device mounted on the shaft. DOE is aware that shafts of special diameter, length, or design are often provided at a customer's request for use in particular applications. DOE has

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[h] DOE approved test methods are IEEE 112 Test Method B and CSA C390.

also learned that some manufacturers utilize shafts of special dimensions in the belief that electric motors with special shaft dimensions are not covered under EPCA. In the proposed test procedure rule published in January 2011, DOE proposed guidance on shaft diameter, length, shoulder location, and special designs. 76 FR 671-672.

DOE received comments that advocate covering a motor with a single- or double-shaft extension that may otherwise be constructed according to non-NEMA standard dimensions or additions in an effort to preclude loopholes and thereby circumvent compliance. (ASAP and NEMA, No. 12 at p. 8) Baldor expressed a similar concern during the public meeting when it mentioned that large manufacturers had approached them about using shaft alterations as a means of skirting EISA requirements. (Baldor, Public Meeting Transcript, pp. 96-97) ASAP and NEMA submitted comments in response to the RFI on scope expansion and suggested that manufacturers could demonstrate compliance for these motors by testing similar models that could more easily be attached to a dynamometer. (ASAP and NEMA, No. 20 at p. 4)

In DOE's view, shaft alterations do not affect a given motor's efficiency because the motor shaft does not impact the electromagnetic properties of the motor. Consistent with this view, DOE plans to regulate motors irrespective of the given diameters, lengths, shoulder locations, and special designs in an effort to simplify compliance and to discourage attempts to circumvent the energy conservation standards. This approach would also address efforts to incorporate alterations made to double-shaft motors. DOE requests comment on whether to include motors with the aforementioned alterations in the expanded scope of coverage. Additionally, DOE requests comment on difficulties that may arise from testing motors with non-standard shaft alterations. More specifically, testing a "similar model" to show compliance would likely create difficulties in ensuring the accuracy of claimed efficiency ratings. DOE is interested in information about other methods for testing such motors -- and whether certain changes to the current test procedure are needed to address such situations. If changes are needed, DOE requests comments from interested parties regarding what those changes should be.

Electric Motors with Brake Components

Brake motors are motors with a braking mechanism either attached to an exterior shaft or built inside the motor enclosure. The brake mechanism is typically mounted on the end opposite the drive of the motor. The braking system is typically an electrically released, spring-loaded mechanism. The brake component is "energized" during normal operation of the motor. During this normal operation, the brake component is not touching or interfering with the motor operation, but is drawing power from the same source as the electric motor. When an emergency situation arises, power is cut off from the brake component, and the brake then "clamps" down on the motor shaft to quickly stop rotation of the motor.

The Copper Development Association (CDA) commented that brake motors are relatively high unit-shipment volume motors with heavy duty-cycles (even 24/7) that can achieve higher motor efficiencies and that higher efficiencies could provide significant energy savings. (CDA, No. 18 at p. 1) NEMA and ASAP also submitted comment specifically supporting the inclusion of brake motors in an expanded scope of coverage. (ASAP and NEMA, No. 20 at p. 3)

Additionally, NEMA submitted a separate comment advocating the exclusion of integral brake motors as called out in appendix A to subpart B of CFR Part 431. (NEMA, No. 19 at p. 2)

In a 1997 rulemaking, DOE did not cover integral brake motors, described as "integral brake design factory built within the motor," from the scope of coverage because they are "special purpose motors." 62 FR 59978 (November 5, 1997) As mentioned previously, DOE is now considering efficiency standards for "special purpose" and "definite purpose" electric motors, including certain types of motors with brake components.

DOE plans on proposing definitions for two terms to describe motors with brake components: "non-integral brake motors" and "integral brake motors." A "non-integral brake motor" consists of a brake mounted to the motor in such a fashion that the brake component is typically bolted onto the outside of the fan cover of the motor and could be removed from the motor with minimal disassembly, and the motor could operate as a general purpose electric motor. An "integral brake motor" consists of a factory-built unified assembly typically built either inside the endshield of the motor or in between the motor fan and rotor component. With "integral brake motors," the brake component is difficult to remove, and doing so could adversely affect the performance of the motor.

DOE understands that for both motor types, "non-integral brake" and "integral brake," the braking mechanism does not directly interfere with normal operation because it is only engaged when desired or in an emergency. Additionally, both motor types may be tested using current DOE test procedures without modification to the motor. However, the braking mechanism may contribute to friction and windage losses from rotating brake components, or electrical losses as a result of energizing the brake disc. DOE does not know the extent of these losses, and requests comment on any reports or technical papers regarding losses caused by brake components. At this time, DOE is considering setting efficiency standards for both types of brake motors. DOE requests comment on this tentative decision, as well as comment on any other difficulties arising from testing brake motors, especially "integral brake motors," under the approved test methods. DOE requests comment on any specific recommendations related to the manner in which the losses from the brake component should be taken in to account. Based on the information received, DOE may also consider an approach that tests these motors with the braking mechanism removed.

Customer-Defined Endshields or Flanged Special Motors, Motors with Special Base or Mounting Feet

Motors may have special or customer-defined endshields, flanges, bases, or mounting feet that do not necessarily conform to NEMA MG1-2011 standards. ASAP and NEMA submitted comment advocating the coverage of flanged special motors and motors with a special base or mounting feet. (ASAP and NEMA, No. 12 at pp. 8-9; ASAP and NEMA, No. 20 at p.4) ASAP and NEMA also recommended that DOE address customer-defined endshields. (ASAP and NEMA, No. 20 at p. 4)

Prior to EISA 2007, only electric motors that were general purpose foot-mounting, which meant being built in standard NEMA T-frame with mounting brackets to make the motor suitable for horizontal operation, were subject to energy conservation standards. Therefore, DOE did not cover motors with special bases or face-mounting configurations because such motors did not fall under the definition of ‘electric motor’ as defined in EPCA (42 U.S.C. 6311(13)(A), 1992). 62 FR 59978, 59984 (November 5, 1997) However, as a result of the EISA 2007 amendments, DOE believes that such electric motors could be subject to energy conservation standards because DOE is no longer restricted to only covering general purpose electric motors built in a T-frame.

DOE did not cover motors with customer-defined endshields because their special design for a particular application made them “special” or “definite” purpose motors. However, as noted earlier, the EISA 2007 amendments no longer restrict electric motors solely to “general purpose” electric motors. Consequently, DOE is considering setting energy conservation standards for motors with customer-defined endshields consistent with the approach suggested by both industry and energy efficiency advocates.

DOE understands that motors with customer-defined endshields, special flanges, bases, or mounting feet (except for vertical motors, discussed separately) do not affect efficiency because these are external changes to the motor and do not affect the electromechanical properties of the motors. DOE plans to address motors with these types of custom-frame enclosures, but recognizes that some of these motors may be more difficult to attach to a dynamometer for testing. DOE requests comment on its tentative decision to include these motors as part of its efforts to broaden the application of standards to different electric motors and any testing difficulties that may arise from testing such custom motors.

Partial and Integral Motors

DOE understands that partial motors, also called “partial ¾ motors” or “¾ motors,” are motors missing one or both endshields. Such motors may be closely connected to another piece of equipment, such as a pump or gearbox. When a partial motor is mated to another piece of equipment, it is often referred to as an “integral” motor. For example, an “integral gearmotor” is the combination of a partial motor mated to a gearbox using bolts or some other means of attachment. In this configuration, the gearbox replaces an endshield on the motor and provides a bearing mount for the motor shaft, allowing proper operation.

DOE understands that there is no standard or common industry definition for a partial motor. In one comment, NEMA recommended that DOE continue to exclude partial motors from energy conservation standards because they may not follow NEMA MG1 requirements for thermal, electrical, and/or mechanical performance, but suggested that partial ¾ motors or integrally shafted partial motors should be covered because they are motors missing only a drive-end endshield. (NEMA, No. 19 at p. 3) Subsequently, NEMA and ASAP asserted that partial motors can also be called “partial ¾ motors” and should be categorized with integral shafted partial motors, because they are sold without one or both endshields and could be included in an expanded scope of coverage. (NEMA, No. 20 at p. 3) This apparent contradiction, first grouping partial motors with component sets and then grouping partial motors with partial ¾ motors or integral shafted partial motors, illustrates the need for guidance on how to interpret such terms. Consequently, DOE has created Table 2.4 that outlines its current understanding and interpretation of terms related to partial motors and component sets. (DOE discusses component sets in chapter 3 of the preliminary TSD)

Table 2.4 Partial Motors and Component Sets

Row	Name	Also Called	Description	Example
1	Partial electric motor	Partial ¾ motor, integral shafted motor, integral shafted partial motor, integral gearmotors	An electric motor necessitating only the addition of one or two endshields with bearings to create an operable motor.	A complete motor with one endshield removed and mated to a gearbox.
2	Component set	Wound stator/squirrel-cage rotor sets	A combination of motor parts that require more than the addition of one or two endshields with bearings to create an operable motor. These parts may consist of any combination of a stator frame, wound stator, rotor, shaft, or endshields.	A wound stator and squirrel-cage rotor sold independently of any other motor components. End-user must provide shaft, frame, and other components to create a running motor.

Previously, DOE did not cover “integral gearmotors,” from efficiency standards because, at that time, they did not meet the statutory definition of “electric motor.” DOE understands integral gearmotors to be a subset of partial motors. An integral gearmotor is an assembly of a motor and a specific gear drive or assembly of gears, such as a gear reducer, as a unified package. DOE did not cover such motors because the motor portion of an integral gearmotor is not necessarily a complete motor, since the end bracket or mounting flange of the motor portion is also part of the gear assembly and cannot be operated when separated from the complete gear assembly. Also, an integral gearmotor is not necessarily manufactured to the standard T-frame dimensions specified in NEMA MG1. DOE found that these characteristics precluded the motor from being used in most general purpose applications without significant modifications and, consequently, integral gearmotors fell outside the scope of the previous statutory definition of ‘‘electric motor.’’ 62 FR 59978, 59982 (November 5, 1997).

Although DOE believes that integral gearmotors are a subset of partial motors, many of the reasons for not including integral gearmotors in the 1997 final rule apply to partial motors as a whole. Partial motors are special purpose motors that are unable to run when operated without one or both endshields. However, with the addition of an endshield, these partial motors can become operational. DOE believes that the absence of one or both endshields does not degrade the efficiency of a motor, rather its ability to operate independently of its driven equipment. When one or two “dummy” endshields are attached to the motor, the motor may have no other characteristics that would otherwise degrade efficiency when compared to a general purpose, subtype I motor designed and built with in a complete frame assembly or housing. DOE is giving serious consideration to including partial motors as part of any effort to expand efficiency standards coverage, particularly in those cases where the motor is operational when paired with at least one end plate. DOE requests feedback on this tentative approach to include partial motors in the expanded scope of standards coverage.

Additionally, DOE is particularly interested in comment concerning how to test a partial motor in a consistent and repeatable manner. The CDA indicated that a new test procedure may be required for partial motors and that the DOE should consider developing a new test standard for these and similar motors. (CDA, No. 18 at p. 2) DOE has received feedback suggesting that manufacturers could show compliance by testing a similar model that could more easily be attached to a dynamometer. (ASAP and NEMA, No. 12 at p. 9) Alternatively, another option would allow a manufacturer to provide one or two "dummy" endshields that could be attached to the motor for the purpose of testing. This approach would enable testing of the motor in question.

Totally Enclosed, Non-Ventilated Motors

Unlike totally enclosed, fan-cooled (TEFC) motors, totally enclosed, non-ventilated motors (TENV) are motors that have no external fan blowing air over the outside of the motor. TENV motors may be used in environments where an external fan could clog with dirt or dust. TENV motors are cooled by natural conduction and convection of the motor heat into the surrounding environment, which results in a motor that operates at higher temperatures than a TEFC motor. TENV motors may deal with the higher operating temperatures by adding more frame material to dissipate excess heat or by upgrading stator winding insulation to withstand the higher operating temperatures.

ASAP and NEMA recommended that DOE include TENV motors in an expanded scope of coverage and suggested that manufacturers could demonstrate compliance by testing similar models. (ASAP and NEMA, No. 12 at p. 7) ASAP and NEMA later scaled back its recommendation and supported the coverage of only 140 T- and 180 T-frame size TENV motors. (ASAP and NEMA, No. 20 at p. 3) ASAP and NEMA did not explain their reasoning, but DOE notes that TENV motors are most commonly built in these two frame sizes. DOE requests additional comment regarding the approach suggested by ASAP and NEMA, including the merits of extending standards coverage to other TENV motors as well as reasons in favor of this more limited approach. The CDA also supported the coverage of TENV motors and added that DOE may need to develop new test procedures for these motors. (CDA, No. 18 at p. 2) CDA did not indicate whether the current procedures could be modified to test these motors or what specific steps would need to be included to test these types of motors.

Previously, DOE did not cover TENV motors, believing that they could not be used in most general purpose applications, under the likelihood of a TENV motor being built in a frame size larger than that of a TEFC motor of the same horsepower rating to dissipate the same amount of heat. 62 FR 59978, 59982 (November 5, 1997) Further, TENV motors may have design and construction requirements for extra installation clearances to better dissipate heat in the absence of an external fan. At this time, DOE is considering expanding the scope of standards coverage to include TENV motors in all frame series, rather than to limit this approach solely to 140 T- and 180 T-frame motors. DOE requests comment on this preliminary approach.

Additionally, at this time, DOE does not believe that any special modification to its current test procedures for electric motors would be needed for TENV motors, but requests comment from interested parties about this view.

Motors with Sleeve Bearings

A majority of the electric motors currently covered by DOE’s standards utilize anti-friction ball bearings. Sleeve bearings are used on larger (generally greater than 400 horsepower) motors as an alternative to anti-friction ball bearings. Sleeve bearings typically have a longer life and the ability to operate at higher speeds than anti-friction ball bearings.

Both ASAP and NEMA asserted that motors with sleeve bearings should be included in the scope of coverage and that testing should be performed on a motor with an equivalent electrical design, but with standard bearings installed. (ASAP and NEMA, No. 20 at p. 4) DOE separately consulted with testing laboratories, subject matter experts, manufacturers and reviewed technical papers to determine that sleeve bearings do not significantly degrade efficiency when compared to anti-friction ball bearings.

DOE did not previously cover electric motors equipped with sleeve bearings, believing that their special mechanical construction categorizes them as special-purpose motors as defined in EPCA. 62 FR 59978 (November 5, 1997) However, as stated, DOE is considering extending efficiency standards coverage to electric motors generally, including special- or definite-purpose motors. Furthermore, DOE does not believe that sleeve bearings significantly affect the efficiency capabilities of an electric motor when compared to anti-friction ball bearings. DOE requests comment on the effect sleeve bearings have on efficiency and its preliminary decision to include such motors in the expanded scope of coverage.

Although DOE does not believe that modifications to its current test procedures are needed for sleeve-bearing motors, it has considered the comment submitted by NEMA and ASAP. DOE notes that in its 1999 final rule on test procedures for electric motors, which covered motors constructed with roller bearings, it allowed manufacturers to substitute standard anti-friction bearings for the roller bearings when testing for energy efficiency. (64 FR 54146) As stated, DOE is not aware of any reasons why a motor with sleeve bearings could not be tested with its sleeve bearings using the current DOE test procedures, but requests additional information on this point. DOE also requests comments from interested parties about the feasibility of testing motors with standard anti-friction bearings temporarily installed rather than the sleeve bearings as originally designed.

Vertical Hollow-Shaft and Vertical Motors of all Thrust Configurations

Vertical motors are motors that are designed to operate with the motor mounted in a vertical position, usually with the shaft facing downward. These motors are typically used in pumping applications, such as in wells or pits. Vertical motors can have solid or hollow shafts and those with solid shafts are currently subject to energy conservation standards as a result of EISA 2007. Alternatively, the unregulated hollow shaft vertical motors employ a hollow shaft that allows a pump shaft to be run through the motor shaft. Vertical motors also come in different thrust configurations, such as low, medium, or high. The thrust configuration depends on how much weight the vertical motor's bearings must be able to withstand. The weight on the bearings is a combination of the motor weight, pump shaft weight, and down-thrust created by the pump. The thrust configuration determines which type of bearings the vertical motor may use, either regular anti-friction ball bearings or thrust bearings. Motors with thrust bearings are discussed in more detail in the following section.

ASAP and NEMA were in favor of covering vertical hollow-shaft motors and, more generally, vertical motors of all thrust configurations. (ASAP and NEMA, No. 20 at p. 3) Baldor commented that there is no reason that all vertical motors, including hollow-shaft vertical motors, could not be made in a NEMA Premium® configuration. (Baldor, Public Meeting Transcript, No. 14 at p. 85) Regarding vertical motors, NEMA noted that vertical motors should be tested in a horizontal configuration because test facilities may not be physically able to test them in a vertical arrangement. It added that EISA 2007 recognized this fact when it mandated that a vertical solid-shaft motor be tested in a horizontal configuration. (NEMA, No. 13 at p. 5)

Before EISA 2007 expanded the scope of coverage for motors, vertical motors were not covered equipment because they were not "foot-mounted" ("foot-mounting" was a required construction feature of an "electric motor," as previously defined by statute.) 62 FR 59978 (November 5, 1997) When EISA 2007 expanded the scope of coverage for energy conservation standards for electric motors, it included vertical solid-shaft motors in the definition of general purpose electric motor (subtype II). Vertical hollow-shaft motors were still not covered and vertical motors of different thrust configurations (low, medium, or high) were not addressed.

Based on feedback from manufacturers and discussions with industry experts, DOE does not believe that thrust configuration or shaft type (solid or hollow) affects efficiency levels when vertical motors are tested in a horizontal configuration with anti-friction ball bearings installed. DOE believes that, holding all other variables constant except for shaft type, a vertical, hollow-shaft motor has no electromechanical properties which would cause its efficiency to differ from a vertical solid-shaft motor. Additionally, thrust configuration of a motor should not impact efficiency because any heavy loads that may degrade efficiency when a motor is mounted vertically are not present when the motor is configured in a horizontal position. Therefore, DOE is weighing the possibility of applying energy conservation standards to all hollow-shaft, vertical motors and vertical motors of all thrust configurations with anti-friction ball bearings. Vertical motors of any shaft type or thrust configuration that employ thrust bearings are discussed in the section below. DOE requests comment on the decision to include all permutations of vertical motors in the expanded scope of conservation standards..

Finally, DOE believes the same testing restrictions for solid-shaft vertical motors apply to hollow-shaft vertical motors because they have similar constructions (the only difference being the shaft configuration). Similarly, DOE believes the same testing restrictions for solid-shaft vertical motors of any thrust configuration also apply to hollow-shaft motors of any thrust configuration, for the same reason mentioned above. Additionally, DOE believes it may be necessary to attach a solid-shaft protrusion to the hollow-shaft motor to allow the motor to be attached toa dynamometer for testing. DOE requests comment on attaching a shaft protrusion to a hollow-shaft motor for testing purposes. DOE also requests comment on the preliminary decision to test all vertical motors in a horizontal configuration using anti-friction ball bearings.

Motors with Thrust Bearings

Thrust bearings are specialized bearings that are able to withstand operation under heavy axial loads. These bearings are typically used on vertical motors with medium- to high-thrust configurations where a regular, anti-friction ball bearing may deform under the vertical weight.

ASAP and NEMA submitted comment that motors with thrust bearings should be included in the scope of coverage and that they should be tested with an equivalent electrical design with standard bearings. (ASAP and NEMA No. 20 at p. 4) DOE had not previously covered motors with thrust bearings because their special mechanical construction meant they were categorized as special-purpose motors as defined in EPCA. 62 FR 59978 (November 5, 1997) Although DOE understands thrust bearings could potentially degrade efficiency, it agrees with commenters and believes that such motors should be covered. DOE requests additional comments on this potential expansion of scope.

Additionally, EISA 2007 provided that, within the context of subtype II electric motors, vertical motors are to be tested in a horizontal configuration. See 42 U.S.C. § 6311(13)(B)(v) (noting that a subtype II electric motor includes a "vertical solid shaft normal thrust motor (as tested in a horizontal configuration)"). However, DOE understands thrust bearings cannot operate in a horizontal configuration, which means special treatment is necessary for testing these motors in a horizontal configuration. Preliminarily, DOE is evaluating the suggestion made by ASAP and NEMA and considering allowing manufacturers to temporarily swap in grease-lubricated ball bearings for the purposes of testing in a horizontal configuration. Again, this is consistent with the approach that DOE has taken in the past with motors containing roller bearings. DOE requests comment on its understanding of the limitations of thrust bearings with respect to operating in a horizontal configuration for testing, and any additional changes to the test procedure that may be necessary to appropriately test motors with thrust bearings.

Inverter Capable, Inverter-Only Duty Motors

An inverter drive is a device used to control the speed or torque characteristics of a motor. Inverter drives are also referred to as variable speed drives, variable frequency drives, adjustable frequency drives, AC drives, or microdrives, which serve as special electronic controllers to help manipulate the power source of a motor. Inverter drives are used to slow a motor down or provide a constant torque output of the motor. Motors that can operate on an inverter may require special hardware or design to withstand the abnormally harsh operating conditions an inverter drive may create, such as increased operating temperatures or harmonic distortion of the motor's power supply. Inverter drives are considered part of an "Advanced Motor System" by DOE and are discussed in more detail in section 2.3.4.

Manufacturer catalogs refer to motors capable of being run on an inverter as "inverter duty." However, DOE understands there are two distinct types of motors that are referred to as "inverter duty" in manufacturer catalogs. The first type is a motor that has the ability to be run on an inverter drive, but can also run continuously when connected directly to a polyphase, sinusoidal power source (i.e., it can be run continuously without an inverter drive). DOE plans to refer to this type of motor as an "inverter capable" motor because it is capable of withstanding inverter duty operation, but the motor design does not necessitate an inverter drive for continuous operation.

The second type of motor that manufacturer catalogs refer to as "inverter duty" is a motor that cannot operate continuously without an inverter drive. This motor may have heavy insulation or other design changes to deal with operating conditions that may result from inverter operation, such as harmonic distortion of the power signal or dielectric stresses resulting from voltage spikes. This motor, unlike an "inverter capable" motor, is specifically built for inverter-fed operation and is generally more expensive to build than an "inverter capable" motor. This second motor type could not be used for continuous duty operation without an inverter drive. DOE plans to refer to this second type of motor as an "inverter-only duty" motor because it is specifically built to only operate continuously on an inverter.

DOE wishes to clarify these two terms because it understands that there is no industry accepted definition that delineates between motors capable of being run on an inverter and motors that can only be run on an inverter. This planned distinction is illustrated in Table 2.5.

Table 2.5 Inverter Duty and Inverter Capable Motor Definitions

Covered	Not Covered
<u>Inverter-Capable Electric Motor</u> – An electric motor that can run continuously when directly connected to a polyphase, sinusoidal bus, but is also capable of handling operation on an inverter drive.	<u>Inverter-Only Duty Electric Motor</u> – An electric motor designed such that it can only be run continuously when operated on an inverter drive.

NEMA responded to the RFI by suggesting that DOE not cover an inverter duty motor if it is in full compliance with NEMA MG1-2006 Part 31 (titled "Definite-Purpose Inverter-Fed Polyphase Motors"), or if an inverter-duty motor has variable-frequency drive rating information on the nameplate. NEMA also suggested that DOE should use the term "definite purpose inverter-fed motors" for inverter duty motors that are not covered. (NEMA, No. 19 at p. 3) DOE believes this approach opens a possible compliance loophole where a manufacturer may produce and nameplate a continuous-duty motor in full compliance with the applicable provisions under 10 CFR Part 431, but which could also be run continuously without an inverter drive. DOE has presented the terms "inverter-capable" and "inverter-only duty" in an effort to effectively differentiate between the two types of motors and simplify compliance.

DOE discussed inverter-duty motors in previous motor rulemakings. In the 1997 Policy Statement and the 1999 final rule, DOE noted that "NEMA Design A or B motors that are single-speed, meet all other criteria under the definitions in EPCA for covered equipment, and can be used with an inverter in variable speed applications as an additional feature, are covered equipment under EPCA. In other words, being suitable for use on an inverter by itself does not exclude a motor from EPCA requirements". 62 FR 59978 (November 5, 1997) and 64 FR 54114 (October 5, 1999). DOE is continuing with this approach and is considering setting standards for "inverter-capable" motors while not covering "inverter-only duty" motors. DOE is considering the adoption of these terms and the related definitions that would apply to help clarify the scope of coverage and to prevent potential compliance loopholes. DOE requests feedback on this approach, including the presented terms and accompanying definitions.

Finally, at this time, DOE does not believe any specific alterations to its test procedures are necessary for "inverter capable" motors because DOE does not believe these motors have any characteristics that would prevent them from being tested according to 10 CFR 431.16. Nevertheless, DOE requests feedback on this understanding and whether "inverter-capable" motors require any changes to the current DOE test procedure.

Immersible Electric Motors

Immersible motors are electric motors capable of being submerged and removed from a liquid without causing damage to the motor. Immersible motors are different than submersible motors because they are not designed to run while submerged in liquid but rather are designed to withstand temporary immersion in liquid. An immersible motor uses special seals to prevent water from getting in to its enclosure.

In response to the framework document, NEMA and ASAP commented that greater clarification was needed by NEMA for this category of product. (ASAP and NEMA, No. 12 at p. 9). DOE is aware of the lack of a definition for immersible motors and seeks to clarify the distinctions between immersible and submersible motor types.

In a 1997 rulemaking, DOE discussed motors with seals and their effect on efficiency. In that rulemaking, DOE found that when a motor with new seals is tested, the efficiency is significantly understated due to the fact that new seals are stiff relative to "broken in" seals and, consequently, loses caused by friction increase. FR 59978, 59980 (November 5, 1997)

In light of the 1997 rulemaking decision and DOE's evaluation of the possible expansion of scope of conservation standards, DOE is considering subjecting immersible electric motors to minimum efficiency standards. Aside from seals, which could possibly be removed during testing, DOE does not believe there are any other characteristics of immersible motors that inhibit improved efficiency. Additionally, DOE does not believe there are any abnormal difficulties with attaching immersible motors to a dynamometer for testing. DOE requests comment on the decision to include immersible electric motors in the expanded scope of conservation standards. DOE also requests comment on the definition of immersible electric motors. Lastly, DOE requests comment on the testing of immersible motors, especially with regards to removing seals before testing or any other characteristics that may affect efficiency or the ability to test these motor types.

2.3.3 Motor Types not Covered under Expanded Scope of Coverage

Through its RFI, DOE sought information regarding a wide variety of motors employing fundamentally different designs and technologies. ASAP and NEMA responded by urging DOE to exclude from any potential standards all of the motors listed in Table 2.6 with the exception of Totally Enclosed Air-Over (TEAO) motors. (ASAP and NEMA, No. 20 at p. 4) In subsequent communications with DOE, these parties modified their views in favor of not covering TEAO motors from standards.

Table 2.6 Electric Motors Excluded from Expanded Scope of Coverage

Electric Motor Description	
Totally-Enclosed Air Over (TEAO)	Direct current
Component sets	Single phase
Intermittent duty	Liquid cooled
Inverter-only duty	Submersible
Multispeed	-

Additionally, the CDA commented that some of the electric motors in Table 2.6, such as inverter-only duty motors and TEAO motors, should be included and new test procedures provided because of their increasing shipment volumes. (CDA, No. 18 at p. 2) However, the CDA did not provide any additional information on what such test procedures might entail.

At this time, DOE is not including any of these types of electric motors in its expanded scope of coverage. DOE understands that some of the motors listed in Table 2.6 would require extensive modifications to the currently accepted test procedures. TEAO, liquid cooled, and submersible motors are all continuous-duty motors, but are required to operate in special environments, such as underwater or in an area with a minimum amount of airflow, to prevent the motors from overheating during continuous duty operation. IEEE 112B and CSA C390 are designed to test motors with self-contained cooling devices, such as a totally enclosed fan-cooled motors, and do not present procedures for the testing of motors in specialized environments.

Other motors, such as intermittent duty and inverter-only duty motors, are not capable of continuous-duty operation and, therefore, never reach a steady-state temperature which IEEE 112B requires for certain calculations. Direct current and single-phase motors do not run on AC, polyphase sinusoidal power, which is also required for IEEE 112B. Additional information on each of these motor types can be found in chapter 3 of the preliminary TSD.

2.3.4 Advanced Electric Motor Systems

The motor systems listed in Table 2.7 are systems that DOE tentatively views as “advanced electric motor systems.” DOE believes that these systems are advanced motor systems because there are significant differences between these motors or controllers and general purpose motors that run directly on a polyphase, AC sinusoidal bus discussed in section 2.3.2. DOE believes that if it were to include these types of motors as part of its standards analysis, extensive test procedure changes would be required because they have drastically different electromechanical properties relative to squirrel-cage induction motors and they do not run directly off of polyphase, AC sinusoidal power sources, which is required for testing with IEEE

112B. Generally, DOE understands that there are no current test procedures for these “advanced electric motor systems,” but seeks comment on the potential for significant energy savings with these motor systems. DOE’s preliminary findings on these motors are discussed below.

Table 2.7 Advanced Electric Motor Systems

Motor Description
Inverter Drives
Permanent magnet motors
Electrically commutated motor
Switched reluctance motors

Inverter Drives

The current scope of coverage includes motors with a single, constant rotational speed. A motor’s rotational speed is determined by the frequency of the power source, as well as the pole configuration of the motor. The equation determining a motor’s speed is:

$$Speed\ of\ motor = \frac{120 * (Frequency\ of\ power\ source)}{Number\ of\ Motor\ Poles}$$

Inverter drives, also called variable-frequency drives (VFDs), variable-speed drives, adjustable frequency drives, AC drives, microdrives, or vector drives, work by changing the frequency of the power source fed into an electric motor. The equation above shows that controlling the frequency of the power source of a motor allows the user to control the speed of that motor. One of the biggest advantages of a VFD is the ability to reduce the speed of a motor when the full, nameplate-rated speed is not needed. This practice can save energy over a motor’s lifetime. VFDs can also control start-up characteristics of motors, such as locked-rotor current or locked-rotor torque, which allows motors to achieve higher efficiencies when running at rated speed.[i]

DOE is aware of the energy saving potential of motors that run on VFDs[j][k]. However, DOE does not know of any relevant test procedures for testing motors run on a VFD. IEEE 112B requires a motor to be tested at its nameplate-rated speed, but motors only capable of running on an inverter will not have a nameplate rated speed. DOE requests information on whether a test procedure, which accounts for the entire motor system, including the VFD, is being developed.

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[i] Li, Harry. *Impact of VFD, Starting Method and Driven Load on Motor Efficiency*. 2011.Siemens Industry, Inc.

[j] S. Dereyne, K. Stockman, S. Derammelaere, P. Defreyne. *Variable Speed Drive Evaluation Using Iso Efficiency Maps*. 2011. Technical University College of West-Flanders. Department of Electrical Energy, Systems and Automation, Ghent University.

[k] Rajagopalan, Satish, Vairamohan, Baskar Vairamohan, and Samotyj, Marek. *Electric Motors for the Modern World - A Look at New Motor Technologies and New Applications*. 2011. Electric Power Research Institute (EPRI)

Permanent Magnet Motors

In both polyphase AC induction motors and permanent magnet motors, the stator is energized by three-phase alternating current, which induces a magnetic field that rotates around the stator. This rotating magnetic flux induces a voltage in the squirrel-cage rotor, which in turn creates a current in the squirrel-cage rotor. These currents then create an opposing magnetic field in the rotor that causes it to rotate at a slower speed than the stator field.[l] In permanent magnet motors, the rotor uses an embedded permanent magnet to create a constant magnetic field that causes the rotor to rotate as the stator magnetic field rotates. Since the rotor is rotating at the same speed as the rotating stator field, the motor can be referred to as a synchronous motor. Permanent magnet motors have several advantages over AC induction motors including a higher efficiency potential, higher power/torque density, lower operating temperature, smaller size and quieter operation.[m] In AC induction motors, some of the stator current is used to induce rotor current in order to produce magnetic flux in the rotor. These additional currents generate heat in the motor, leading to increased losses. Permanent magnet motors, on the other hand, do not require a current in the rotor to produce magnetic flux since the flux is already provided by the permanent magnets. With no current in the rotor there are no rotor losses, which contributes to the high efficiency of permanent magnet motors.

Permanent magnet motors can be classified into two major groups: those with permanent magnets mounted on the surface of the rotor and those with permanent magnets placed in the interior of the rotor core. Surface permanent magnet (SPM) motors employ arc-shaped magnets glued or secured to the outer surface of the rotor core. This arrangement is not as structurally robust as the arrangement used in interior permanent magnet (IPM) motors, which instead have their permanent magnets placed inside of slots made in the interior of the laminated rotor core, thereby increasing retention of the magnet during high-speed operation compared to SPM designs. Different magnet grades are used in permanent magnet motors, with ceramic-ferrites and rare-earth metals being the most common choices. Although rare-earth magnets are more expensive than ceramic-ferrites, they have a higher magnetic energy density which permits increased energy output from a motor. However, the market for rare-earth metals is highly concentrated, with the vast majority of supply coming from China.[n] Wide-spread adoption of permanent magnet motors could be hindered by the inability of suppliers to respond to increased global demand as well supply disruptions caused by Chinese export policy.

Synchronous motors are typically not capable of starting from a fixed frequency AC power source. If the rotor is stationary when the stator field starts rotating at full speed, the rotor will not develop enough starting torque to overcome its own inertia. One popular method for overcoming this constraint is to use a VFD to start the motor. By increasing the frequency of the

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[l] When a motor operates with the rotor rotating at a speed slower than the rotating stator field, it is considered to be "asynchronous."

[m] Rajagopalan, S., B. Vairamohan, and M. Samotyj. *Electric Motors for the Modern World - A Look at New Motor Technologies and Applications.* 2011. Electric Power Research Institute: Palo Alto, CA.

[n] U.S. Department of Energy. *Critical Materials Strategy*. December 2011. Washington, DC.

AC signal from zero to the desired running speed, the rotor is able to operate at synchronous speed with the accelerating stator field. This method of starting has the added benefit of the energy savings associated with adjustable speed control as discussed in section 2.3.2. Alternatively, some designs of interior permanent magnet motors incorporate a squirrel cage in the rotor, allowing the rotor to start across-the-line like an AC induction motor. These types of self-starting motors are called line start permanent magnet (LSPM) motors. During the motor transient start up, the squirrel cage in the rotor contributes to the production of enough torque to start the rotation of the rotor, albeit at an asynchronous speed. When the speed of the rotor approaches synchronous speed, the constant magnetic field of the permanent magnet locks to the rotating stator field, thereby pulling the rotor into synchronous operation. LSPM motors would be suitable in applications where the higher efficiency of permanent magnet motors is desired, but for which the added cost of a VFD remains prohibitive.

DOE is aware of the energy saving potential of permanent magnet motors. DOE does not know of any relevant test procedures for testing these motors. IEEE 112B is specific to polyphase induction motors and does not specify how to segregate losses for permanent magnet motors. The DOE requests comment on the potential energy savings from permanent magnet motors, as well as any relevant test procedures that are used to measure the efficiency of these motors. DOE also seeks information regarding whether already existing test procedures could be modified to test the efficiency of these motors, including specific recommendations as to how to modify those procedures.

Electronically Commutated Motors

Electronically commutated motors (ECMs), also called brushless DC motors, are permanent-magnet synchronous motors combined with an on-board electronic controller that can measure and regulate the motor’s performance. The commutator in older, brushless motors previously consisted of a rotary mechanical component that manipulated the power being fed to the stator. In ECMs, an electronic microprocessor controls the rotary mechanical component − and, consequently, the power supply. The use of the microprocessor permits greater customized control over motor performance. Some ECMs run on a DC power supply, while others run on a single phase or polyphase AC power supply which is rectified (i.e., converted) to DC power in the motor’s controllers. The microprocessor in the motor control converts this DC power into a trapezoidal three-phase AC signal (unlike the sinusoidal AC signal used to power the permanent magnet motors discussed in the previous paragraph), inducing a rotating magnetic field in the stator windings. The rotor uses an embedded permanent magnet to create a constant magnetic field that causes the rotor to rotate as the stator magnetic field rotates. The position of the rotor is monitored by a microprocessor, which adjusts the magnetic fields in the stator to achieve the desired operating speed and torque. The motor can also communicate its status to the equipment it is powering, offering instant feedback of the unit’s performance.

Like other types of permanent magnet synchronous motors, ECMs have several advantages over AC induction motors due to their higher efficiency, higher power/torque density, lower operating temperature, smaller size and quieter operation. ECMs also offer adjustable speed control with their programmable electronics, which can save energy in a manner similar to VFDs, which are discussed earlier in this section. However, the inclusion of programmable electronic controls also increases the cost of manufacturing an ECM.

However, DOE does not know of any relevant test procedures for testing electronically commutated motors. IEEE 112B requires that a motor be tested at its nameplate rated speed. However, motors capable of only being run on an electronic commutator will not have a nameplate rated speed because they are variable speed motors and can be run at a range of speeds as specified by the user. Additionally, the electronic commutator has its own electrical losses which are not accounted for in IEEE 112B. These electrical losses are the result of manipulating the power source into the motor. DOE requests comment on the potential energy savings from electronic commutated motors, as well as any relevant test procedures. DOE also seeks information regarding whether already existing test procedures could be modified to test the efficiency of these motors, including specific recommendations as to how to modify those procedures.

Switched Reluctance Motors

Switched reluctance (SR) motors are synchronous motors that operate on the principle of magnetic reluctance. Magnetic reluctance is a measure of the permeability of a given material with respect to magnetic flux. Compared to high reluctance materials, low reluctance materials offer lower resistance to the passage of magnetic lines of force. In a magnetic circuit, the presence of a magnetic field causes magnetic flux to follow the path of least magnetic reluctance. When low reluctance materials (such as iron) are in the presence of a magnetic field, flux will tend to concentrate in the low reluctance material, forming strong temporary poles that cause an attractive force toward regions of higher flux. Just as in a DC motor, the stator in a SR motor consists of wound field coils. Unlike induction and permanent-magnet motors, the rotor does not contain any windings or magnets. The rotor in a SR motor consists of a low reluctance material, such as laminated silicon steel, with multiple projections that act as magnetic poles through magnetic reluctance. An electronic controller is used to energize each phase in sequence. As each phase is energized, the poles of the rotor are drawn to the position of least magnetic reluctance, which occurs when the poles of the stator and rotor are aligned. A full rotation of the rotor can be achieved by sequentially energizing each phase.

SR motors have several advantages over AC induction motors, such as higher efficiency and simpler construction. Unlike permanent-magnet motors, they do not rely on rare-earth magnets in their construction. However, they also have several disadvantages including high torque ripple (the difference between the maximum and minimum torque during one revolution) and noise (associated with torque ripple). Additionally, SR motors cannot be run on commercially available drives that can both operate induction and permanent-magnet motors, a fact that could discourage users who have already invested in VFDs from adopting SR motors.

DOE does not know of any relevant test procedures for testing switched reluctance motors. DOE requests comment on the potential energy savings from switched reluctance motors, as well as any relevant test procedures or the potential to modify the current existing test procedures.

2.3.5 Equipment Class Groups and Equipment Classes

Within each set of electric motors it addressed, EISA 2007 prescribed separate energy conservation standards by horsepower, enclosure, and pole configuration. The standards correspond to Table 12-12 of NEMA MG 1-2006 (which is equivalent to NEMA Premium efficiency levels) for subtype I electric motors; and Table 12-11 of NEMA MG1-2006 (which is equivalent to EPACT 1992 efficiency levels for motors from 1 to 200 horsepower and 2 to 6 poles) for subtype II, fire pump electric motors, and NEMA Design B electric motors greater than 200 horsepower. [o] (42 U.S.C. 6313(b)(2))

When DOE amends energy conservation standards, it often divides covered equipment into classes. By statute, these classes are based on: (a) the type of energy used; (b) the capacity of the equipment; or (c) any other performance-related feature that justifies different standard levels, such as features affecting consumer utility. (42 U.S.C. 6295(q)) As a result of changes introduced by EISA 2007, particularly with the addition of general purpose electric motors (subtype II) as a subset of motors covered by the term “electric motor,” there are a large number of motor design features that DOE must consider in this rulemaking. In the following sections, DOE discusses a variety of design features that DOE is considering for inclusion as part of its analysis.

Due to the large number of characteristics involved in electric motor design (e.g., horsepower rating, pole-configuration, etc.), DOE currently plans to use two constructs to help develop appropriate energy conservation standards for electric motors: “equipment class groups” and “equipment classes.” An equipment class group is a collection of electric motors that share a common design type. Equipment class groups include motors over a range of horsepower ratings, enclosure types, and pole-configurations. Essentially, each equipment class group is a collection of a large number of equipment classes with the same design type. An equipment class represents a unique combination of motor characteristics for which DOE will determine an energy efficiency conservation standard. For example, given a combination of motor design type, horsepower rating, pole-configuration, and enclosure type, the motor design type dictates the equipment class group, while the combination of the remaining characteristics dictates the specific equipment class.

The framework document divided those electric motors that are currently covered by standards (but which did not include all of the motors discussed in section 2.3.2) into ten equipment class groups based on combinations of motor design (NEMA Design A or B, NEMA

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[o] In NEMA MG1-2011, the latest version of MG1, two tables were added as extensions to tables 12-11 and 12-12. Table 20A was added as an extension to Table 12-11, which includes efficiency ratings for 6- and 8-pole motors from 300 to 500 horsepower. Similarly, Table 20B was added as an extension to Table 12-12, which also includes efficiency ratings for 6- and 8-pole motors from 300 to 500 horsepower. Additionally, Table 12-12 itself was expanded to include efficiency ratings for 8-pole motors below 200 horsepower. Finally, the actual efficiency values found in these tables have not changed over time for a given rating. For example, the 12-12 (or 12-11) efficiency value for an open, 4-pole, 5 horsepower electric motor is the same in MG1-2006, MG1-2009, and MG1-2011.

Design C, vertical solid shaft normal thrust, or fire pump electric motor), frame type (U- or T-frame), and enclosure (open or enclosed). Based on additional analysis and a review of comments, DOE has reduced this number down to three groups based on two main characteristics: the designated NEMA design letter and whether the motor meets the definition of a fire pump electric motor. DOE's resulting equipment class groups are for NEMA Design A and B motors, NEMA Design C motors, and fire pump electric motors. Within each of these three broad groups, DOE uses combinations of other pertinent motor characteristics to enumerate its individual equipment classes. To illustrate the differences between the two terms, consider the following example. A NEMA Design B, 50 horsepower (hp), 2-pole enclosed electric motor and a NEMA Design B, 100 hp, 6-pole open electric motor would be in the same equipment class group (for the preliminary analysis, group 1), but each would represent a unique equipment class that will ultimately have its own efficiency standard. There are 510 potential equipment classes consisting of all permutations of NEMA design type, standard horsepower ratings, pole configurations, and enclosure types. Table 2.8 outlines the relationships between equipment class groups and the characteristics used to define equipment classes. The following sections discuss a variety of these design features in greater detail.

Table 2.8 Electric Motor Equipment Class Groups

Equipment Class Group	Electric Motor Design	Horsepower	Poles	Enclosure
1	NEMA Design A & B*	1-500	2, 4, 6, 8	Open
				Enclosed
2	NEMA Design C*	1-200	2, 4, 6, 8	Open
				Enclosed
3	Fire Pump*	1-500	2, 4, 6, 8	Open
				Enclosed

*Including IEC equivalents.

In response to the framework document, NEMA suggested that the number of classes be kept to a minimum when establishing efficiency standards in a manner similar to what Congress did when it separated electric motors into general purpose electric motor (subtype I) and (subtype II). (NEMA, No. 13 at p. 7) NEMA also suggested that when looking at any increase in efficiency levels, coverage should be based on a common set of technology options for the electric motors covered. (NEMA, No. 13 at p. 3) Table 2.8 presents a simplified version of the ten equipment class groups presented during the framework stage of the analysis. The technical basis for the simplified groups is described in the following paragraphs. DOE requests comment on these simplified groups.

NEMA also asserted that it did not appear that DOE intends to establish separate equipment class groups for general purpose subtype I and subtype II electric motors. (NEMA, No. 13 at p. 3) NEMA is correct. DOE based its groups in Table 2.8 on the NEMA design types (NEMA Design A, B, or C) rather than the characteristics designating a motor as subtype I or II. Because DOE is considering expanding the scope of coverage to include motors beyond just general purpose electric motors, it decided not to base equipment class groupings on subtype I and subtype II definitions. This approach would allow DOE to simplify its expansion of scope of coverage to include all NEMA Design A, B, or C continuous, polyphase, squirrel cage induction motors. Additionally, DOE understands that certain criteria that were used to delineate subtype I and subtype II motors do not have any effect on motor efficiency, such as a motor being footless.

2.3.5.1 Electric Motor Design

The NEMA Standards Publication MG1-2011, "Motors and Generators," defines a series of standard electric motor designs that are differentiated by variations in performance requirements (See NEMA MG1-2011, paragraph 1.19.1). NEMA MG1 defines Designs A, B, and C electric motors, which constitute all NEMA defined electric motors covered by this preliminary analysis. These designs are categorized based on performance requirements for full-voltage starting and developing locked-rotor torque, breakdown torque, and locked-rotor current, all of which affect an electric motor's utility and efficiency.

NEMA Design A and NEMA Design B electric motors have different locked-rotor current requirements. Whereas NEMA Design A electric motors have no locked-rotor current limits, NEMA Design B electric motors are required to stay below maximum levels specified in NEMA MG1-2011 paragraph 12.35.1. This tolerance for excess current will allow NEMA Design A motors to reach the same efficiency levels as NEMA Design B with fewer design changes and constraints. Therefore, DOE has preliminarily concluded that the potential efficiency differences between NEMA Design A and B electric motors are not significant enough to warrant a separate equipment class group for these two NEMA Design types.

DOE also notes that Congress held NEMA Design A and NEMA Design B motors to the same energy conservation standards in both EPACT 1992 (Pub. L. No. 102–486) and EISA 2007 (Pub. L. No. 110–140).[p] However, DOE believes that the different torque requirements for NEMA Design C electric motors represent a change in utility that can affect efficiency performance. The difference in torque requirements will restrict which applications can use which NEMA Design types. As a result, NEMA Design C motors cannot always be replaceable with NEMA Design A or B motors, or vice versa. For the framework document, DOE had taken an approach similar to the approach in EPACT 1992 and EISA 2007. DOE considered NEMA Design A and B motors in a group together, while placing NEMA Design C motors in their own equipment class group.

Comments from Baldor and NEMA suggested that by grouping NEMA Design A and B electric motors together, DOE should be aware that increasing locked-rotor current requires other design changes, such as the inclusion of protective devices into a given motor design, so potential efficiency increases should be based on the more restricted motors − i.e. NEMA Design B electric motors. (Baldor, Public Meeting Transcript, No. 14 at p. 77; NEMA, No. 13 at p. 4)

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[p] EPACT 1992 defined "electric motor" to include both NEMA Design A and Design B motors and established standards for such motors. Similarly, EISA 2007 included NEMA Design A and Design B motors in the definition of "general purpose electric motor (subtype I)" and established standards for such motors.

Per NEMA MG1, Design B electric motors are designed with more stringent design constraints than NEMA Design A electric motors. As mentioned, NEMA Design B motors have limits on locked-rotor current whereas NEMA Design A motors do not. This design requirement constrains the potential energy efficiency improvements that can be made for NEMA Design B motors relative to NEMA Design A motors. Because of these design constraints, and as discussed further in the engineering analysis section of this preliminary TSD, DOE conducted its analysis using NEMA Design B electric motors as the representative unit for equipment class group 1. By doing so, DOE ensured that all electric motors within equipment class group 1 (i.e., NEMA Design A and B motors) would be capable of reaching all of the efficiency levels analyzed.

The CDA supported this approach and cited the low shipment volumes of NEMA Design A electric motors as another reason for analyzing NEMA Design A and B motors together. (CDA, No. 18 at p. 2) DOE agrees and, as is demonstrated in its shipments analysis (preliminary TSD chapter 9), NEMA Design B electric motors constitute an overwhelming majority of electric motor shipments. Because of this fact, DOE projects that minimal energy savings would be likely to result from separating NEMA Design A motors into another equipment class group.

Finally, NEMA asserted that there are no performance standards – minimum locked-rotor torque, breakdown torque, or pull-up torque – that define a NEMA Design C electric motor either in a 2-pole configuration or greater than 200 hp in NEMA MG1-2009. (NEMA No. 13 at p. 4) In other words, in its view, because NEMA itself has not prescribed the particular operating performance characteristics and standards for Design C motors in either a 2-pole configuration or with a rating greater than 200 horsepower, there can be no motor with either of these configurations that can be considered a NEMA Design C motor.

In spite of NEMA's claim, DOE has found numerous instances where manufacturers offer for sale electric motors with a horsepower rating greater than 200 advertised as NEMA Design C electric motors. For this stage of the analysis, DOE has not examined efficiency levels for NEMA Design C electric motors over 200 hp or in a 2-pole configuration. However, DOE requests public comment on whether electric motors that are labeled as NEMA Design C electric motors, but that are outside the defined performance standards for NEMA Design C electric motors in NEMA MG1-2009 (now NEMA MG1-2011), can be considered Design C motors. The metric for including these NEMA Design C motors may be comparing performance characteristics to other industry standards, using a relative deviation from the corresponding performance requirements for high horsepower NEMA Design A or B motors, or some other metric.

2.3.5.2 Horsepower Rating

Horsepower is a critical performance attribute of an electric motor that is directly related to the capacity of an electric motor to perform useful work. Additionally, efficiency generally scales with horsepower. In other words, with all else equal, a 50 hp electric motor is usually more efficient than a 10 hp electric motor. Because there is a direct correlation between horsepower and efficiency, DOE preliminarily used horsepower rating as a criterion for distinguishing equipment classes in the framework document and continues with that approach for the preliminary analysis.

DOE received public comments advocating that NEMA Design A and B electric motors from 1 horsepower through 500 horsepower meet the same efficiency level rather than continuing to use the 200 horsepower mark set forth in EISA 2007. (ACEEE, Public Meeting Transcript, No. 14 at p. 18; Baldor, No. 8 at p. 2) DOE agrees with this approach and has preliminarily adopted a simplified approach that does not separate the NEMA Design A and B motors at any particular horsepower rating.

2.3.5.3 Pole Configuration

The number of poles in an induction motor determines the synchronous speed (i.e., revolutions per minute) of that motor. There is an inverse relationship between the number of poles and a motor's speed. As the number of poles increases from two to four to six to eight, the synchronous speed drops from 3,600 to 1,800 to 1,200 to 900 revolutions per minute, respectively. In addition, manufacturer feedback and independent analysis indicated that the number of poles has a direct impact on the electric motor's performance and achievable efficiency because some pole configurations utilize the space inside of an electric motor enclosure more efficiently than other pole configurations. DOE used the number of poles as a means of differentiating equipment classes in the framework document and has maintained this approach in the preliminary analysis.

Baldor commented that there are currently no standardized NEMA efficiency values for 8-pole motors in NEMA MG1-2009 Table 12-12, which equates to the NEMA Premium efficiency level. (Baldor, Public Meeting Transcript, No. 14 at p. 140) Baldor added that NEMA is developing efficiency levels for these motors and hopes to have them completed before DOE's final rule is published (Baldor, Public Meeting Transcript, No. 14 at p. 140). At this time, NEMA MG1-2011 has been updated to include efficiency ratings for 8-pole motors in Table 12-12. DOE has used these updated efficiency values for its analysis.

2.3.5.4 Enclosure Type

EISA 2007 prescribes separate energy conservation standards for open and enclosed electric motors. (42 U.S.C. 6313(b)(1)) Electric motors manufactured with open construction allow a free interchange of air between the electric motor's interior and exterior. Electric motors with enclosed construction have no direct air interchange between the motor's interior and exterior (but are not necessarily air-tight) and may be equipped with an internal fan for cooling (see NEMA MG1-2011, paragraph 1.26). Whether an electric motor is open or enclosed affects its utility in that open motors are generally not used in harsh operating environments, whereas totally enclosed electric motors often are. The enclosure type also affects an electric motor's ability to dissipate heat (the open motors' free air exchange allows for better thermal dissipation), which enables open motors to achieve higher efficiency levels than their enclosed counterparts. DOE used an electric motor's enclosure type (open or enclosed) as an equipment class setting criterion in the framework document and, having received no comments regarding this approach, it continued to use this criterion in the preliminary analysis.

As discussed previously, DOE plans to include TENV motors in its expanded scope of coverage. DOE understands that TENV motors may have characteristics that may affect efficiency, namely the higher operating temperature of the motor. However, at this time, DOE does not believe that these higher operating temperatures will prevent the motors from being able to meet the same efficiency standards as typical enclosed motors and, thus, warrant a separate equipment class group. This preliminary decision is based on a review of catalog data and the range of efficiencies offered for TENV motors, as well as manufacturer feedback advocating the inclusion of TENV motors in the expanded scope of coverage. DOE requests comments regarding this preliminary decision to not establish a separate equipment class group for TENV motors.

2.3.5.5 Frame Type

EISA 2007 prescribed energy conservation standards for electric motors built with a U-frame, whereas previously only electric motors built with a T-frame were covered.[q] (Compare 42 U.S.C. § 6311(13)(A)(1992) with 42 U.S.C. §6311(13)(B)(2011) In general, for the same combination of horsepower rating and pole configuration, an electric motor built in a U-frame is built with a larger "D" dimension than an electric motor built in a T-frame. The "D" dimension is a measurement of the distance from the centerline of the shaft to the bottom of the mounting feet. In the framework document, DOE separated T-frame and U-frame electric motors into separate equipment class groups because U-frame motors have a larger frame size than T-frame motors of the same rating. DOE believed that this frame size increase for U-frame electric motors could lead to higher efficiencies relative to T-frame motors.

Baldor commented that it manufactures only a low volume of U-frame electric motors. Baldor and NEMA noted that most U-frame electric motor customers, who are in the automotive industry, purchase these motors to replace current U-frame motors in existing applications − not for new installations. (Baldor, No. 8 at p. 4; NEMA, No. 19 at p. 6) Baldor added that these automotive companies previously specified that all U-frame electric motors used in their plants meet certain efficiency levels that were lower than those set in EISA 2007. However, as EISA 2007 expanded coverage to include these motors, that trend is changing and Baldor noted that U-frame motors, because of their larger frame size, could be designed to meet the same efficiency levels as T-frame motors. Baldor also stated that, despite the possibility of being redesigned and made more efficient, U-frame electric motors were viewed as outdated and being phased out. (Baldor, Public Meeting Transcript, No. 14 at pp. 126-127, 132-133) Finally, NEMA concluded that efficiency differences between U-frame and T-frame electric motors are negligible. (NEMA, No. 19 at p. 6)

While DOE recognizes that automotive manufacturers may set their own specifications for the U-frame motors used in their plants, DOE's standards set the minimum efficiency levels that a given covered motor would be required to meet. As a result, any standards that DOE may set for U-frame motors are likely to have a substantially broader and more significant impact

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[q] The terms "U-frame" and "T-frame" refer to lines of frame size dimensions, with a T-frame motor having a smaller frame size for the same horsepower rating as a comparable U-frame motor. In general, "T" frame became the preferred motor design around 1964 because it provided more horsepower output in a smaller package.

than the internal requirements of a particular industry. DOE also notes that those requirements may vary by manufacturer or plant, a factor that could reduce the impact of any projected benefits of these manufacturer requirements. Regarding the phasing out of U-frame motors, DOE largely agrees with this assessment based on the limited amount of information it has reviewed. That fact notwithstanding, DOE believes that, due to their larger frame size, a U-frame electric motor should be able to achieve any efficiency that identically or similarly-rated T-frame electric motor can. (Larger sized motors are capable of being more efficient because they can use more electrical steel which, in turn, can help lower core losses).

DOE also received feedback during manufacturer interviews indicating that increased efficiency levels for U-frame electric motors may cause them to exit the market rather than invest the money to design a more efficient U-frame electric motor. Manufacturers cite a lack of profit in this sector as a reason for exiting it rather than spending more money on research and development to increase U-frame motor efficiency. DOE is aware of such limiting factors.

Based on comments received during the framework meeting and manufacturer interviews, DOE is combining U-frame and T-frame electric motors in the same equipment class for the following reasons:

1) U-frame electric motors have a very small and shrinking market share of less than 3 percent, as they are being phased-out of production. Because of this trend toward T-frame electric motors, NEMA has removed any discussion of U-frame electric motors in MG1 in favor of T-frame electric motors.

2) A U-frame design electric motor does not have unique utility when compared to its smaller equivalent in a T-frame design. In general, a T-frame design could replace an equivalent U-frame design with minor modification of the mounting configuration for the driven equipment. By comparison, a U-frame design that is equivalent to a T-frame design would require substantial modification to the mounting configuration for the same piece of driven equipment.

3) Available market data indicate that for the range of horsepower ratings that are covered by the scope of motors examined in preparation of this preliminary analysis, T-frame electric motors are already being manufactured with higher efficiencies than their U-frame counterparts.

2.3.5.6 Vertical Electric Motors

EISA 2007 also prescribed energy conservation standards for vertical solid shaft normal thrust electric motors as tested in a horizontal configuration. (42 U.S.C. § 6311(13)(B)(v)) Additionally, DOE is contemplating expanding its scope to include vertical motors of all configurations and shaft types (solid or hollow). These electric motors are most often found as NEMA Design A and NEMA Design B electric motors in a wide range of horsepower ratings and in all four pole configurations currently covered by subpart B of 10 CFR Part 431. One of the major differences between these vertical-mounting electric motors and typical horizontal-mounting general purpose electric motors is the P-base mounting.[r] Additionally, as its name suggests, these electric motors operate while mounted vertically, but are tested while mounted horizontally (as mandated by EISA 2007). In the framework document, DOE considered using this design characteristic to disaggregate equipment class groups.

In response to the framework document, NEMA asserted that any efficiency standard for vertical solid shaft normal thrust electric motors should be based on the efficiency level measured when the motor is tested in the horizontal position. (NEMA, No. 13 at p. 5) According to NEMA, test facilities may not be capable of testing in a vertical position, and testing in a horizontal configuration negates the vertical thrust loads on the bearings, which may affect efficiency levels. (NEMA, No. 13 at p. 5) Baldor commented that not only should vertical electric motors be included in the scope, but added that the efficiency level that can be obtained by vertical solid shaft normal thrust electric motors when tested in a horizontal configuration is the same as that for a normal (horizontal) mounted electric motor. (Baldor, Public Meeting Transcript, No. 14 at pp. 85, 127; Baldor, No. 8 at p. 4) Baldor stated that vertical electric motors use the same stator and rotor parts as horizontal configuration motors, but they have a different bearing support system that enables the motor to run in a vertical position. Therefore, Baldor believes there is no reason that these motors cannot achieve the same efficiencies as their horizontal counterparts (Baldor, No. 8 at p. 4)

As mandated by EISA 2007, all vertical solid shaft normal thrust motors are to be tested in a horizontal configuration (42 U.S.C. § 6311(13)(B)(v)). Although DOE believes a change in utility affecting performance, including efficiency, occurs when these electric motors are operated while mounted vertically, the horizontal testing requirement will allow these electric motors to be required to meet the same efficiency standards as normal, horizontal, electric motors tested in a horizontal position. DOE does not believe that there is any electromechanical difference between vertical-mounting and horizontal-mounting electric motors − instead, the difference is based solely on how these motors are operated in the field. Therefore, because EISA 2007 requires that these motors be tested horizontally and these electric motors are electromechanically equivalent to typical, horizontal electric motors, DOE has tentatively decided to eliminate the vertical position as an equipment class setting criterion in the preliminary analysis.

As previously mentioned, DOE is planning to expand the scope of coverage to include all vertical-mounting electric motors, including hollow shaft, solid shaft, and other vertical motors of any thrust configuration. However, DOE still plans to eliminate the vertical configuration as a class setting criterion in the preliminary analysis. DOE does not believe there are any electromechanical differences between hollow shaft and vertical shaft motors or vertical motors with different thrust configurations when horizontally mounted using antifriction bearings for

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[r] A P-base mounting configuration is the typical mounting configuration for vertically mounted motors. The P-base mounting configuration generally takes the place of the horizontal foot-mounting configuration for vertical motors.

testing. Therefore, DOE maintains that these characteristics are not necessary as equipment class setting criteria in the preliminary analysis. DOE requests feedback on the decision not to use the vertical motor configuration (whether hollow shaft, vertical solid shaft, or thrust configuration variations) as equipment class setting criteria.

2.3.5.7 Thrust or Sleeve Bearings

DOE's planned expansion of coverage includes motors with thrust or sleeve bearings. DOE understands that thrust bearings are primarily used on vertical motors, but may also be used on horizontal motors in the form of angular bearings. DOE does acknowledge that thrust bearings may degrade efficiency. However, by statute, vertical motors are to be tested in a horizontal configuration. Thrust bearings cannot properly operate in a horizontal position, and for this reason, motors that are tested in a horizontal configuration will likely have its thrust bearings replaced with regular, anti-friction ball bearings for testing purposes. The absence of thrust bearings during testing drives DOE's decision not to use thrust bearings as a class setting criterion in the preliminary analysis.

DOE also plans on expanding the scope to cover motors with sleeve bearings. Sleeve bearings are typically used on fractional horsepower motors or motors over 400 horsepower. Sleeve bearings are used as an alternative to ball bearings due to their longer life and suitability for direct-connect applications. DOE consulted with testing laboratories, subject matter experts, technical papers, and manufacturers and determined that sleeve bearings do not significantly affect efficiency and therefore DOE has not established a separate equipment class group for these motors.[s]

DOE requests feedback on the decision not to use thrust bearings or sleeve bearings as equipment class setting criteria.

2.3.5.8 Close-Coupled Pump Electric Motor

EISA 2007 prescribed energy conservation standards for close-coupled pump electric motors. (42 U.S.C. § 6311(13)(B)) These electric motors can be purchased as NEMA Design A, Design B, or Design C electric motors, and are usually in two- or four-pole configurations. Close-coupled pump electric motors are frequently built with different shafts than a typical general purpose electric motor. Although these shafts may represent a separate utility, such as allowing the motor to be coupled to a pump, DOE does not believe that this change significantly affects the efficiency of the electric motors because shaft geometry does not affect the electromechanical functions of an electric motor. Therefore, DOE preliminarily decided not to use this motor characteristic as an equipment class setting criterion in the framework document.

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[s] William R. Finley and Mark. M Hodowanec. Sleeve Vs. Anti-Friction Bearings: Selection of the Optimal Bearing for Induction Motors. 2001. IEEE. USA.

Interested parties indicated that close-coupled pump electric motors generally have long running times and are similar to other general purpose electric motors (subtype II). Because of these factors, these commenters asserted that close-coupled pump motors should be required to meet the NEMA Premium efficiency levels that subtype II motors must currently meet. (Baldor, Public Meeting Transcript, No. 14 at p. 83; NEMA, No. 13 at p. 4) DOE is unaware of any specific design constraints that would prevent close-coupled pump electric motors from reaching NEMA Premium efficiency levels. Therefore, DOE is not using this characteristic as an equipment class setting criterion for the preliminary analysis and DOE has not performed a separate engineering analysis on close-coupled pump electric motors.

DOE requests feedback on the decision not to use this characteristic as equipment class setting criteria.

2.3.5.9 Fire Pump Electric Motors

EISA 2007 prescribed energy conservation standards for fire pump electric motors. (42 U.S.C. § 6313(b)(2)(B)) As stated previously, DOE adopted a definition of "fire pump electric motor," which incorporated portions of National Fire Protection Association Standard (NFPA) 20, "Standard for the Installation of Stationary Pumps for Fire Protection" (2010). Pursuant to NFPA 20, these electric motors must comply with NEMA Design B performance standards. In addition to meeting the performance requirements for NEMA Design B electric motors, fire pump electric motors must continue running even if the electric motor is overheating or may be damaged due to continued operation. These additional requirements for fire pump electric motors constitute a change in utility that DOE believes could also affect their performance and efficiency. Therefore, DOE contemplated examining fire pump electric motors in their own equipment class group in the framework document.

Interested parties indicated that fire pump electric motors run for very few hours each year and do not present a significant opportunity to reduce energy consumption. (Baldor, No. 8 at p. 4) Regardless, interested parties expressed concern that they may be exploited as a means to circumvent efficiency standards. (ASAP and NEMA, No. 12 at p. 4) While DOE seeks to simplify equipment class groups, it recognizes that fire pump electric motors are defined, in part, by the NFPA 20, Standard for the Installation of Stationary Pumps for Fire Protection, 2010 Edition, and have a unique utility that differentiates them from other NEMA Design B electric motors. As such, DOE is also aware of the unique safety and operating requirements for fire pump motors, as defined under chapter 9 of NFPA 20, Electric Drive for Pumps, and the relatively low operating time for a fire pump electric motor. In view of the foregoing, DOE is considering the possibility of setting efficiency levels for fire pump electric motors at a level that would help close potential loopholes in the efficiency standards. Therefore, the preliminary analysis includes polyphase, single speed continuous fire pump electric motors as a separate equipment class group.

2.3.5.10 Voltage

EISA 2007 also expanded the range of voltages under which polyphase electric motors operate and are required to meet energy conservation standards. (42 U.S.C. § 6311(13)(B)) In addition to the currently regulated polyphase electric motors that operate at 230 and 460 volts, EISA 2007 added all other polyphase electric motors operating at voltages less than 600 volts. Currently, electric motors designed to run on 230 volts or 460 volts are required to meet the same efficiency standards. DOE understands that this is the case because design voltage does not have a bearing on an electric motor's efficiency capability. This is not to say that DOE believes that an electric motor specifically designed to run on 460 volts will perform as well, in terms of efficiency, if run on 575 volts. Rather, DOE believes that an electric motor designed to run on 575 volts can perform as well (in terms of efficiency) as an otherwise equivalent electric motor designed to run on 460 volts. This is corroborated by the fact that NEMA and ASAP recommended that all motors with a voltage of 600 or less should be set to the same efficiency levels. (ASAP and NEMA, No. 12 at p. 7) Since DOE does not believe that a motor's voltage impacts its efficiency, DOE does not plan to use it as an equipment class setting criterion in the preliminary analysis.

Baldor urged DOE to exclude non-standard voltage levels that, in its view, were never meant to be regulated. (Baldor, Public Meeting Transcript, No. 14 at p. 78) It noted that including a wide range of voltages may inadvertently cover variable-frequency motors used with variable-speed controls, which often have non-standard voltage ratings. (Baldor, Public Meeting Transcript, No. 14 at pp. 78-79) Baldor also commented that voltages such as 575 volts are already covered at NEMA Premium levels. (Baldor, Public Meeting Transcript, No. 14 at p. 83) DOE clarifies that, based on materials it has reviewed, an electric motor designed for a non-standard voltage or that is used with a variable-speed controller does not preclude that electric motor from current standards coverage as either a general purpose electric motor (subtype I) or a general purpose electric motor (subtype II), so long as such voltage rating or controller does not signify that such a motor is a special or definite purpose electric motor. (Should DOE decide to apply standards to special or definite purposes electric motors, this standards coverage gap would be closed.) Baldor's comment reinforces this view − i.e., that voltage changes do not affect efficiency levels of the electric motors discussed in this scope. To aid in its understanding of the industry's classification process, DOE requests additional information on variable-frequency motors and how the electric motor industry classifies such motors.

Finally, NEMA commented on the expanded scope of coverage to all voltages not more than 600 volts that resulted from EISA 2007's amendments. NEMA recommended that DOE should consider the standard voltages for U.S. power systems in developing equipment classes or as a criterion applicable to all equipment classes and that should be included in the definition of "electric motor" in 10 CFR 431.12. (NEMA, No. 13 at p. 5) But because voltage ratings have no bearing on the efficiency potential for an electric motor, DOE does not believe it is necessary to establish different equipment classes and accompanying standards for electric motors designed for different voltages. Since this standard, if adopted, would only apply to those electric motors sold or imported into the United States, DOE believes that the standard voltages for U.S. power systems will be inherent to the electric motors. Therefore, DOE decided not to use operating voltage as an equipment class setting criterion in the preliminary analysis.

2.3.5.11 Mounting Feet

Mounting feet refer to external attachments on the electric motor housing that secure the electric motor to a mounting base. They are external to the electric motor housing and play no role in how an electric motor operates and therefore DOE did not use this characteristic as an equipment class setting criterion in the framework document.

NEMA commented that Congress distinguished between footed and footless electric motors, such as C-face mounting or D-flange mounting, when it created a specific classification for footless motors under the subtype II motor designation. NEMA agreed that mounting feet have no effect on efficiency and therefore do not require a separate analysis from general purpose electric motors. (NEMA, No. 13 at p. 6) While mounting feet will have no impact on the efficiency of a given motor, in NEMA's view, this feature can impact the installation cost of footless electric motors because consumers will have to find alternate means to secure the electric motor to a base and DOE should account for this factor in its analysis. (NEMA, No. 13 at p. 6) Baldor also commented that footless electric motors are currently at a separate efficiency level than their footed counterparts and it may be difficult determining at which efficiency level to start when grouping footed and footless electric motors together. (Baldor, Public Meeting Transcript, No. 14 at pp. 79-80)

DOE believes that a footless electric motor has no electromechanical differences from its footed counterparts. The only difference between these motors would be the mounting configuration, which affects a motor's overall utility to the end user. In DOE's view, the presence of that feature alone is insufficient to warrant a separate equipment class because it has no effect on the electromechanical workings of the electric motor and therefore will not affect efficiency. Consequently, in DOE's view, there should be no added difficulty in designing a footless motor to meet the same efficiency level as a motor equipped with feet. In the life-cycle cost analysis, DOE estimates life-cycle cost savings between baseline efficiency motors and higher efficiency motors of the same configuration and footless and footed motors are not compared against each other. Further, DOE found no evidence that installation costs would increase with higher electric motor energy efficiency (see section 2.8.4). Therefore, DOE did not incorporate changes in installation costs for electric motors that are more efficient than baseline equipment. However, because footless electric motors (subtype II) are at a lower efficiency level than subtype I motors, DOE will account for this distribution of efficiencies currently available in the market when it conducts the national impact analysis. Please refer to preliminary TSD chapter 10 for additional details on how DOE accounts for this condition.

2.3.6 Market Assessment

For the market assessment, DOE researches manufacturers, trade associations, and the quantities and types of equipment sold and offered for sale. Issues addressed in this market assessment included: (1) national electric motor shipments, (2) identification of the largest companies in the electric motor industry, (3) existing non-regulatory efficiency improvement initiatives, (4) developments around standards in States and neighboring countries, and (5) trends in equipment characteristics and retail markets. The information collected serves as resource material that DOE uses throughout the rulemaking. Detailed information can be found in chapter 3 of the preliminary TSD.

2.3.6.1 National Shipments Estimate

DOE estimates the annual electric motor shipments to prepare an estimate of the national impact of energy conservation standards for electric motors. Unit shipments are calculated for each horsepower rating within each equipment class. The foundation for DOE's shipment estimate comes from market research reports, interested parties' responses to the Request for Information (RFI) published in the Federal Register (76 FR 17577 (March 30, 2011)), and stakeholder input.[t]

Table 2.9 shows a summary of the 2011 shipments of motors in scope DOE estimated. For more information on annual and historical shipments please refer to the "Shipments Analysis" chapter of this preliminary TSD (Chapter 9) and section 2.9.

Table 2.9 Estimated 2011 Shipment Data

2011 Units Shipment by Category			
Design A	Design B	Design C	Fire Pump
46,512	4,498,896	9,120	5,472

2.3.7 Technology Assessment

The technology assessment provides information about existing technology options and designs to construct more energy-efficient electric motors. There are four main types of losses in electric motors: losses due to the resistance of conductive materials (I^2R losses), core losses, friction and windage losses, and stray load losses. Measures taken to reduce one type of loss typically increase the other type of losses. Some examples of design options to improve efficiency include: (1) higher-grade electrical core steels, (2) use of different conductor types and materials, and (3) increasing the amount of copper wire in the stator (also called slot fill).

In consultation with interested parties, DOE identified several technology options and designs for consideration. These technology options are presented in Table 2.10. Additional detail on these technology options can be found in chapter 3 of the preliminary TSD.

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[t] DOE based its shipments estimates on the following sources of data: market research report (IMS Research (February 2012), The World Market for Low Voltage Motors, 2012 Edition, Austin), stakeholder responses to the Request for Information (RFI) published in the Federal Register (76 FR 17577 (March 30, 2011)), and stakeholder input.

Table 2.10 Options to Increase Electric Motor Efficiency

Type of Loss to Reduce	Design Options Considered
I^2R Losses	Use copper die-cast rotor cage
	Decrease the length of coil extensions
	Increase cross-sectional area of rotor conductor bars
	Increase end ring size
	Increase the amount of copper wire in stator slots
	Increase the number of stator slots
Core Losses	Improve grades of electrical steel
	Use thinner steel laminations
	Add stack length (*i.e.*, add electrical steel laminations)
	Increase flux density in air gap
Friction and Windage Losses	Use bearings and lubricant with lower losses
	Install a more efficient cooling system
Stray Load Losses	Remove skew on conductor cage
	Improve rotor bar insulation

DOE received comment on the validity of the Epstein test results it used to help select higher-efficiency electrical steels for reducing core loss. Epstein test results are used to determine the watts of loss per pound of electric steel and help benchmark the loss properties of various grades of electrical steel. Commenters noted that Epstein test results do not directly correlate to the efficiencies of electric motors and there are other variables to take into account when determining what efficiency gains can be produced from improved electrical steels. (Advanced Energy, Public Meeting Transcript, No. 14 at p. 109; Baldor, Public Meeting Transcript, No. 14 at p. 107; Baldor, No. 8 at p. 5) NEMA added that the only proven way to evaluate the use of a new type of electrical steel for use in an electric motor is to build several prototype electric motors using the new type of steel and compare the results to electric motors of the same designs built using other types of electrical steel. (NEMA, No. 13 at p. 9)

While Epstein test results may not be entirely indicative of potential efficiency gains achievable in an electric motor design, they are helpful in estimating the relative efficiency performance of multiple electrical steels. Because they are capable of providing this type of data, DOE may continue to use Epstein test results as part of its analysis to help determine the potential efficiency levels that may be achievable when modeling its max-tech units. If DOE chooses to use Epstein test results as part of its analysis, DOE will also consider additional testing on prototypes in accordance with 10 CFR 431.17 to confirm the Epstein testing results.

DOE also received feedback concerning efficiency increases by increasing the amount of copper wire in the stator slots, or slot fill. NEMA commented that increasing slot fill to more than 80 percent of the area of the stator slots cannot be achieved by machine winding, and the resulting hand winding methods cause a huge increase in labor content that companies typically offset by shifting production to lower cost countries, resulting in a loss of U.S. jobs. (NEMA, No. 13 at p. 11) Nidec also indicated that an increase in slot fill will force manufacturers to move from machine winding to hand winding which will entail moving those operations off-shore for cheaper labor. (Nidec, Public Meeting Transcript, No. 14 at p. 111) Finally, Baldor added that increasing slot fill to levels requiring hand winding will make them non-competitive in a global market. (Baldor, No. 8 at p. 6)

DOE is aware of the cost increases caused by hand winding motors and considers that factor in its engineering analysis. As is discussed in Chapter 5 of the preliminary TSD, DOE analyzed the winding of each motor that it tore down. Any motor which was found to be hand wound, DOE assigned a larger amount of labor hours in an effort to capture the increased costs. DOE also assigned more labor time for most software modeled designs due to the higher slot fill percentages than the torn down motors. DOE requests additional interested party feedback on the validity of its approach and any industry data on the percentage of motors that are hand wound and the impact of hand winding on manufacturers.

2.3.7.1 Copper Rotor Designs

DOE understands that several companies worldwide are commercially producing polyphase electric motors with copper rotor bars and a select few manufacturers are producing copper die-cast rotors. Copper, due to its lower resistivity relative to aluminum (the most common rotor conductor material), reduces I^2R losses and therefore increases electric motor efficiency. Motor modeling, performed on DOE's behalf, of copper rotor designs indicated that copper rotors increased efficiency levels in the range of 1-2 NEMA bands. A single NEMA band represents a 10 percent reduction in losses from the previous nominal efficiency. For example, increasing an electric motor's efficiency from a NEMA nominal efficiency of 93.6 percent to the next NEMA nominal efficiency band of 94.1 percent would entail reducing the losses by 10 percent.

Responding to the framework document, Baldor argued that efficiency gains with copper rotors are minimal and that copper die-cast rotors are expensive to produce, with copper die casting presses costing in excess of $2 million each and the number of required presses being significantly greater than the number needed for aluminum casting. (Baldor, No. 8 at p. 5) While DOE recognizes the potential costs involved with this technology shift, DOE is aware of at least one major manufacturer who produces copper die-cast rotors. As noted earlier, technology options are not automatically eliminated due to cost concerns but are weighed as part of the manufacturer impact analysis.

NEMA also voiced concerns about the ability to mount fan blades on the rotor when casting a copper squirrel-cage rotor. Fan blades are typically welded or casted onto the ends of the rotor to help sink heat away from the core of the rotor and to circulate air inside of the electric motor. According to NEMA, the ability to mount fan blades on a die-cast copper rotor has not yet been proven and therefore removing heat from the cast copper bars is more difficult than for aluminum cast rotor bars. (NEMA, No. 13 at p. 10) It suggested that any analysis utilizing cast copper rotors in subtype I or subtype II electric motors must include a detailed thermal analysis in order to properly evaluate the feasibility of the technology and the effect on the level of efficiency that can actually be obtained. (NEMA, No. 13 at p. 10) DOE will take into account technology constraints and any problems that may arise in increasing efficiency levels. DOE may conduct extensive thermal analyses of its software modeled electric motors in the next phase of the analysis, which includes thermal analyses of the copper rotor designs. However, DOE notes that working models of die-cast copper rotors exist and are sold in the electric motor market, demonstrating that copper die-cast rotors are feasible for manufacturers to employ.

2.4 SCREENING ANALYSIS

After DOE identified the technologies that might improve the energy efficiency of electric motors, DOE conducted a screening analysis. The purpose of the screening analysis is to determine which options to consider further and which to screen out. DOE consulted with industry, technical experts, and other interested parties in developing a list of design options. DOE then applied the following set of screening criteria, under sections 4(a)(4) and 5(b) of appendix A to subpart C of 10 CFR Part 430, to determine which design options are unsuitable for further consideration in the rulemaking:

- *Technological Feasibility:* DOE will consider only those technologies incorporated in commercial equipment or in working prototypes to be 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 DOE will consider that technology practicable to manufacture, install, and service.

- *Adverse Impacts on Equipment Utility or Equipment Availability:* DOE will not further consider a technology if DOE determines it will have a significant adverse impact on the utility of the equipment to significant subgroups of customers. DOE will also not further consider a technology that will 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.

- *Adverse Impacts on Health or Safety:* DOE will not further consider a technology if DOE determines that the technology will have significant adverse impacts on health or safety.

For a complete discussion of the screening analysis, refer to chapter 4 of the preliminary TSD.

NEMA commented on DOE’s “Technological Feasibility” screening criterion and stressed that a prototype that incorporates a particular type of technology should not be misconstrued as demonstrating that it is commercially viable. (NEMA, No. 13 at p. 11) DOE clarifies that the “Technological Feasibility” criterion is only used to determine whether a technology option is possible from a technical perspective. Therefore, a “working prototype” is all that is needed to pass this criterion.

However, this element constitutes only one of DOE’s four screening criteria. DOE also determines commercial viability by examining the practicability to manufacture, install, and service equipment with that considered technology, the adverse impacts on equipment utility or equipment availability, and the adverse impacts on health or safety.

NEMA commented that the “Technological Feasibility” screening criterion would rule out all the technology options that are not presently in use. (NEMA, No. 13 at p. 11) Baldor submitted a similar comment, stating that it is unclear how technological feasibility applies to the technology options because it seems to rule out all the tech options that are not presently in use. (Baldor, Public Meeting Transcript, No. 14 at p. 115) However, Baldor also commented that all the listed technology options are things that are done or have been tried and that DOE should keep in mind cost and payback periods of these technology options. (Baldor, Public Meeting Transcript, No. 14 at p. 121) DOE believes that all technologies listed in Table 2.10 are either currently used or have been used in the past to increase efficiency. Therefore, DOE does not believe that its “Technological Feasibility” screening criterion would eliminate any of these design options. DOE notes that although it does not consider cost and payback periods in the screening analysis, it does do so in downstream analyses, such as in the LCC.

DOE received comment on its “Practicability to Manufacture, Install, and Service” screening criterion as well. Nidec suggested that if manufacturers shift to more efficient motors, the motors will likely become larger to reduce core losses. This increase in size could impact retrofitting efforts because the replacement motor may no longer fit into the original motor’s application. (Nidec, Public Meeting Transcript, No. 14 at p. 116) DOE understands these concerns and as efficiency levels increase DOE will ensure that utility, which includes frame size considerations, is maintained. Additionally, increased costs due to space-constrained installation and increased shipping costs are taken into account in the national impact analysis (NIA) and the life-cycle cost (LCC) analysis portions of DOE’s analytical procedures.

Additionally, DOE received comment on the feasibility of the various core steel materials it plans to examine in setting standards that would help improve electric motor efficiency. Specifically, interested parties recommended that DOE incorporate into its analysis the use of materials that are readily available or could be produced in significant volume for the entire industry. (NEMA, No. 13 at p. 9) Specifically, manufacturers mentioned that there is a very limited supply of U.S.-made fully-processed Type 6 steel that can be used to reduce core losses and that a particular steel grade may be available only from one mill with insufficient production capacity to supply electric motor manufacturers. (Baldor, No. 8 at p. 4; Baldor, Public Meeting Transcript, No. 14 at p. 103) Additionally, Baldor voiced concern that the general quality of steel has worsened in the past few years due to an increase in recycled content. Baldor notes that the losses in this recycled steel are greater, which makes it impossible to achieve the same efficiency for an electric motor without the addition of more steel, copper, and aluminum. (Baldor, No. 8 at p. 4) Under its *Practicability to Manufacture, Install, and Service* screening criterion, DOE intends to screen out any materials that would not be readily available or could not be produced in significant volume for the entire industry. For the preliminary analysis, DOE has used M47, M36, M19, and M15 grade electrical steels. DOE requests comment from industry on the commercial availability of these electrical steel grades and whether DOE should consider others.

Baldor commented on the *Adverse Impacts on Equipment Utility or Equipment Availability* and submitted comment that, in its view, Appendix A to subpart B of 10 CFR Part

431 (now removed from the CFR and to be amended and placed onto DOE’s electric motors webpage in the future as guidance) provides that “any rating electric motor built in a NEMA frame larger than the standard NEMA frame series number for that horsepower rating is not considered a ‘general purpose electric motor’ and consequently is not required to meet the efficiency standards in EPCA.” (Baldor, No. 8 at p. 7) Baldor believes that this creates a confusing situation as manufacturers may be required to change frame number series in order to meet a standard level, but then that electric motor would no longer be covered by energy efficiency standards because it would no longer be considered a general purpose electric motor. (Baldor, No. 8 at p. 7) DOE understands that NEMA MG1-2011 Part 13, "Frame Assignments for Alternating Current Integral Horsepower Induction Motors," provides frame assignments for standard horsepower ratings of NEMA Design A and B motors. DOE agrees with Baldor that where a motor designed for use on a particular type of application which is in a frame size that is built in a frame one or more *series* larger than the frame size assigned to that rating by NEMA Standards Publication MG1, it is no longer considered general purpose. However, as will be discussed in the engineering analysis portions of this preliminary TSD, DOE strives to maintain utility (including the baseline frame series) as higher efficiency levels are examined. This step is taken to avoid setting energy conservation standards so high that consumers lose certain utilities.

DOE also received comment on the safety hazards that copper rotors impose upon workers handling molten copper. Due to the higher melting temperature of copper, (almost 2000°F , as opposed to aluminum’s 1220°F) working with molten copper is more dangerous than working with aluminum. NEMA asserted that any electric motor designs requiring the use of cast copper rotors also require personnel to work daily in close proximity to hot molten material which will increase workplace injuries. (NEMA, No. 13 at p. 12) (NEMA provided no supporting data for this claim.) Baldor states that cast copper rotors may create several problems that are larger than any advantages it may present, especially in terms of production safety and extra needed energy. (Baldor, No. 8 at p. 5) DOE acknowledges manufacturer concerns over the potential for increased hazards associated with copper die-cast rotors but notes that Baldor provided no data in support of its claim. Accordingly, DOE has not ruled out copper die-cast rotors as an option, particularly in light of the absence of any supporting data regarding the potential risks and the fact that manufacturers are already producing such equipment, which suggests that such equipment can be safely produced in mass quantities. DOE invites manufacturers and others to provide information pointing to the additional risks posed by the manufacture of these types of rotors.

2.4.1 Technology Options Screened Out

DOE developed an initial list of design options from the technologies identified in the technology assessment. DOE reviewed the list to determine if the design options are practicable to manufacture, install, and service; would adversely affect equipment utility or equipment availability; or would have adverse impacts on health and safety. In the engineering analysis, DOE considered those design options that satisfied the four screening criteria. It did not consider those options that failed to satisfy one or more of the screening criterion. The design options screened out are summarized in Table 2.11.

Table 2.11 Design Options Screened Out of the Analysis

Design Option Excluded	Eliminating Screening Criterion
Plastic Bonded Iron Powder (PBIP)	Technological Feasibility
Amorphous Steels	Technological Feasibility

Chapter 4 of this preliminary TSD discusses each of these screened out design options in more detail, as well as the design options that DOE considered in the electric motor engineering analysis. The chapter also includes a list of emerging technologies that could impact future electric motor manufacturing costs.

2.4.1.1 Plastic Bonded Iron Powder

DOE has previously considered plastic bonded iron powder (PBIP) as a replacement for electrical steel in its rulemaking for small electric motors, at 74 FR 32059 (July 7, 2009). PBIP is based on an iron powder alloy that is suspended in plastic, and is used in certain electric motor applications such as fans, pumps, and household appliances. The compound is then shaped into electric motor components using a centrifugal mold, reducing the number of manufacturing steps.[u] Potential advantages of this technique include lower core losses, a reduced number of production steps, and increased efficiency.

NEMA commented that PBIP has not been incorporated into a working prototype and lacks structural integrity. For these reasons, it suggested that DOE not treat this option as a feasible design option. (NEMA, No. 13 at p. 10) DOE is not aware of any polyphase induction electric motors that have been prototyped using PBIP. Therefore, DOE does not consider this option to be technologically feasible and has screened it out of this rulemaking.

Additionally, DOE remains uncertain whether PBIP is practicable to manufacture, install, and service as insufficient information is available to make a judgment on the ability to manufacture this technology. DOE is also uncertain whether the material has the structural integrity to form into the necessary shape of an electric motor steel frame. Consistent with the approach DOE took in the small electric motors standards rulemaking, DOE believes the lack of a working prototype and the uncertainty regarding the structural integrity of PBIP are sufficient reasons to screen out this technology option.

2.4.1.2 Amorphous Steels

Amorphous core material has been in existence for more than 35 years. Amorphous magnetic steels are non-crystal alloys characterized by extremely low losses, high magnetic permeability and high fracture toughness. Amorphous magnetic steels have low hysteresis losses and high electrical resistance that both help to minimize eddy current loss. They are also thin and

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[u] Horrdin, H., and E. Olsson. *Technology Shifts in Power Electronics and Electric motors for Hybrid Electric Vehicles: A Study of Silicon Carbide and Iron Powder Materials.* 2007. Chalmers University of Technology. Göteborg, Sweden.

brittle, making it difficult to cut and machine the material into shapes suitable for electric motor cores.[v] Additional barriers to the use of amorphous steels include higher production costs and the existence of few electric motors utilizing the technology.[w] While some prototypes have been developed using amorphous core material, DOE is not aware of any polyphase induction motors that use amorphous core technology. Therefore, based on available information, DOE does not believe that this option is likely to be technologically feasible at this time.

2.5 ENGINEERING ANALYSIS

The engineering analysis (Chapter 5) develops cost-efficiency relationships for equipment types that are the subject of a rulemaking, estimating manufacturer selling price (MSP) as it relates to increased levels of efficiency. The relationship between the MSP and energy efficiency serves as the basis of the cost-benefit calculations performed during the LCC phase of the analysis. This section provides an overview of the engineering analysis methodology, including a discussion of the representative equipment classes and units, the development of candidate standard levels, a preliminary scaling methodology, price derivations and analysis, and other key issues or regulatory impacts.

2.5.1 Methodology

In general, the engineering analysis estimates the efficiency improvement potential of individual design options or combinations of design options that pass the four criteria in the screening analysis. DOE uses this cost-efficiency relationship, developed in the engineering analysis, in the LCC analysis.

In general, DOE can use three methodologies to generate the manufacturing costs needed for the engineering analysis. These methods are:

1. the design-option approach – reporting the incremental costs of adding design options to a baseline model;

2. the efficiency-level approach – reporting relative costs of achieving improvements in energy efficiency; and

3. the reverse engineering or cost assessment approach – involving a "bottom up" manufacturing cost assessment based on a detailed bill of materials derived from electric motor teardowns.

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[v] Research Centre of China, Bejing, China. Amorphous and Nanocrystalline products branch, Advanced Technology and Materials Co., Ltd., Central Iron and Steel research Institute, Bejing, China. *Application of Amorphous Alloy in the New Energy-Efficient Electrical Electric Motor (2011).*

[w] School of Mechanics and Engineer, ShanDong University, Weihai 264209, China. *Review on Applications of Low Loss Amorphous Metals in Electric motors (2010).*

DOE's analysis for the electric motor rulemaking is based on a combination of the efficiency-level approach and the reverse engineering approach. Due to limited manufacturer feedback concerning cost data and production costs, DOE derived its production costs by tearing down electric motors and recording detailed information regarding individual components as a means to derive material and labor costs. The process was performed on the representative units illustrated below in Table 2.12. DOE used the cost derived from the engineering teardown and the corresponding nameplate nominal efficiency of the torn down motor to report the relative costs of achieving improvements in energy efficiency. DOE derived material prices from current, publicly available data. DOE supplemented the findings from its tests and teardowns through: (1) a review of data collected from manufacturers about prices, efficiencies, and other features of various models of electric motors; and (2) interviews with manufacturers about the techniques and associated costs used to improve efficiency. DOE then aggregated the cost numbers by weighing individual data points by company-level sales volumes for each equipment class. In addition, DOE will use the cost data generated by the engineering analysis in the manufacturer impact analysis (see section 12).

To develop levels with the highest efficiency and that are technologically feasible (*i.e.*, the "max-tech" levels) for each representative unit analyzed, DOE used a combination of electric motor software design programs, manufacturer feedback, and manufacturer supplied data from interviews. DOE's engineering analysis documents the design changes and associated costs when improving electric motor efficiency from a baseline level up to a max-tech level. This analysis includes considering improved electrical steel for the stator and rotor, improved electrical conductors, and any other applicable design options remaining after the screening analysis. As each of these design options are added, the manufacturer's cost generally increases and the electric motor's efficiency improves.

DOE received comment on the use of software products as a method of simulating its max-tech electric motors. Baldor stated it was unaware of any software that will model the most advanced technologies. Baldor continued, suggesting that results need to be accurate and verified, and recommended consulting with Dr. James Kirtley at the Massachusetts Institute of Technology, an expert in motor modeling software who could provide guidance on selecting and using such software. (Baldor, Public Meeting Transcript, No. 14 at pp. 157, 162) NEMA reaffirmed Baldor's concern and commented that it was unaware of any commercially available software that can properly model all of the technology options that DOE indicated that it would study for electric motors. (NEMA, No. 13 at p. 12) NEMA added that it knew of no software that includes an analysis of the thermal characteristics of an electric motor that would enable one to properly evaluate the temperature rise at rated load and its effect on the calculated efficiency. This last element, according to NEMA, is especially important in evaluating the possibility of using a change in materials, such as copper rotors. (NEMA, No. 13 at p. 13) Lastly, WEG commented that there are several key parameters, such as locked-rotor current and torque, pull-up torque, breakdown torque, and frame size that must be considered when modeling new electric motor designs to ensure they are compatible with existing applications, protection systems, and codes. (WEG, No. 5 at p. 1)

DOE is aware of the difficulties in accurately modeling electric motors using design software and the need to consult with knowledgeable experts. Additionally, DOE understands the possibility that software-modeled electric motors may not perform the same way when built and operated in the real world if the software models are not applied properly by an experienced engineer. In response to these concerns, DOE has located an industry expert to work in conjunction with DOE's software modeling expert to potentially design and build software modeled prototypes to verify their performance ratings. Prototyping software modeled electric motors will be a way of validating software modeled designs to ensure DOE bases its maximum technology efficiencies on achievable design parameters.

Additionally, manufacturers stressed that DOE should be aware of the design constraints of fire pump electric motors listed in NFPA 20 and 70 as well as the National Electrical Code (NEC), the Occupational Safety and Health Administration (OSHA), and the Environmental Protection Agency (EPA) when designing fire pump electric motors. (Baldor, Public Meeting Transcript, No. 14 at p. 175; NEMA, No. 13 at p. 19) While DOE does not plan on modeling fire pump electric motors it requests comment on which particular NFPA, NEC, OSHA, and EPA design constraints it should consider and whether the costs associated with these constraints increase as efficiency increases.

2.5.2 Representative Units

As discussed in section 2.3, DOE placed electric motors into three separate equipment class groups. Due to the high number of equipment classes within these groups, DOE selected and analyzed only a few representative units from each equipment class group and based its overall analysis for all equipment classes (within that equipment class group) on these representative units. Table 2.12 lists the design criteria that enumerate all electric motor equipment classes. During the preliminary analysis, DOE selected three units to represent equipment class group 1 and two units to represent equipment class group 2. DOE based the analysis of equipment class group 3 on the representative units for equipment class group 1 because of the low shipment volume and run time of fire pump electric motors.

Table 2.12 Variable Motor Design Criteria

Design Criteria	Notes
Design type	Dictates equipment class group
Horsepower rating	Given a design type, and therefore equipment class group, the combination of these three criteria determines an electric motor's equipment class within said equipment class group.
Pole-configuration	
Enclosure type	

Design Type

For equipment class group 1, which includes NEMA Design A and B electric motors, DOE only selected NEMA Design B motors as representative units to analyze in the engineering analysis. DOE chose NEMA Design B electric motors because NEMA Design A electric motors can generally meet NEMA Design B efficiency levels due to their less stringent locked-rotor current limits. Additionally, NEMA Design B units have much higher shipment volumes than NEMA Design A motors. As mentioned, for equipment class group 2, DOE selected two representative units to analyze. Because Design C is the only NEMA design type covered by this equipment class group, DOE only selected NEMA Design C motors for analysis as its representative units. Equipment class group 3 consists of fire pump electric motors. For equipment class group 3, DOE plans on developing any potential amended energy conservation standards based off of its analysis of equipment class group 1 because fire pump electric motors are required to meet National Electrical Manufacturers Association (NEMA) Design B performance standards.

Horsepower Rating

Horsepower rating is an important equipment class setting criterion. DOE received comments about this issue with respect to representative unit selections. Baldor asserted that when DOE selects representative units, the entire range of horsepower ratings needs to be examined and multiple models need to be tested. (Baldor, Public Meeting Transcript, No. 14 at p. 137) NEMA emphasized its belief that DOE must select at least three or four separate electric motor ratings to adequately cover the NEMA frame number series used for electric motors rated from 1 to 500 horsepower and suggested the following configurations: (1) NEMA Design B, 5 horsepower, 4-pole, enclosed; (2) NEMA Design B, 50-hp, 6-pole open; (3) NEMA Design B, 250-hp, 4-pole open; (4) NEMA Design C, 10-hp, 4-pole, open; (5) NEMA Design C, 40-hp, 6-pole, open; and (6) NEMA Design C, 200-hp, 4-pole, enclosed. (NEMA, No. 13 at p. 14)

When DOE selected its preliminary analysis representative units, DOE chose those horsepower ratings that constitute a high volume of shipments in the market and provide a sufficiently wide range upon which DOE could reasonably base a scaling methodology. For NEMA Design B motors, for example, DOE chose 5-, 30-, and 75-hp rated electric motors to analyze as representative units. DOE selected the 5-hp rating because it is the rating with the highest shipment volume of all motors. DOE selected the 30-hp rating as an intermediary between the small and large frame number series electric motors. Although 75 horsepower is not as high a horsepower rating as recommended by NEMA, DOE believes that this rating can be used to model the highest horsepower ratings. This is because there is less variation in efficiency for horsepower ratings above 75 and therefore DOE determined it was not necessary to analyze a 250 horsepower motor. For NEMA Design C electric motors, DOE again selected the 5-hp rating as well as a 50-hp rating. DOE only selected two horsepower ratings for these electric motors because of the low shipment volumes. For more information on how DOE selected these horsepower ratings see chapter 5 of the preliminary TSD.

Pole-Configuration

Pole-configuration is another important equipment class setting criterion which DOE had to consider when selecting its representative units. For the preliminary analysis, DOE selected 4-pole motors for all of its representative units. DOE chose 4-pole motors because they represent the highest shipment volume of motors compared to other pole configurations. DOE chose not to alternate between pole configurations for its representative units, as recommended by NEMA, because it wanted to keep as many design characteristics constant as possible. By doing so, it would allow DOE to more accurately identify how design changes affect efficiency across horsepower ratings. For example, if DOE compared a 5-hp, 4-pole electric motor and a 50-hp, 6-pole electric motor at the NEMA Premium efficiency level it would be difficult to determine how much of the efficiency change occurred because of the change in horsepower rating and how much occurred because of the pole-configuration change. Additionally, DOE believes that the horsepower rating-versus-efficiency relationship is the most important (rather than pole-configuration and enclosure type versus efficiency) because there are significantly more horsepower ratings to consider.

Enclosure Type

The final equipment class setting criterion that DOE had to consider when selecting its representative units was enclosure type. For the preliminary analysis, DOE elected to only analyze electric motors with enclosed designs rather than open designs for all of its representative units. DOE selected enclosed motors because, as with pole-configurations, these motors have higher shipments than open motors. Again, DOE did not alternate between the two design possibilities for its representative units because it sought to keep design characteristics as constant as possible in an attempt to more accurately identify the reasons for efficiency improvements.

Frame Type

The last criterion that DOE considered when selecting its representative units was frame type (i.e. U- or T-frame). DOE selected T-frame motors because they represent the highest volume of shipments. As discussed in section 2.3, the scope of coverage set by EISA 2007 included both NEMA U-frame and T-frame designs. However, NEMA indicated that the low volume of U-frame electric motors makes it unnecessary to select a U-frame electric motor as a representative unit. NEMA added that the energy savings and cost analyses pertinent to U-frame electric motors can be incorporated into the analysis of the overall set of general purpose electric motors (subtype II). (NEMA, No. 13 at p. 13) For these reasons and those discussed above in 2.3.5.5, DOE did not select any U-frame motors as representative units and at this time does not plan to do so in the latter stages of this rulemaking. This approach may change depending on the data and comments DOE receives in response to this preliminary analysis.

Finally, Table 2.13 illustrates the representative units that DOE selected for the preliminary analysis. DOE requests comment on the appropriateness of these representative units.

Table 2.13 Representative Units for Preliminary Analysis

Representative Unit	Specifications	
1	NEMA Design B, T-frame, Enclosed, 4-pole	5 Horsepower
2		30 Horsepower
3		75 Horsepower
4	NEMA Design C, T-frame, Enclosed, 4-pole	5 Horsepower
5		50 Horsepower

2.5.3 Candidate Standard Levels Analyzed

For each representative unit, DOE selected a baseline model as a reference point against which to measure changes that may result from energy conservation standards. For each equipment class directly analyzed, DOE looked at manufacturer catalogs to determine the minimum efficiencies of motors currently available. This search included motors previously not covered by conservation standards, but would be covered in the planned expansion of scope. DOE used these minimum efficiency levels as the baseline efficiencies for each equipment class directly analyzed. Then, the energy savings and price of the baseline model is compared to the energy savings and price of each higher energy efficiency level. Energy efficiency levels are termed "candidate standard levels" (CSLs) and are meant to characterize the cost-efficiency relationship.

In the framework document, DOE used the MotorMaster+ database in developing potential CSLs for electric motors.[x] Baldor expressed concern with this approach and stated that the MotorMaster+ database needs updating. (Baldor, Public Meeting Transcript, No. 14 at p. 152) DOE confirmed this claim after comparing the MotorMaster+ database with current manufacturer catalog data. As a result, DOE created its own electric motor database built from up-to-date manufacturer catalog data and used the manufacturer catalog database it created as a reference point when developing potential CSLs. This information was supplemented with data collected at manufacturer interviews as well as by contacting electric motor manufacturers and distribution channels to gather the most current catalog data available.

2.5.3.1 Baseline Candidate Standard Level

In the framework document, DOE laid out an approach it was considering for selecting its baseline models, or baseline efficiency levels. Baseline models serve as reference points for each equipment class against which DOE can measure changes in efficiency and costs resulting from potential energy conservation standards. In the framework document, DOE stated that the baseline models it would select would correspond to the least efficient, most typical electric motor sold in a given equipment class. At the time, DOE had not yet considered expanding the scope of conservation standards, and therefore specified that the baseline models would be equivalent to the minimum applicable energy conservation standards set by EISA 2007. However, for the preliminary analysis, DOE has revised the baseline efficiency levels to accommodate motors now included in the expanded scope of coverage. None of the motors in the planned scope expansion are currently held to any conservation standards, therefore, the baseline efficiencies of some representative units are below the current required EISA 2007 standards. DOE used manufacturer catalogs to select the baseline efficiency levels for its representative units. These levels were the minimum observed catalog efficiencies for all NEMA Design A and B motors (equipment class group 1) for which DOE plans on establishing or

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[x] MotorMaster+ is an energy-efficient motor selection and management tool, which includes a database of over 20,000 electric motors. For more information about MotorMaster+, visit *www1.eere.energy.gov/industry/bestpractices/software.html#mm*

amending energy conservation standards. Table 2.14 shows the nameplate efficiencies of the baseline representative units for this equipment class group.

For the NEMA Design C equipment class group (equipment class group 2) DOE did not find any NEMA Design C motors (equipment class group 2) below EISA 2007 efficiency levels, and therefore is using the EISA 2007 conservation standards as the baseline for equipment class group 2.

Should DOE not find any economic justification for amended energy conservation standards above the baseline efficiency level, subtype I and subtype II motors would remain subject to the same efficiency levels (i.e., different from each other) mandated by EISA 2007. Additionally, DOE notes that although the efficiencies in Table 2.14 represent the baseline, DOE's efficiency distribution for this equipment class group shows a significant portion of motors already above the baseline efficiency level.

Table 2.14 Representative Unit Baseline Efficiency Level versus Current Lowest Energy Conservation Standards

Motor	Nameplate Baseline Efficiency	NEMA MG1-2011 Table 12-11 (EPACT 1992) Efficiency
5 horsepower, 4-pole enclosed frame NEMA Design B motor	82.5%	87.5%
30 horsepower, 4-pole enclosed frame NEMA Design B motor	89.5%	92.4%
75 horsepower, 4-pole enclosed frame NEMA Design B motor	93.0%	94.1%

2.5.3.2 Improved Candidate Standard Level

As previously discussed, DOE had considered using EISA 2007 efficiency levels for the baseline CSL efficiencies in the framework public meeting, but changed its decision in light of the planned expansion of scope. Since DOE plans on using the lowest-observed catalog efficiencies to characterize the new baseline efficiency level, DOE plans on basing the improved CSLs on efficiencies levels equivalent to the applicable energy conservation standards that were set by EISA 2007 (previously the basis for the baseline CSL).

NEMA suggested that DOE develop its baseline efficiency levels for electric motors based on the EISA 2007 regulations. (NEMA, No. 13 at p. 13) DOE agrees with establishing a CSL based on the EISA 2007 regulations, however, because of the planned scope of conservation standards expansion, it will not correspond to the baseline efficiency, but rather the first and second incremental CSLs. DOE selected the NEMA MG1-2011, Table 12-11 efficiency values as the first incremental CSL over the baseline level for the NEMA Design A and B equipment class group (equipment class group 1). NEMA MG1-2011, Table 12-11 is equivalent to the EPACT 1992 levels for 1 to 200 horsepower electric motors and the EISA 2007 levels for NEMA Design B electric motors with a horsepower rating greater than 200. EISA 2007 also mandated that general purpose electric motors (subtype I) from 1 to 200 horsepower and 2 to 6 poles meet efficiency levels that correspond to NEMA MG1-2011, Table 12-12[y] (i.e., equivalent to NEMA Premium levels). Therefore, DOE selected NEMA MG1-2011, Table 12-12 (including the new NEMA Premium ratings for 8-pole motors) as its second incremental CSL. Because equipment class group 1 includes motors that are considered general purpose electric motors (subtype II) and EISA 2007 mandated efficiency standards equivalent to Table 12-11 for these motors, DOE believes Table 12-11 is the appropriate first incremental efficiency level to represent equipment class group 1.

Baldor commented that although fire pump electric motors are used very intermittently, if they were deregulated or were prescribed lower efficiency standards than general purpose motors, manufacturers could sell them cheaply for general purpose applications as a means of skirting efficiency laws. Baldor stated that manufacturers could potentially do this because there are no regulations limiting the applications in which a fire pump motor may be used. (Baldor, Public Meeting Transcript, No. 14 at pp. 129, 130) Baldor did not address the additional costs manufacturers must expend when producing a motor that satisfies the NFPA requirements and whether sufficient incentives exist for this potential circumvention path. Nevertheless, DOE notes that it will assess the feasibility of raising fire pump electric motors to higher efficiency levels, which could have the added benefit of discouraging their use as a compliance loophole. NEMA added that because of their low quantity, the sparse potential energy savings, and the projected life cycle costs of fire pump electric motors, DOE should incorporate the analysis of these motors into the overall class of general purpose subtype II electric motors (NEMA, No. 13 at p. 13).

Additionally, NEMA cited NFPA 20, which states that polyphase fire pump electric motors must comply with NEMA Design B standards. However, NEMA emphasized that fire pump motors have additional requirements that distinguish them from typical, general purpose, NEMA Design B electric motors. (NEMA, No. 13 at p. 13) As mentioned previously, DOE is aware of the low volume and run-time of fire pump electric motors as well as the design restrictions placed on fire pump electric motors. Therefore, DOE has created a separate equipment class group for fire pump motors which it will use to analyze these motors. However, as fire pump motors have to meet the performance criteria for NEMA Design B motors and DOE is directly analyzing NEMA Design B motors for equipment class group 1, DOE will partially base its fire pump motor analysis on the results of the equipment class group 1 analysis.

When selecting incremental CSLs for equipment class group 1, DOE based its second incremental CSL (CSL 2) on the NEMA MG1-2011, Table 12-12 (i.e., NEMA Premium)

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[y] EISA 2007 actually referred to the 2006 version of NEMA MG1, but as the industry document has been updated and the efficiency values for the pertinent ratings (i.e. combination of horsepower, pole-configuration, and enclosure type) have not changed, DOE has referenced the most up to date version of MG1, NEMA MG1-2011. Another benefit of using the most recent version of this industry document is that tables 12-11 and 12-12 have been expanded to include additional motor ratings.

efficiency levels. This level is generally one or two NEMA "bands" more than the NEMA MG1-2011 Table 12-11 (i.e. EPACT 1992) values, which constitute DOE's first incremental CSL (CSL 1). As mentioned earlier, NEMA defines a "band" as a 10 percent reduction in losses from the lower level of efficiency. Actual efficiency numbers in the NEMA MG1-2011 efficiency tables are based on this "band" rule as well as a NEMA survey on achievable efficiencies by individual manufacturers. The standardized NEMA nominal efficiency values can be found at NEMA MG1-2011 Table 12-10.

The third incremental CSL (CSL 3) for equipment class group 1 is based on the most efficient levels DOE found in its electric motor database. This level represents the best or near best efficiency level at which current manufacturers are producing electric motors and generally exceeds the NEMA Premium level by one NEMA band of efficiency. DOE also created a fourth incremental CSL (CSL 4) that is an incremental efficiency level one NEMA band above CSL 3 that DOE developed using computer software modeling.

The final CSL (CSL 5) is based on the theoretical maximum efficiency possible using design options that were not screened out in DOE's screening analysis. DOE based its efficiency value on computer software modeling and manufacturer feedback. Table 2.15 shows DOE's preliminary CSLs for equipment class group 1 electric motors.

Table 2.15 Candidate Standard Levels for Equipment Class Group 1 Motors

CSL Number	CSL Name	NEMA MG1-2011 Tables	Note
0	Baseline	--	Lowest observed efficiency in catalogs
1	EPACT 1992	12-11 (and 20A[z])	Minimum EISA 2007
2	NEMA Premium	12-12 (and 20B[aa])	Maximum EISA 2007
3	Best-in-Market	--	--
4	Incremental Level	--	--
5	Maximum Technologically Feasible	--	--

Because fewer NEMA Design C motors are available on the market, DOE used a slightly different method for developing its CSLs for equipment class group 2. For more information see Chapter 5 (Engineering Analysis) of the preliminary TSD.

DOE received feedback on increasing efficiency levels beyond NEMA Premium levels. ACEEE and Baldor commented that DOE should not try to exceed the NEMA Premium levels. (ACEEE and Baldor, Public Meeting Transcript, No. 14 at pp. 88-89) Baldor added that technology constraints can make the market much more difficult because replacing a NEMA

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[z] Table 20A was added in NEMA MG1-2011 as an extension to Table 12-11, which includes efficiency ratings for 6- and 8-pole motors from 300 to 500 horsepower.

[aa] Table 20B was added in NEMA MG1-2011 as an extension to Table 12-12, which includes efficiency ratings for 6- and 8-pole motors from 300 to 500 horsepower.

Design B electric motor with a NEMA Design A electric motor (which can be more efficient) could cause problems when starting an application. Because NEMA Design A motors allow a larger locked-rotor current (also known as starting current) than NEMA Design B motors, the replacement motor may cause circuits to trip because of the larger current used at startup. (Baldor, Public Meeting Transcript, No. 14 at p. 89)

Although ACEEE, speaking on behalf of ASAP and NEMA, advocated expanding the scope of coverage and moving all electric motors to NEMA MG1-2009, Table 12-12 efficiency levels in this rulemaking, they also stated that moving to or beyond these levels would be in the best interest of consumers, manufacturers, and the economy. (ACEEE, NEMA, and ASAP, Public Meeting Transcript, No. 14 at p. 22) The CDA submitted similar comments, suggesting that even higher minimum efficiencies are cost-effective, especially for the larger 200-500 horsepower electric motors that are usually heavy-duty-cycle electric motors. The CDA also suggested that for these motors, payback of the increased costs because of higher efficiency standards could be achieved in months or one year of operation. (CDA, No. 18 at p. 3) ASAP and NEMA later tempered its position somewhat in its written comments, noting that they do not support DOE creating standards more efficient than the Table 12-12 levels. (ASAP and NEMA, No. 12 at p. 2) ASAP and NEMA reiterated this position in response to the RFI that DOE published in March 2011. (ASAP and NEMA, No. 20 at p. 5) NEMA emphasized the “strategic value” of current NEMA Premium efficiency level standards and suggested that DOE should be careful not to inadvertently ignore the risks to electric motor users of being non-competitive if they are raised. (NEMA, No. 13 at p. 11)

DOE appreciates the comments from all interested parties on its candidate standard levels. DOE is aware of the design changes required to meet efficiencies up to and beyond the Table 12-12 levels. However, DOE plans to run a full analysis on the market and on cost increases as efficiency increases beyond the Table 12-12 levels. DOE will characterize the relationship between cost and efficiency to such levels and will consider how consumers, utilities, manufacturers, and the Nation as a whole will be affected.

Additionally, NEMA suggested that when DOE determines efficiency levels based on test results, it should use the provisions outlined in 10 CFR 431.17. NEMA asserted that “based on the experience with the testing of baseline small electric motors and the improper conclusions arrived at when testing too small a sample size, then DOE should follow the requirements of the procedure in 10 CFR 431.17 when the efficiency is determined by testing.” (NEMA, No. 13 at p. 15) Baldor added that any efficiency values of modeled electric motors that fall between NEMA nominal efficiency levels should be rounded down. (Baldor, Public Meetings Transcript at p. 172)

DOE notes that 10 CFR 431.17 provides the provisions that manufacturers must follow in order to demonstrate compliance with an electric motor energy conservation standard and, thus, it includes stipulations for sample sizes. But because NEMA has provisions in place that guarantee to customers the minimum energy efficiency performance of electric motors with labeled nominal full-load efficiencies, DOE believes that repetitive testing of the same model was unnecessary. All motors tested and torn down by DOE were manufactured by NEMA members. As a result, the preliminary analysis ultimately relies on the manufacturer’s nominal nameplate efficiency, so long as the results from testing in accordance with 10 CFR 431.16 yielded results that fell within the allowable variance as provided in NEMA MG1-2011. DOE uses the nameplate nominal efficiency of tested electric motors to represent its CSLs, except for some of the highest CSLs, which are based on the efficiencies of computer modeled designs rounded to the next lowest NEMA nominal efficiency level. For each CSL based on the data gleaned from a tested and torn-down motor, DOE tested one unit (11 total).

Finally, Baldor urged DOE to consider NEMA MG1-2009's requirements − e.g., specific torque or current requirements − when developing potential efficiency levels. (Baldor, Public Meeting Transcript, No. 14 at p. 99) NEMA added that DOE should review the NEMA MG1-2009 standards in their entirety to understand all of the performance requirements for general purpose electric motors such that designs developed by DOE meet all of those requirements. (NEMA, No. 13 at p. 8) DOE recognizes these concerns and the importance of maintaining utility within the context of improving efficiency levels. Therefore, for a given representative unit, DOE sought to ensure that all of the electric motors tested and modeled contained comparable performance characteristics − i.e., within the specifications laid out in NEMA MG1-2011 (which is equivalent to those provided in MG1-2009 as requested by interested parties)).

2.5.4 Material Price Analysis

DOE conducted the engineering analysis using material prices based on manufacturer feedback, industry experts, and publicly available data. Most material prices were based on the 2010 price of the material. However, cast copper and copper wire pricing were based on prices tracked over a five-year time period from 2007 through 2011. DOE used a five-year average price for copper materials because of the high volatility of copper prices relative to other electric motor materials such as electrical steel or aluminum, prices of which experience relatively little yearly fluctuation.

DOE received very limited feedback concerning material prices for any of the previous five-year span. Manufacturers suggested using the London Metal Exchange (LME) as a starting point for raw metal prices and applying a markup to compensate for wire processing or steel extruding. For the preliminary analysis, DOE did use the LME material prices as well as Producer Price Indices to derive previous year's prices.

DOE requests comment on its tentative decision on its reference case material price scenario, which is to use 2010 prices for all of its material prices other than copper. DOE also requests comment on its preliminary decision to use a five-year average for its material prices for cast copper and copper wiring.

2.5.5 Cost Model and Markups

DOE derived the manufacturer's selling price for each design in the engineering analysis by considering the full range of production costs and non-production costs. The full production cost is a combination of direct labor, direct materials, and overhead. The overhead contributing to full production cost includes indirect labor, indirect material, maintenance, depreciation, taxes, and insurance related to company assets. Non-production cost includes the cost of selling, general and administrative items (market research, advertising, sales representatives, logistics), research and development (R&D), interest payments, warranty and risk provisions, shipping, and profit factor. Because profit factor is included in the non-production cost, the sum of production and non-production costs is an estimate of the manufacturer's selling price (MSP). DOE utilized various markups to arrive at the total cost for each component of the electric motor. These markups are outlined in detail in Chapter 5 of the preliminary TSD. Figure 2.5.1 presents the components of the MSP.

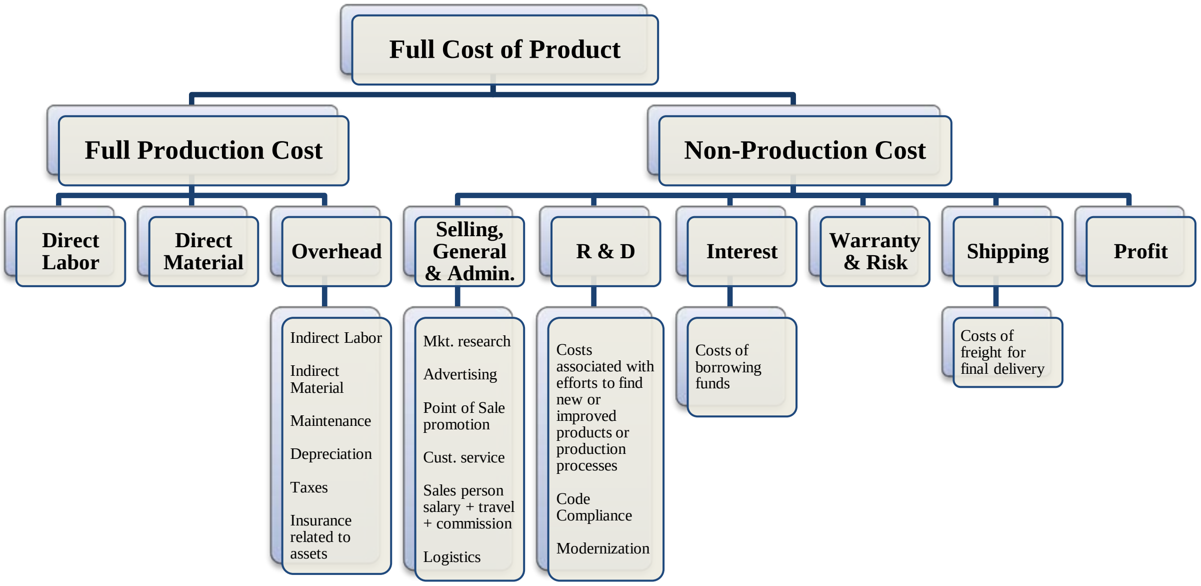

Figure 2.5.1 Method of Cost Accounting for Electric Motors Rulemaking

In response to the framework document, Baldor suggested that DOE consider differentiating the costs for a hand-wound electric motor design from a machine-wound one when determining prices for its electric motor. Baldor specifically noted that during tear-downs, DOE should note this fact because it signifies a large change in labor costs. (Baldor, No. 8 at p. 6) To account for this factor, the preliminary analysis includes an aggregate labor rate of foreign and domestic labor. DOE looked at the percentage of electric motors imported to the U.S. and the percentage of electric motors built domestically and based the balance of foreign and domestic labor rates on these percentages. During tear-downs, DOE examined stator construction to determine if it was machine-wound or hand-wound. DOE found none of its physically torn down motors were hand wound. However, DOE increased labor hours to compensate for hand winding for software modeled motors with reported slot fill over 80 percent. Additional details regarding these assumptions can be found in Chapter 5 (Engineering Analysis) of the preliminary TSD.

Baldor commented that the cost and selling price are not directly related, and that some high-volume original equipment manufacturers (OEMs) demand lower prices. This, in turn, causes margins to shrink between cost and selling price. (Baldor, No. 8 at p. 6) DOE is aware that advertised or negotiated prices are not always indicative of production costs for manufacturers. Accordingly, DOE plans to derive its own cost basis for electric motor production. Price determination begins with electric motor tear-down and pricing of raw material to which various markups are applied as illustrated in figure 2.5.2.

Baldor asserted that low-volume electric motors often mean less automation and therefore higher labor cost to manufacture. (Baldor, No. 8 at p. 7) DOE will consider the possibility of higher labor costs for low-volume electric motors and seeks manufacturer feedback on specific electric motors which may fall into a “low-volume” category and what variations in labor costs may be associated with these motors.

Finally, NEMA suggested that DOE clarify how it plans to resolve any differences between the costs it derives and the actual costs the manufacturer incurs. NEMA also stated that DOE should account for manufacturing techniques that may vary among different manufacturers. (NEMA, No. 13 at p. 15) NEMA also commented that they are not able to qualify a relationship between cost and efficiency, but in general terms higher efficiency levels require more raw material and therefore higher costs. (NEMA, No. 19 at p. 4) DOE is aware of the difficulty of determining accurate costs for electric motor designs and production. While DOE does not generate a different set of costs for individual manufacturers, it has spoken to individual manufacturers and examined publicly available information, such as SEC 10-Ks, in effort to understand subtle differences among manufacturers. Consequently, DOE has one set of markups that it applies to its bills of materials, which is designed to be a typical markup scheme for an electric motor manufacturer. Refer to chapter 5 of the preliminary TSD for more detail on DOE’s cost model

2.5.6 Scaling Methodology

Once DOE has identified cost-efficiency relationships for the representative units that it has selected, it must appropriately scale the engineering analysis results of these representative units to the other equipment classes not directly analyzed. To scale the findings from one equipment class to another, DOE identifies relationships between the equipment classes through a characterization of the current market. To do this, DOE considered two methodologies, which are described in detail in Chapter 5 of the preliminary TSD. In response to the framework document, DOE received several interested party comments on scaling the results of the engineering analysis.

NEMA suggested that any standards that DOE develops from any scaling method should also yield values corresponding to the values for nominal efficiency in table 12-10 of NEMA MG1-2009. (NEMA, No. 13 at p. 17)

As discussed previously, DOE based the first three of its CSLs for equipment class group 1 on torn down motors. As these motors were marketed and sold with NEMA nominal efficiencies, DOE used those values to denote each of those CSLs. Consequently, the efficiency levels that DOE scaled to for the non-representative units were also selected from the NEMA nominal efficiency levels. For the two CSLs that were achieved for the representative units using software modeling, DOE used the NEMA nominal efficiency values.

With regards to the scaling methodology, Baldor commented that it would be very difficult to scale between (1) different enclosure types and pole configurations and (2) horsepower ratings (the latter because frame sizes change which could limit stack length increases). (Baldor, Public Meeting Transcript, No. 14 at pp. 166 and 170) It added that when scaling from open to enclosed motors, comparisons should be based on the same frame size and number of poles. (Baldor, No. 8 at p. 7) Baldor also mentioned that NEMA does not have Premium efficiency levels for 8-pole electric motors, but these levels may be published in the near future before DOE completes its standards rulemaking. (Baldor, Public Meeting Transcript, No. 14 at pp. 140-41) NEMA also expressed concern over scaling between different pole configurations and indicated that it was unclear how DOE intended to do this. (NEMA, No. 13 at p. 17) NEMA voiced concerns about scaling efficiency relative to horsepower rating as well and suggested that scaling can only be performed on electric motors of the same frame number series because it is not necessarily true that all technologies will translate to increased efficiencies in other ratings. (NEMA, No. 13 at p. 18) NEMA added that a scaling relationship cannot consistently be used because of many variables, such as frame size, power density, and cooling. (NEMA, No. 19 at p. 4) Finally, NEMA suggested that the designs for various horsepower and efficiency ratings should be modeled and checked against the results to obtain confidence in the scaling method. (NEMA, No. 13 at p. 18) DOE invites comments from interested parties on potential scaling methodologies based motor losses and corresponding levels of energy efficiency.

DOE recognizes that scaling motor efficiencies is a complicated proposition that has the potential to result in efficiency standards that are not evenly stringent across all equipment classes. However, between DOE’s three equipment class groups, there are several hundred combinations of horsepower rating, pole configuration, and enclosure. Within these combinations there are still a large number of standardized frame number series. Given this sizable number of frame number series, DOE cannot feasibly analyze all of these variants -- hence, the need for scaling. Scaling across horsepower ratings, pole configurations, enclosures, and frame number series is a necessity. For the preliminary analysis, DOE considered two methods to scaling, one that develops a set of power law equations based on the relationships found in the EPACT 1992 and NEMA Premium tables of efficiency and one based on the incremental improvement of motor losses. Ultimately, DOE did not find a large discrepancy between the two methods and elected to use the, simpler, incremental improvement of motor losses approach.

The baseline efficiency (CSL 0) is based on the lowest efficiency levels for each horsepower rating, pole configuration, and enclosure type observed in motor catalog data for the motors that DOE plans on including in the expanded scope of conservation standards. For CSL 1 (NEMA MG1-2011 Table 12-11) and CSL 2 (NEMA MG1-2011 Table 12-12), DOE did not have to do any scaling and simply used the efficiency values found in those newly expanded tables.

For the higher CSLs, namely 3, 4, and 5, DOE’s conservation of motor losses approach relies on NEMA MG1-2011 Table 12-10 of nominal efficiencies and the relative improvement in motor losses of the representative units. As has been discussed, each incremental improvement in NEMA nominal efficiency (or NEMA band) corresponds to roughly a 10 percent reduction in motor losses. After CSLs 3, 4, and 5 were developed for each representative unit, DOE applied the same reduction in motor losses (or the same number of NEMA band improvements) to various segments of the market based on the representative units. DOE assigned a segment of the electric motors market, based on horsepower ratings, to each representative unit analyzed. DOE's assignments of these segments of the markets were in part based on the standardized NEMA frame number series that NEMA MG1-2011 assigns to horsepower and pole combinations. In the end, each CSL above CSL 2 was one NEMA band above the previous CSL for each representative unit -- i.e. CSL 3 exceeded Table 12-12 by one band, CSL 4 by two, and CSL 5 by three. The second scaling approach that DOE considered is described in detail in Chapter 5 of the preliminary TSD.

2.5.7 Other Regulatory Impacts on the Engineering Analysis

In conducting an engineering analysis, DOE recognizes that regulatory changes occurring outside of the standards-setting process can affect equipment manufacturing. Some of these changes can also affect the efficiency of the equipment. DOE attempts to identify all "outside" issues that can impact the engineering analysis.

2.6 MARKUPS ANALYSIS

Chapter 6 describes how DOE determined the installed price of electric motors. DOE derived the installed price by applying markups to the manufacturer selling price it determined in the engineering analysis (chapter 5). Markups, sales tax, and installation costs are the costs associated with bringing a manufactured electric motor into service as an installed piece of electrical equipment.

For electric motors, DOE defined six distribution channels and estimated their respective shares of shipments. The six channels are:

(1) from manufacturers to original equipment manufacturers (OEMs) and then to end-users (50 percent of shipments);
(2) from manufacturers to distributors and then to end-users (24 percent of shipments);
(3) from manufacturers to distributors to OEMs and then to end-users (23 percent of shipments);
(4) from manufacturers to end-users through contractors (less than 1 percent of shipments);
(5) from manufacturers to distributors to contractors and then to end-users (less than 1 percent of shipments); and
(6) directly to the end-user (less than 2 percent of shipments). [bb]

Weighting the markups in all six channels by each channel's share of shipments yields an average overall baseline markup of 1.63 and an overall incremental markup of 1.50. DOE used those markups for each equipment class. DOE also analyzed shipping costs as one of the costs that determine installed equipment price.

[bb] Total does not add up to 100 percent due to rounding

Several of the interested parties commented on the distribution channels for electric motors. Nidec, NEMA, and Baldor stated that about half of the electric motors they sold were sold to OEMs, and the other half to distributors. (Nidec, Public Meeting Transcript, No. 14 at pp. 187-188; NEMA, No. 13 at p. 20; Baldor, No. 8 at p. 8) Nidec and NEMA both commented that less than one or two percent of electric motors were sold directly to end-users and contractors. (Nidec, Public Meeting Transcript, No. 14 at pp. 187-188; NEMA, No. 13 at p. 20) Baldor agreed with this comment and further suggested that the contractors category should be removed from the distribution channels. (Baldor, Public Meeting Transcript, No. 14 at pp. 188-189)

NEMA commented that electric motor distributors sell 60 percent of their units to end-users for replacement of failed electric motors or capital projects, while the remaining 40 percent units goes to smaller OEMs. (NEMA, No. 13 at p. 20) Baldor commented similarly that electric motor distributors sell half their electric motors to EASA repair shops and half to national distributors. (Baldor, No. 8 at p. 8, Public Meeting Transcript, No. 14 at pp. 188-189)

GE suggested that importers should be included as part of the distribution chain and commented that electric motors can be sold from OEMs to distributors and from distributors to OEMs. (GE, Public Meeting Transcript, No. 14 at p. 192)

DOE based the description of the distribution channels on a literature review, expert inputs and stakeholder comments received during the public meeting. More details on the description of the distribution channels are available in chapter 6. DOE welcomes stakeholder feedback on the different shares of shipments being sold through each channel.

Two of the interested parties commented that electric motor prices are highly variable and determined mostly at the project level. Nidec commented that the margin on an individual electric motor can vary greatly, based on availability and market opportunities, and there is no average margin or average selling price. (Nidec, Public Meeting Transcript, No. 14 at pp.186-187, 190-191) NEMA commented that there is no linear relationship between cost and selling price. It noted that while margins are important, they are managed at the customer or project level, not at the individual stock-keeping unit level. NEMA further suggested that DOE should include detailed variable and fixed labor and burden rates as well as country of manufacture variances and freight costs. (NEMA, No. 13 at p. 15)

DOE acknowledges that its approach is a simplification of real-world practices, but DOE is unaware of a tractable method for incorporating the practices mentioned in the comments, or for including detailed variable and fixed labor and burden rates as well as country of manufacture variances. Therefore, in the preliminary analysis DOE estimated the equipment price using the markup approach it has used in other energy conservation standards rulemakings. DOE also estimated shipping costs and integrated these in the LCC analysis. DOE requests input from interested parties regarding any viable alternative approach and source of information that could be used to develop equipment prices.

2.7 ENERGY USE CHARACTERIZATION

The energy use characterization (chapter 7) estimates the energy use by electric motors. The energy use by electric motors equals the end-use load plus any energy losses associated with electric motor operation. The energy use is derived from three components: useful mechanical shaft power, electric motor losses, and reactive power.[cc] Electric motor losses consist of I^2R (resistance heat) losses, core losses, stray-load losses, and friction and windage losses.

The annual energy consumption of an electric motor that has a given nominal full-load efficiency depends on the electric motor's sector (industry, agriculture, or commercial) and application (compressor, fans, pumps, material handling and processing, fire pumps, and others), which in turn determine the electric motor's annual operating hours and loading.

To calculate the annual kilowatt-hours (kWh) consumed at each efficiency level in each equipment class, DOE used the nominal efficiencies at various loads from the engineering analysis, along with estimates of operating hours and electric motor loading for electric motors in various sectors and applications.

To determine the variation in field energy use in the industry sector, DOE used statistical information on annual electric motor operating hours and loading derived from a database of more than 15,000 field measurements obtained through the Washington State University and the New York State Energy Research and Development Authority. For agriculture and the commercial sector, DOE relied on data found in the literature.

Chapter 7 provides greater detail on the methods, data, and assumptions used for the energy use characterization.

2.7.1 Variability in Field Operating Conditions

Two of the interested parties commented on the variability of electric motor usage and energy costs across different types of industry. NEMA commented that process industries and commercial buildings often run electric motors continuously, while many equipment manufacturers operate one or two shifts with a 5-day work week. (NEMA, No. 13 at p. 21) WEG commented that energy costs should be weighted by the hours of operation per industry to ensure that the industries with the highest usage hours and lowest energy costs are properly accounted for. (WEG, No. 5 at p. 1)

[cc] In an alternating current power system, the reactive power is the root mean square (RMS) voltage multiplied by the RMS current, multiplied by the sine of the phase difference between the voltage and the current. Reactive power occurs when the inductance or capacitance of the load shifts the phase of the voltage relative to the phase of the current. Although reactive power does not consume energy, it can increase losses and costs for the electricity distribution system. Electric motors tend to create reactive power because the windings in the electric motor coils have high inductance.

In the preliminary analysis, DOE characterized the electric motor usage (i.e. load and annual operating hours) by sector and application and developed statistical distributions to represent variability in the field.

2.7.2 Impact of Repair on Efficiency

The Electrical Apparatus Service Association (EASA) commented that a comprehensive study has been done by EASA and the Association of Electrical and Mechanical Trades to investigate the effect of repair and rewind on electric motor efficiency. EASA commented that the study showed that electric motor efficiency could be maintained by following the good practices identified in the study. (EASA, No.7 at pp. 1-2)[dd]

In the preliminary analysis, DOE assumed that one-third of repairs are done following good practice as defined by EASA and do not impact the efficiency of the electric motor (i.e., no degradation of efficiency after repair). DOE assumed that two-thirds of repairs do not follow good practice and that a slight decrease in efficiency occurs once the electric motor is repaired. DOE assumed the efficiency decreases by 1 percent in the case of electric motors less than 40 horsepower, and by 0.5 percent in the case of larger electric motors. DOE request comments on this approach.

2.7.3 Electric Motor Efficiency and Slip

Baldor commented that the installation of a more efficient electric motor could lead to less energy savings than anticipated. Baldor pointed out that, because a more efficient electric motor usually has less slip than a less efficient one does, this attribute can result in a higher operating speed and a potential overloading of the electric motor. Baldor recommended that DOE include the consequence of a more efficient electric motor operating at an increased speed in any determination of energy savings. (Baldor, No. 8 at pp. 7-8)

DOE acknowledges that the arithmetic cubic relation between speed and power requirement in many variable torque applications can affect the benefits gained by efficient electric motors, which have a lower slip. However, DOE does not have robust data to incorporate this effect in the main analysis. Instead, DOE developed assumptions where no solid data were available and estimated the effects of higher operating speeds as a sensitivity analysis in the LCC spreadsheet. For the eight representative units analyzed in the LCC analysis, the LCC spreadsheet allows one to consider this effect as a sensitivity analysis according to a scenario described in appendix 7A of the TSD.

DOE seeks stakeholder inputs on the methodology and the assumptions that might be used to quantify the impact of higher speeds in energy savings calculations where appropriate and on how to extend this analysis in the NIA. DOE also requests stakeholder input on a possible

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[dd] Both EASA Standard AR100-2010 and the EASA/AEMT Rewind Study are available at http://www.easa.com

increase in installation costs when replacing a baseline efficiency electric motor with a more efficient electric motor with a lower slip, due to the necessary speed adjustments required.

2.8 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

In determining whether new or amended energy conservation standards would be economically justified, DOE must consider a number of factors, including the economic impact of potential standards on end-users. (42 U.S.C. § 6295(o)(2)(B)(i)) Chapter 8 describes the LCC analysis, which calculates the discounted savings in operating costs throughout the estimated average life of the covered equipment compared to any increase in the equipment's installed cost likely to result directly from the imposition of a standard. The effect of standards on individual customers includes a change in operating expense (usually a decrease) and a change in purchase price (usually an increase). DOE analyzed the net effect by calculating the change in LCC compared to the base case. Inputs to the LCC calculation include the installed customer cost (purchase price plus shipping, sales tax, and installation cost); operating expenses (energy and maintenance costs); lifetime of the equipment; and a discount rate.

In considering the economic impacts of standards, DOE calculates a PBP as well as changes in LCC that are likely to result from each CSL. Chapter 8 describes the PBP analysis, which calculates the amount of time needed to recover the additional cost that customers pay for increased efficiency. Numerically, the simple PBP is the ratio of the increase in purchase price to the decrease in annual energy costs.

2.8.1 Approach

In calculating both the LCC and the PBP, DOE used Monte Carlo simulation and probability distributions (described in appendix 8B) to model both the uncertainty and variability in inputs. Results are represented by distributions. Inputs to the LCC and PBP analysis are:

- electric motor application and sector,
- annual energy use,
- electric motor efficiency,
- electricity prices and price trends,
- operating hours,
- electric motor lifetime, and
- a discount rate.

These variables, and the interactions among them, are discussed further below.

In each Monte Carlo simulation, one application is identified by sampling a distribution of applications for each equipment class. The selected application determines the number of operating hours per year as well as the electric motor loading. DOE used the operating hours and electric motor loading for each application to estimate electric motor energy use. Because of the wide range of applications and electric motor use characteristics considered in the LCC and PBP analysis, the range in annual energy use is quite broad.

There is also a distribution of sectors (i.e., industry, agriculture, and commercial) associated with each application. The sector to which an application belongs determines the energy price and discount rate DOE used to calculate the LCC in each simulation.

Using a baseline distribution of equipment efficiencies for each representative unit, DOE assigned specific equipment efficiency to each unit. If an electric motor was assigned an equipment efficiency that was greater than or equal to the efficiency of the standard level under consideration, the LCC calculation showed that the electric motor unit would not be impacted by that standard level.

DOE collected technical data (e.g., technical specifications, efficiency level, weight) and price information on electric motors currently available for purchase by compiling major manufacturers and distributors' equipment catalogs in a single database and reviewing electric motor data available from MotorMaster+ 4.01.01 (an online NEMA Premium efficiency motor selection and management tool which includes a catalog of more than 20,000 low-voltage induction motors).[ee] The data collected corresponds to the latest catalog data available at the time when the information was collected (between March and May 2012).

DOE welcomes any inputs on alternative sources of information that DOE should consider to improve its knowledge of the current market and technical characteristics of electric motors, and efficiency distributions.

2.8.2 Electricity Prices

DOE derived sector-specific average electricity prices for four different U.S. Bureau of the Census (Census) regions (Northeast, Midwest, South, and West) using data from the Energy Information Administration (EIA Form 861). For each sector, DOE assigned electricity prices using a Monte Carlo approach that incorporated weightings based on the estimated share of electric motors in each region. The regional shares were derived based on indicators specific to each sector (e.g., for industry, the value of shipments by Census region from the Manufacturing Energy Consumption Survey [MECS]). To estimate future trends in energy prices, DOE used projections from the EIA's *Annual Energy Outlook 2011* (*AEO 2011*).

Baldor commented that DOE should account for electricity price variations and the distribution of electric motors across the United States. (Baldor, Public Meeting Transcript, No. 14 at pp. 195-196) In the LCC analysis, DOE accounted for the variability in electricity prices as

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[ee] MotorMaster+ is a free online National Electrical Manufacturers Association (NEMA) Premium® efficiency motor selection and management tool that supports motor and motor systems planning by identifying the most efficient action for a given repair or motor purchase decision. The tool includes a catalog of more than 20,000 low-voltage induction motors and features motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities. See http://www1.eere.energy.gov/industry/bestpractices/software_motormaster.html.

follows. DOE first derived an average electricity price for four different Census regions (Northeast, Midwest, South and West). For each end use sector, DOE assigned electricity prices using a Monte Carlo approach with weightings according to the estimated share of electric motors in each region. The regional shares were derived based on indicators specific to each sector (e.g., for the electric motor industry, DOE relied on the shipment values by Census region from the MECS).

2.8.3 Electric Motor Lifetime

DOE estimated the mechanical lifetime of electric motors in hours (i.e., the total number of hours an electric motor operates throughout its lifetime, including repairs, and routine maintenance) depending on its horsepower size. DOE then developed Weibull distributions of mechanical lifetimes. The lifetime in years for a sampled electric motor was then calculated by dividing the sampled mechanical lifetime by the sampled annual operating hours of the electric motor. This model produces a negative correlation between annual hours of operation and electric motor lifetime: electric motors operated many hours per year are likely to be retired sooner than electric motors that are used for only a few hundred hours per year. DOE considered that electric motors of less than 75 horsepower are most likely to be embedded in a piece of equipment (i.e., an application). For such applications DOE developed Weibull distributions of application lifetimes expressed in years, then compared the sampled motor mechanical lifetime (in years) with the sampled application lifetime. DOE assumed that the electric motor would be retired at the younger of the two ages.

2.8.4 Installation Costs

DOE found no evidence that installation costs would increase with higher electric motor energy efficiency. Thus, DOE did not incorporate changes in installation costs for electric motors that are more efficient than baseline equipment.

Several of the interested parties commented that DOE should consider that increasing the efficiency of an electric motor would change its mechanical configuration, specifically its diameter or length. (Nidec, Public Meeting Transcript, No. 14 at pp. 200-201; NEMA, No. 13 at p. 20) Nidec further commented that a change in the mechanical configuration would increase installation costs, compared to installing a baseline electric motor. (Nidec, Public Meeting Transcript, No. 14 at pp. 200-201) Baldor commented similarly, asserting that improving the efficiency of its electric motors would require an increase in stack length. In the case of steel band electric motors, additional stack length will increase frame length and the overall size of the electric motor. Baldor stated that, in the case of cast-iron frame electric motors, there is a fixed length of casting, and adding more stack to increase the electric motor's efficiency would require the electric motor to be built with a larger diameter frame. (Baldor, Public Meeting Transcript, No. 14 at pp. 202-203; Baldor, No. 8 at p. 7) WEG commented that the installation cost will remain the same, because the electric motors consist of the same mechanical package unless an incentive was made to the manufacturer to change that package. (WEG, No. 5 at p. 1)

In the engineering analysis, when the efficiency of the electric motors was increased, the electric motor frame remains in the same NEMA frame size requirements as the baseline electric motor. In addition, electric motor installation cost data from RS Means Electrical Cost Data

2010 show a variation in installation costs by horsepower (for three-phase electric motors), but not by efficiency. Therefore, in the preliminary analysis, DOE assumed there is no variation in installation costs between a baseline efficiency electric motor and a higher efficiency electric motor. DOE welcomes comments from interested parties on this issue.

2.8.5 Repair and Maintenance Costs

Nidec commented that repair and maintenance costs could increase with increasing electric motor efficiency, because of a more active material and the difficulty associated with filling the slot pieces to maintain the efficiency. (Nidec, Public Meeting Transcript, No. 14 at p. 201) For the preliminary analysis, DOE accounted for the differences in repair costs of a higher efficiency electric motor compared to a baseline efficiency electric motor, based on data from a price guide for electric motor repair published by the Vaughen's Price Publishing Company. For maintenance costs, DOE did not find data indicating a variation between a baseline efficiency and higher efficiency electric motor. According to Vaughen's, the price of replacing bearings, which is the most common maintenance practice, is the same at all efficiency levels.

2.8.6 Rebates and Incentives

One interested party, Baldor, commented that rebates and incentives from utilities should be included in the LCC calculation. (Baldor, Public Meeting Transcript, No. 14 at pp. 196-197) DOE did not include rebates and incentives in its LCC analysis, because the future prevalence and magnitude of such incentives is highly uncertain. DOE's analysis seeks to evaluate the cost-effectiveness of standards for customers, independent of any other programs that may affect the cost to customers.

2.9 SHIPMENTS ANALYSIS

An important component of any estimate of future impacts from energy conservation standards is equipment shipments (chapter 9). DOE uses projections of shipments for the base case and each potential standards case as inputs to the calculation of national energy savings (NES).

In order to develop shipment estimates for electric motors in the expanded scope by horsepower, DOE used data from a market research report[ff], inputs from interested parties, and interested parties' responses to the Request for Information (RFI) published in the Federal Register. 76 FR 17577 (March 30, 2011). DOE estimates total shipments in scope were 4.56 million units in 2011. DOE then used estimates of market distributions to redistribute the shipments across pole configurations and enclosures to provide shipment values for each electric motor equipment class and sector.

Nidec commented that imported equipment with an embedded electric motor should be

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[ff] IMS Research (February 2012), The World Market for Low Voltage Motors, 2012 Edition, Austin, TX.

counted in the shipments analysis. (Nidec, Public Meeting Transcript, No. 14 at p. 211). DOE's shipments data represent the sum of U.S. production and imports minus exports and include motors imported as part of larger equipment.

DOE's shipments projection assumes that electric motor sales are driven by machinery production growth for equipment including motors. DOE assumed that growth rates for motor shipments correlate to growth rates in fixed investment in equipment and structures[gg] including motors, as provided by the U.S. Bureau of Economic Analysis's (BEA)[hh]. Additional data on "real gross domestic product" (GDP) from *AEO 2011* for 2015–2035 was used to project fixed investments in the selected equipment and.

2.9.1 Repair Versus Replacement

Several of the interested parties commented that higher efficiency levels would increase the rate of repair and rewind, because the significant increase in new electric motor costs prompts users to delay the purchase of new, more efficient electric motors. These commenters added that changes in the physical or electrical characteristics of more efficient electric motors also contribute to an increase in rewind rates. (NEMA, No. 12 at pp. 1-3; NEMA, No. 13 at p. 22; ACEEE, Public Meeting Transcript, No. 14 at p. 95; Baldor, No. 8 at p. 7; UL, Public Meeting Transcript, No. 14 at p. 120)

DOE acknowledges that increased electric motor prices could affect the "repair vs. replace" decision and could lead to increasing the longevity of less efficient electric motors and decreased shipments. However, DOE did not find sufficient data to quantitatively estimate the impact of potential standard levels on shipments and therefore used a price elasticity equal to zero as a default. DOE welcomes recommendations on data sources to help better estimate the impacts of increased efficiency levels on shipments as well as inputs on how to quantitatively estimate these impacts.

Chapter 9 provides greater detail on the methods, data, and assumptions used for the shipments analysis.

2.10 NATIONAL IMPACT ANALYSIS

The national impact analysis (NIA; TSD chapter 10) assesses the aggregate impacts of potential efficiency standards at the national level. DOE determined the NES and NPV for the CSLs considered for the equipment classes analyzed. The NES and NPV impacts are the cumulative energy and economic effects of a standard for electric motor energy use. DOE

[gg] Heating, ventilation, and air conditioning (HVAC) equipment which incorporates motors is typically included in "structures" and not in equipment.

[hh] Bureau of Economic Analysis (March 01, 2012), Private *Fixed Investment in Equipment and Software and structure by Type*. http://www.bea.gov/iTable/iTable.cfm?ReqID=12&step=1

projected impacts from shipments in the 30-year projection period. The NIA includes impacts until all products shipped in the period are retired.

DOE analyzed energy savings, energy cost savings, equipment costs, and NPV of savings (or costs) for each CSL compared to a base case that reflects no amended or new standards. The national energy and cost savings (or increases) that would result from energy conservation standards depend on the projected energy savings per electric motor and the anticipated numbers of electric motors sold. DOE created projections of electric motor shipments in the base case that include the mix of efficiencies being sold at the time the standard would become effective. DOE then derived energy savings for various CSLs for all equipment classes using scaled cost-efficiency relationships from the engineering analysis.

DOE estimated the cumulative national energy consumption of motors shipped during the analysis period, 2015–2044. DOE calculated cumulative NES as the difference between cumulative national energy consumption in the base case (without new or amended energy conservation standards) and under each CSL. DOE estimated energy consumption and savings based on site energy (kilowatt-hours [kWh] of electricity), then converted those values to primary (source) energy using factors that account for losses in transmission, distribution, and electricity generation.

DOE has historically presented NES in terms of primary energy savings. DOE has recently published a Statement of Policy regarding its intent to incorporate full-fuel-cycle (FFC) metrics into its analyses, and outlining a proposed approach. DOE stated that it intends to calculate FFC energy and emission impacts by applying conversion factors generated by the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to the NEMS-based results currently used by DOE. 76 FR 51282 (Aug. 18, 2011). Additionally, DOE will review alternative approaches to estimating these factors and may decide to use a model other than GREET to estimate the FFC energy and emission impacts in any particular future appliance efficiency standards rulemaking. It also stated that DOE will review alternative approaches to estimating these factors and may decide to use a model other than GREET to estimate the FFC energy and emission impacts in any particular future appliance efficiency standards rulemaking. During this review process, DOE examined an approach to developing FFC multipliers using NEMS-BT. This approach is based on AEO projections of future fuel supply and other data that affect the calculations. The GREET model uses a different representation of the energy production system to develop its own internal forecasts, which differ from those in the Annual Energy Outlook. By using the FFC multipliers derived from NEMS-BT, DOE is able to ensure that the multipliers are consistent with the approach used to estimate primary energy savings and emissions impacts.

For this preliminary analysis, DOE calculated FFC energy savings using a NEMS-based methodology described in appendix 10-C. Chapter 10 of this TSD presents both the primary energy savings and the FFC energy savings for the considered candidate standard levels (CSLs).

2.11 CUSTOMER SUBGROUP ANALYSIS

In the NOPR phase of the rulemaking, DOE will evaluate the potential impacts of standards on customer subgroups, such as small businesses, to see whether potential energy conservation standards affect them differentially in a significant manner.

The analysis of subgroups of electric motor owners depends on identifying characteristics related to electric motor use or economics that sets a subgroup apart from other electric motor owners. DOE will analyze the effects on those groups by comparing the electric motor owners' capital and operating costs with and without an energy conservation standard. DOE will use LCC analysis methods for subgroup analysis by modifying cost assumptions to reflect the situations of each subgroup. Factors that could result in differential impacts to subgroups include differences in energy prices and electric motor usage.

2.12 PRELIMINARY MANUFACTURER IMPACT ANALYSIS

The purpose of the MIA is to identify the likely impacts of higher energy conservation standards on manufacturers. The Process Rule provides guidance for conducting this analysis with input from manufacturers and other interested parties.[ii] DOE will apply this methodology to its evaluation of amended standards for electric motors. The Process Rule gives guidelines for considering financial impacts and a wide range of quantitative and qualitative industry impacts that might occur after adoption of a standard. For example, a particular standard level could require changes to manufacturing practices of electric motors. DOE will identify and discuss these impacts in interviews with manufacturers and other interested parties during the NOPR stage of the analysis.

DOE will conduct the MIA in three phases, and will further tailor the analytical framework based on the comments it receives. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepares an industry cash-flow model and an interview questionnaire to guide subsequent discussions. In Phase III, DOE interviews manufacturers and assesses the impacts of amended standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash flow and NPV using the Government Regulatory Impact Model (GRIM). DOE then assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions.

In the past, DOE reported MIA results in its standards rulemakings only in the NOPR phase of the rulemaking. However, DOE is now evaluating and reporting preliminary MIA information at this preliminary analytical phase. DOE gathered the information for the analysis

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[ii] See appendix A to subpart C of 10 CFR Part 430--Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products.

during the manufacturer interviews conducted after the engineering analysis. See Chapter 12 of the preliminary TSD for more detail on the MIA.

ASAP and NEMA stated that the technical parameters to manufacture electric motors for higher efficiency levels can be very difficult or even impossible to implement. For example, the physical size of the electric motor housing cannot be increased in many applications. Also, mandating higher efficiency levels for Design B electric motors may cause the in-rush current to exceed the limits specified in NEMA MG1-2011 paragraph 12.35.1. ASAP and NEMA also commented that manufacturers would be required to use expensive materials in order to meet higher efficiency levels, resulting in increased costs to consumers. (ASAP and NEMA, No. 12 at pp. 2-3) DOE will take these design constraints into consideration when developing equipment and capital conversion costs at each efficiency level for the NOPR phase. DOE will also include the additional material costs at each efficiency level in its manufacturer production cost (MPC) calculations. Both of these costs are integral inputs to the Government Regulatory Impact Model (GRIM) that will be developed during the NOPR phase.

Baldor recommended that DOE attempt to interview and visit both domestic and non-domestic electric motor manufacturers, including some of the smaller foreign electric motor manufacturers, because a large number of electric motors are imported into the U.S. as stand-alone electric motors or included in other equipment. (Baldor, No. 8 at p. 6) DOE seeks to interview a representative cross-section of the electric motors industry and intends to contact manufacturers, including domestic, non-domestic, large, and small manufacturers that can provide a representative picture of the industry.

ASAP and NEMA also commented that forcing manufacturers to invest in small increases in electric motor efficiency above NEMA Premium levels would divert research and development resources from advanced electric motor technologies with better potential for energy savings. (ASAP and NEMA, No. 12 at p. 3) DOE recognizes that there is an opportunity cost associated with any investment and agrees that manufacturers would need to spend capital to meet any efficiency levels above the base case. As a result, manufacturers must determine the extent to which they will balance the investment in upgrading existing electric motors with the decision to invest in new equipment development. DOE will include the equipment and capital conversion costs necessary to meet potential standards in its NOPR analysis.

2.12.1 Sources of Information for the Manufacturer Impact Analysis

Several analyses provide important information applicable to the MIA. Such information includes manufacturing costs from the engineering analysis, shipment forecasts, and efficiency distributions. DOE will supplement this information with company financial data and other information gathered during interviews with manufacturers.

The interview process plays a key role in the MIA. DOE aggregates information across manufacturers, creating a combined opinion or estimate for DOE. DOE conducts detailed interviews with manufacturers to gain insight into the range of potential impacts of standards.

Typically, DOE solicits both quantitative and qualitative information during the interviews on the potential impacts of efficiency levels on sales, direct employment, capital assets, and industry competitiveness. DOE prefers an interactive interview process, rather than a written response to a questionnaire, because it helps clarify responses and identify additional issues. Before the interviews, DOE will circulate a draft document showing estimates of the financial parameters based on publicly available information. DOE will solicit comment on these estimates during the interviews. See chapter 12 of the preliminary TSD for more detail on the methodology used in the MIA.

2.12.1.1 Industry Cash-Flow Analysis

The industry cash-flow analysis relies primarily on the GRIM. DOE uses the GRIM to analyze the financial impacts of more stringent energy conservation standards on the industry.

The GRIM analysis uses several factors to determine annual cash flows from an amended energy conservation standard: annual expected revenues; manufacturer costs (including cost of goods sold, depreciation, research and development, selling, and general and administrative expenses); taxes; and conversion capital expenditures. DOE compares the results against base-case projections that involve no amended energy conservation standards. The financial impact of amended energy conservation standards is the difference between the two sets of discounted annual cash flows. Other performance metrics, such as return on invested capital, also are available from the GRIM. See chapter 12 of the preliminary TSD for more information on the industry cash-flow analysis.

2.12.2 Manufacturer Subgroup Analysis

Industry cost estimates are inadequate to assess differential impacts among subgroups of manufacturers because these subgroups may have different cost structures or regulatory frameworks that affect their respective business models. For example, small and niche manufacturers, or manufacturers whose cost structure differs significantly from the industry average, could experience a more negative impact. Ideally, DOE would consider the impact on every firm individually; however, because this usually is not possible, DOE typically uses the results of the industry characterization to group manufacturers exhibiting similar characteristics.

During the interview process, DOE will discuss the potential subgroups and subgroup members it has identified for the analysis. DOE will encourage manufacturers to recommend subgroups or characteristics that are appropriate for the subgroup analysis. See chapter 12 of the preliminary TSD for more detail on the manufacturer subgroup analysis.

2.12.3 Competitive Impacts Assessment

EPCA directs DOE to consider any lessening of competition likely to result from the imposition of standards. (42 U.S.C. § 6295(o)(2)(B)(i)(V)) It further directs the Attorney General to determine in writing the impacts, if any, of any lessening of competition. (42 U.S.C. § 6295(o)(2)(B)(ii))

DOE will make a determined effort to gather firm-specific financial information and impacts and report the aggregated impact of the amended standard on manufacturers. The competitive impacts analysis will focus on assessing the impacts on smaller manufacturers. DOE will base the assessment on manufacturing cost data and information collected from interviews with manufacturers. The manufacturer interviews will focus on gathering information that would help in assessing asymmetrical cost increases to some manufacturers, an increase in the proportion of fixed costs (with the potential to elevate business risk), and potential barriers to market entry (e.g., proprietary technologies). DOE will provide the Attorney General with a copy of the NOPR for consideration in his evaluation of the impact of standards on the lessening of competition. DOE will publish the Attorney General's letter and address any related comments in the final rule.

2.12.4 Cumulative Regulatory Burden

DOE recognizes and seeks to mitigate the overlapping effects on manufacturers of new or amended DOE standards and other regulatory actions affecting the same equipment. DOE will analyze and consider the impact on manufacturers of multiple, equipment-specific regulatory actions.

2.12.5 Preliminary Results for the Manufacturer Impact Analysis

One important aspect of the preliminary MIA is the opportunity it creates for DOE to identify key manufacturer issues early in the development of amended energy conservation standards. During preliminary interviews, manufacturers identified five major areas of concern: (1) core steel availability, (2) equipment conversion costs, (3) die cast copper rotors, (4) impacts on competition and domestic production, and (5) increase in equipment repair.

DOE requests comment on its identification of key issues and requests data and information from interested parties that can assist in evaluating the potential impact of amended standards on manufacturers.

2.12.5.1 Core Steel Availability

Manufacturers commented that there is a limited global supply for the types of core steel necessary to build higher efficiency electric motors, particularly high-grade lamination steel. This shortage of higher grade steel could be exacerbated if efficiency standards for other equipment require more widespread use of this steel, causing a sudden increase in demand.

DOE welcomes comment on the supply of core steels used in its designs. In particular, DOE seeks comment on the global and domestic supply of lower loss electrical steels such as M36, M19, and M15 as compared to the projected consumption based on candidate standard levels.

2.12.5.2 Equipment Conversion Costs

Some manufacturers publicly commented that certain technology options required to meet higher efficiency levels may require large capital investments. NEMA stated that a change in materials can have a significant impact on the manufacturing of electric motors, such as the safe handling of the materials, incoming material testing, new tooling, development of new manufacturing processes, and quality control procedures. (NEMA, No. 13 at p. 23) Baldor similarly stated that if high efficiency standards are set, extensive changes in tooling and manufacturing will be required before any energy savings can be realized. (Baldor, No. 8 at p. 2) DOE intends to include all relevant conversion costs driven by standards during the NOPR phase.

During interviews, manufacturers voiced concern about the potential for assets to be stranded due to higher energy conservation standards. For every new capital investment made by manufacturers, some portion of the manufacturers' existing equipment for core production would be stranded. Additionally, manufacturers indicated that there are often very long lead times for obtaining advanced machinery. Specifically, manufacturers estimated that it would take two years for installation of new machinery to be completed after the purchase request is made for some of these capital investments.

2.12.5.3 Copper Die-cast rotors

Manufacturers commented on the impracticability of die-casting copper rotors. Namely, they were concerned with the rising cost of copper, the health hazards of die casting copper, and the difficulty of purchasing copper die casting equipment. Several manufacturers noted that copper die-casting equipment cannot be purchased; instead, copper die-casting companies require manufacturers to contract out this procedure.

Additionally, Baldor commented that they are concerned about the increased level of carbon emissions and energy consumption at their manufacturing facilities due to die-cast copper rotors as well as the increased cost of medical liability under the upcoming health insurance laws. (Baldor, No. 8 at p. 7) DOE is aware of the higher cost of die-cast copper rotors and seeks data showing the relative increase in energy and carbon emissions from die-casting copper. Additionally, DOE seeks data showing potential health insurance cost increases resulting from the use of copper die-casting equipment.

2.12.5.4 Impacts on Competition and Domestic Production

Some manufacturers commented that their competitive ability would decrease with the implementation of amended energy conservation standards. Baldor stated that hand-winding of electric motors will decrease their competitiveness in the global market due to increased labor costs. (Baldor, No. 8 at p. 8) During interviews, manufacturers stated that companies with domestic production already face difficulty competing with companies who manufacture in lower-labor-cost countries, and any standard that requires additional labor will be detrimental to American manufacturing plants. ASAP and NEMA stated that some domestic electric motor manufacturers may elect to exit portions of the market rather than make the necessary investments to meet higher efficiency levels. (ASAP and NEMA, No. 12 at p. 3) Baldor similarly commented that increasing efficiency standards has the potential to drive some manufacturers out of the market for low-volume electric motor designs or to shift manufacturing to locations outside the U.S. (Baldor, No. 8 at p. 2)

DOE will analyze the potential impacts of standards on competition and domestic employment during the NOPR phase and will take these concerns into account.

2.12.5.5 Increase in Equipment Repair

ASAP and NEMA stated that if standards were implemented at high efficiency levels, the increased cost of obtaining compliant electric motors or the change in physical or electrical characteristics could cause customers to rebuild or repair existing electric motors that are less efficient rather than replace them with new efficient electric motors. This could result in a significant lost opportunity for energy savings, particularly because repairing or rewinding an electric motor may not return that electric motor to its previous efficiency. (ASAP and NEMA, No. 12 at p. 3)

Notwithstanding, DOE understands that current repair and rewind practices set forth in the American National Standards Institute/Electrical Apparatus Service Association (ANSI/EASA) publication AR100-2010: "Recommended Practice for the Repair of Rotating Electrical Apparatus," September 2010, and the EASA/Association of Electrical and Mechanical Trades publication "The Effect of Repair/Rewinding on Motor Efficiency," have greatly improved the rewind and repair process for electric motors, and provide the potential for no loss of efficiency after a motor is rewound or repaired.

DOE will take both of the above into consideration as it conducts its analyses for the NOPR, including the shipment projections.

2.13 UTILITY IMPACT ANALYSIS

The utility impact analysis estimates specific effects of new or amended energy conservation standards on the electric utility industry. For this analysis, DOE adapted the National Energy Modeling System (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 *Annual Energy Outlook* (*AEO*). NEMS, which is available in the public domain, produces a widely recognized baseline energy forecast for the United States through 2035.The typical NEMS outputs include forecasts of electricity sales, prices, and electric generating capacity. 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.

DOE typically 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 projections that deviate from the *AEO* reference case.

2.14 EMPLOYMENT IMPACT ANALYSIS

Standards can affect employment both directly and indirectly. Direct employment impacts are changes in the number of employees at plants that produce the covered equipment and at affiliated distribution and service companies as a result of the new standards. DOE evaluates direct employment impacts in the manufacturer impact analysis. Indirect employment impacts that occur because of the imposition of standards may result from customers shifting expenditures between goods (the substitution effect) and from changes in income and overall expenditure levels (the income effect).

DOE plans to utilize Pacific Northwest National Laboratory's impact of sector energy technologies (ImSET) model to investigate the indirect employment impacts of potential standards. The ImSET model, which was developed for DOE's Office of Planning, Budget, and Analysis, estimates the employment and income effects energy-saving technologies produce in buildings, industry, and transportation. Compared with simple economic multiplier approaches, ImSET allows for a more complete and automated analysis of the economic impacts of energy conservation investments.

2.15 EMISSIONS ANALYSIS

In the emissions analysis, DOE will estimate the reduction in power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), and mercury (Hg) using the NEMS-BT computer model. In the emissions analysis, NEMS-BT is run similarly to the *AEO* NEMS, except that electric motors energy use is reduced by the amount of energy saved (by fuel type) due to each standard level considered. The inputs of national energy savings come from the NIA spreadsheet model, while the output is the forecasted physical emissions. The net benefit of each considered standard level is the difference between the forecasted emissions estimated by NEMS-BT at that level and the latest *AEO* Reference Case.

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

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs, and DOE has preliminarily determined that these programs create uncertainty about the potential standards' impact on SO_2 emissions. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. are also limited under the Clean Air Interstate Rule (CAIR, 70 Fed. Reg. 25162 (May 12, 2005)), which created an allowance-based trading program. 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, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution

Rule. 76 FR 48208 (August 8, 2011). (See http://www.epa.gov/crossstaterule/). On December 30, 2011, however, the D.C. Circuit stayed the new rules while a panel of judges reviews them, and told EPA to continue enforcing CAIR (see *EME Homer City Generation v. EPA*, No. 11-1302, Order at *2 (D.C. Cir. Dec. 30, 2011)).

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. DOE acknowledges, however, that even though there is a cap on SO_2 emissions and uncertainty whether efficiency standards would reduce SO_2 emissions, it is possible that standards could reduce the compliance cost by reducing demand for SO_2 allowances.

2.15.3 Nitrogen Oxides

Under CAIR, there is a cap on NO_x emissions in 28 eastern states and the District of Columbia. All these States and the District of Columbia (DC) have elected to reduce their NOx emissions by participating in cap-and-trade programs for EGUs. Therefore, energy conservation standards for electric motors may have little or no physical effect on these emissions in the 28 eastern states and the DC for the same reasons that they may have little or no physical effect on NO_X emissions. DOE will use the NEMS-BT to estimate NO_x emissions reductions from possible standards in the States where emissions are not capped.

2.15.4 Mercury

On February 16, 2012, EPA announced national emissions standards for hazardous air pollutants (NESHAPs) for mercury and certain other pollutants emitted from coal and oil-fired EGUs. 76 FR 24976. The NESHAPs do not include a trading program and, as such, DOE's energy conservation standards would likely reduce Hg emissions. For the emissions analysis for this rulemaking, DOE plans to estimate mercury emissions reductions using NEMS-BT based on *AEO*, which does not incorporate the NESHAPs. DOE expects that future versions of the NEMS-BT model will reflect the implementation of the NESHAPs.

2.15.5 Particulate Matter

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 smokestack. 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, which are now largely regulated by cap and trade systems.

One stakeholder, Baldor, commented that the change in electric motor manufacturing equipment associated with increasing efficiency—specifically the use of copper rotors, retooling, and a higher level of steel—would cause extra processing to be performed and would increase energy use, potentially increasing air emissions. (Baldor, Public Meeting Transcript, No. 14 at pp. 232-233) In response, DOE notes that EPCA directs DOE to consider the total projected amount of energy, or as applicable, water, savings likely to result directly from the imposition of the standard when determining whether a standard is economically justified. (42 U.S.C. 6295(o)(2)(B)(i)(III)) DOE interprets this to include energy used in the generation, transmission, and distribution of fuels used by appliances or equipment. In addition, DOE is evaluating the full-fuel-cycle measure, which includes the energy consumed in extracting, processing, and transporting primary fuels. DOE's current accounting of primary energy savings and the full-fuel-cycle measure are directly linked to the energy used by appliances or equipment. DOE believes that energy used in manufacturing of appliances or equipment falls outside the boundaries of "directly" as intended by EPCA. Thus, DOE did not consider such energy use and air emissions in the NIA and in the emissions analysis.

2.16 MONETIZATION OF EMISSIONS REDUCTION BENEFITS

DOE will consider the estimated monetary benefits likely to result from the reduced emissions of CO_2 and NO_X that are expected to result from each of the standard levels considered.

In order to estimate the monetary value of benefits resulting from reduced emissions of CO_2, DOE plans to use the most current Social Cost of Carbon (SCC) values developed and/or agreed to by an interagency process. 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 2011, expressed in 2011$, were $5.0, $22.5, $37.0, and $68.4 per metric ton avoided. 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 CO_2 emissions. To calculate a present value of the stream of monetary values, DOE will discount 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 intends to estimate 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 $455 to $4,679 per ton in 2011$).[jj] 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.[kk]

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.

2.17 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE will prepare 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 under the Executive Order by the Office of Information and Regulatory Affairs at the OMB. The RIA addresses the potential for nonregulatory approaches to supplant or augment energy conservation standards in order to improve the energy efficiency or reduce the energy consumption of the equipment covered under this proposed rulemaking.

DOE recognizes that voluntary or other nonregulatory efforts by manufacturers, utilities, and other interested parties can substantially affect energy efficiency or reduce energy

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[jj] 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.

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

consumption. DOE plans to base its regulatory impact assessment on the actual impacts of any such initiatives to date, but also will consider, to the extent possible, information presented by interested parties regarding the impacts current initiatives might have in the future. (See chapter 17 of the preliminary TSD)

REFERENCES

1. Energy Information Administration - Office of Integrated Analysis and Forecasting *The National Energy Modeling System*. (U.S. Department of Energy: Washington DC, 2009).at <http://www.eia.doe.gov/oiaf/aeo/overview/>

2. U.S. Department of Energy-Energy Information Administration 1992 Commercial Buildings Energy Consumption Survey (CBECS). (1992).at <http://www.eia.doe.gov/emeu/cbecs/92microdat.html>

3. U.S. Department of Energy-Energy Information Administration 1995 Commercial Building Energy Consumption and Expenditures (CBECS). (1995).at <http://www.eia.gov/emeu/cbecs/microdat.html>

4. U.S. Department of Energy – Office of Energy Efficiency and Renewable Energy Appendix 8E. Technical Aspects of The Tariff-Based Approach For Room Air Conditioner Energy Price. *Residential Clothes Dryers and Room Air Conditioners Preliminary Technical Support Document* (2010).at <http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/clothesdryers_tsd/clothesdryers_roomac_preanalysis_app8e.pdf>

5. Office of Energy Efficiency and Renewable Energy *Energy Conservation Program for Commercial and Industrial Equipment: Energy Conservation Standards for Electric motors; Final Rule*. *10 CFR Part 431* (2007).

6. U.S. Department of Energy-Office of Building Technologies Chapter 11. Life-Cycle Cost Subgroup Analysis. *Electric motors Energy Conservation Standard Technical Support Document* (2007).

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter provides a profile of the electric motor industry in the United States. The U.S. Department of Energy (DOE) developed the preliminary market and technology assessment presented in this chapter primarily from publicly available information. This assessment is helpful in identifying the major manufacturers and their equipment characteristics, which form the basis for the engineering and life-cycle cost (LCC) analyses.

This chapter consists of two sections: the market assessment and the technology assessment. The market assessment provides an overall picture of the market for the equipment concerned, including a scope of the equipment covered, equipment classes, industry structure, manufacturer market shares; regulatory and non-regulatory efficiency improvement programs; and market trends and quantities of equipment sold. The technology assessment identifies a preliminary list of technology options for reducing motor losses to consider in the screening analysis.

The information DOE gathers for the market and technology assessment serves as resource material for use throughout the rulemaking. DOE considers both quantitative and qualitative information from publicly available sources and interested parties.

3.2 MARKET ASSESSMENT

This section addresses the scope of the rulemaking, identifies potential equipment classes, estimates national shipments of electric motors, and the market shares of electric motor manufacturers. This section also discusses the application and performance of existing equipment and regulatory and non-regulatory programs that apply to electric motors.

3.2.1 Electric Motor Definitions

The Energy Policy and Conservation Act (EPCA), as amended by the Energy Policy Act of 1992 (EPACT 1992), had previously established a definition for “electric motor” as “any motor which is a general purpose T-frame, single-speed, foot-mounting, polyphase squirrel-cage induction motor of the National Electrical Manufacturers Association (NEMA]) Design A and B, continuous rated, operating on 230/460 volts and constant 60 Hertz line power as defined in NEMA Standards Publication MG1–1987.” (42 U.S.C. 6311(13)(A) (1992)) Through subsequent amendments to EPCA and, in particular, the Energy Independence and Security Act that was signed into law on December 19, 2007 (EISA 2007), Congress struck the EPACT 1992 definition and replaced it with language that covered a broader scope of general purpose electric motors, (See 42 U.S.C. 6311(13)(A)-(B) (2010)).

Consequently, the new terminology adopted as a result of EISA 2007 generated confusion over the definitions of the terms “electric motor” and “general purpose electric motor.” As a result, DOE sought to clarify its interpretations of these definitions in a rulemaking about test procedures for electric motors. On May 4, 2012, DOE published in the *Federal Register* a test procedure final rule for electric motors which clarified the two definitions. 77 FR 26608 A regulatory definition of “electric motor” was promulgated in light of EISA 2007’s removal of the statutory definition of “electric motor.” The definition of “general purpose motor” (now “general purpose electric motor”) was taken directly from the industry standard NEMA MG1-1993 and was intended to specify a broad category of motors that were potentially subject to regulation. The term “electric motor” enumerated specific construction and performance characteristics required for a “general purpose motor” to be covered equipment under Title 10 of the Code of Federal Regulations, Part 431 (10 CFR Part 431).

The test procedure was intended to clear up confusion over the definitions of “electric motor” and “general purpose electric motor.” The test procedure final rule defined the two terms as follows:

“Electric motor means a machine that converts electrical power into rotational mechanical power.”

and

“General purpose electric motor means any electric motor that is designed in standard ratings with either:

(1) Standard operating characteristics and mechanical construction for use under usual service conditions, such as those specified in NEMA MG1–2009, paragraph 14.2, “Usual Service Conditions,” (incorporated by reference, see § 431.15) and without restriction to a particular application or type of application; or

(2) Standard operating characteristics or standard mechanical construction for use under unusual service conditions, such as those specified in NEMA MG1–2009, paragraph 14.3, “Unusual Service Conditions,” (incorporated by reference, see § 431.15) or for a particular type of application, and which can be used in most general purpose applications.”

EISA 2007 also introduced and established energy conservation standards for several new categories of electric motors. As such, the test procedure final rule sought to clarify DOE’s interpretation of these terms. Ultimately, DOE created new definitions for the terms “general purpose electric motor (subtype I),” “general purpose electric motor (subtype II),” “NEMA Design B motor,” and “fire pump electric motor,” which are shown below.

As a result of the recent electric motors test procedure final rule, 10 CFR 431.12 now defines a general purpose electric motor (subtype I) as a general purpose electric motor that:

(1) Is a single-speed, induction motor;
(2) Is rated for continuous duty (MG1) operation or for duty type S1 (IEC);
(3) Contains a squirrel-cage (MG1) or cage (IEC) rotor;
(4) Has foot-mounting that may include foot-mounting with flanges or detachable feet;

(5) Is built in accordance with NEMA T-frame dimensions or their IEC metric equivalents, including a frame size that is between two consecutive NEMA frame sizes or their IEC metric equivalents;
(6) Has performance in accordance with NEMA Design A (MG1) or B (MG1) characteristics or equivalent designs such as IEC Design N (IEC);
(7) Operates on polyphase alternating current 60-hertz sinusoidal power, and:
(i) Is rated at 230 or 460 volts (or both) including motors rated at multiple voltages that include 230 or 460 volts(or both), or
(ii) Can be operated on 230 or 460 volts (or both); and
(8) Includes, but is not limited to, explosion-proof construction.

Further, the recent electric motors test procedure final rule amended 10 CFR 431.12, which now defines a general purpose electric motor (subtype II) as any general purpose electric motor that incorporates design elements of a general purpose electric motor (subtype I) but, unlike a general purpose electric motor (subtype I), is configured in one or more of the following ways:

(1) Is built in accordance with NEMA U-frame dimensions as described in NEMA MG1–1967 (incorporated by reference, see § 431.15) or in accordance with the IEC metric equivalents, including a frame size that is between two consecutive NEMA frame sizes or their IEC metric equivalents;
(2) Has performance in accordance with NEMA Design C characteristics as described in MG1 or an equivalent IEC design(s) such as IEC Design H;
(3) Is a close-coupled pump motor;
(4) Is a footless motor;
(5) Is a vertical solid shaft normal thrust motor (as tested in a horizontal configuration) built and designed in a manner consistent with MG1;
(6) Is an eight-pole motor (900 rpm); or
(7) Is a polyphase motor with a voltage rating of not more than 600 volts, is not rated at 230 or 460 volts (or both), and cannot be operated on 230 or 460 volts (or both).

Also, as a result of the electric motors test procedure final rule, 10 CFR 431.12 defines a NEMA Design B motor as a squirrel-cage motor that is:

(1) Designed to withstand full-voltage starting;
(2) Develops locked-rotor, breakdown, and pull-up torques adequate for general application as specified in sections 12.38, 12.39 and 12.40 of NEMA MG1– 2009 (incorporated by reference, see § 431.15);
(3) Draws locked-rotor current not to exceed the values shown in section 12.35.1 for 60 hertz and 12.35.2 for 50 hertz of NEMA MG1–2009; and
(4) Has a slip at rated load of less than 5 percent for motors with fewer than 10 poles.

Finally, the electric motors test procedure final rule, amended 10 CFR 431.12 by defining a fire pump electric motor in the following manner:

Fire pump electric motor means an electric motor, including any IEC-equivalent, that meets the requirements of section 9.5 of NFPA 20 (incorporated by reference, see § 431.15).

3.2.1.1 Expanded Scope Definitions

DOE's expanded scope of coverage requires clarifying the terminology related to a number of motor types and, in particular which types of motors would be subject to energy conservation standards and which types would not be subject to minimum standards. NEMA MG1-2011 contains defining language for some of these electric motor types. Where possible, DOE used this language from NEMA MG1–2011 to build potential definitions for some motor types, such as "encapsulated electric motor" as well as NEMA Design A and C electric motors. However, some of the motor types that DOE plans on subjecting to energy conservation standards, such as "partial electric motor" or "air-over electric motor," are not defined in NEMA MG1–2011. Additionally, DOE is not aware of standard, industry-accepted definitions for many of these motor types and will look to create them in a test procedure rulemaking that is being developed in parallel with this motor standards rulemaking. DOE believes the lack of clearly defined, standard motor definitions could cause confusion concerning which motor types are subject to efficiency regulations. Therefore, DOE has worked with industry experts in an effort to create working definitions for various motor types that DOE plans on including in the expansion of energy conservation standards. DOE also looks to create definitions for motor types that are specifically called out from being covered under energy conservation standards. A more in-depth discussion of these motor types, as well as reasons for DOE including or excluding them in the expanded scope of energy conservation standards, are discussed in more detail in chapter 2 of the preliminary technical support document (TSD). Below, DOE presents a short summary of the motor characteristics and the definitions it is considering for each motor type.

Air-Over Electric Motors

Air-over electric motors require an external, separate means of cooling to allow continuous duty operation. These motors are subject to over-heating and therefore cannot run continuously without a specified amount of air flowing over the motor housing, which is typically specified by the manufacturer.

DOE may consider proposing to include a definition for "air-over electric motor" based on the MG1–2011 paragraph 1.26.9 definition of a "totally enclosed air-over machine" with modifications to the definition to also include air-over electric motors with an open-frame construction. DOE wishes to make this change in an effort to broaden the scope of the NEMA MG1–2011 definition to include air-over electric motors with both totally enclosed and open-frame constructions. DOE believes both frame constructions of these motor types use the same methods for heat dissipation and therefore looks to define them under the same term. DOE is considering the following definition for "air-over electric motor:"

> *Air-over electric motor* means an electric motor designed for cooling by a ventilating means external to and not supplied with the motor.

Electric Motors with Brake Components

Brake motors are motors with a braking mechanism either attached to an exterior shaft or built inside the motor enclosure. The brake mechanism is typically mounted on the end opposite the drive of the motor. The braking system is typically an electrically released, spring-loaded mechanism. The brake component is "energized" during normal operation of the motor. During this normal operation, the brake component is not touching or interfering with the motor operation, but is drawing power from the same source as the electric motor. When an emergency situation arises, power is cut off from the brake component, and the brake "clamps" down on the motor shaft to quickly stop rotation of the motor.

DOE may consider proposing definitions for two terms to describe motors with brake components: "non-integral brake motors" and "integral brake motors." A "non-integral brake motor" consists of a brake mounted to the motor in such a fashion that the brake component is typically bolted onto the outside of the fan cover of the motor and could be removed from the motor with minimal disassembly and the motor could operate as a general purpose electric motor. An "integral brake motor" consists of a factory-built unified assembly typically built either inside the endshield of the motor or in between the motor fan and rotor component. With "integral brake motors," the brake component is difficult to remove, and doing so could require disassembly of the motor which may adversely affect its performance.

DOE is considering the following definitions for "non-integral brake motor" and "integral brake motor" based on comments and feedback from industry experts and NEMA. DOE is using comments and feedback to define these motor types because there is no definition for these motor types in MG1–2011. DOE plans to adopt the following definitions:

> *Integral brake motor* means an electric motor containing a brake mechanism either inside of the motor endshield or between the motor fan and endshield such that removal of the brake component would require extensive disassembly of the motor or motor parts.
>
> *Non-integral brake motor* means an electric motor containing a brake mechanism attached externally in such a manner that it could be readily detached from the motor without extensive disassembly of the motor or motor components.

Component Sets

Component sets of electric motors are comprised of a combination of motor parts, such as a stator, rotor, shaft, stator housing, shaft bearings, endshields, or other electric motor parts. DOE delineated between component sets and partial motors in chapter 2 of the preliminary TSD when it called out partial motors as motors only missing one or more endshields. Endshields are the circular, metal plates on each end of the motor that enclose the ends of the motor and house the shaft bearings and possibly other components. Component sets are typically sold to be turned into complete electric motors or installed in equipment by the end-user.

DOE is considering the following definition of "component sets" of electric motors based on comments gathered from subject matter experts (SME), NEMA, and other industry experts. DOE is taking this approach because there is no definition for these motor types in MG1–2011.

> *Component set* means a combination of motor parts that require more than the addition of two endshields to create an operable motor. These parts may consist of any combination of a stator frame, wound stator, rotor, shaft, or endshields.

Motors with Customer Defined Endshields

Motors may have special or customer-defined endshields, flanges, bases, or mounting feet that do not conform to NEMA MG1–2011 standards for typical endshields, flanges, bases, or mounting feet dimensions. DOE may consider proposing a definition for motor types with "customer-defined endshields" that are based on comments and feedback from industry experts and NEMA. DOE bases this definition on electric motors that deviate from the standard endshield or flange mounting specifications for Type C face-mounting, Type D flange-mounting, or Type P flange-mounting types specified in NEMA MG1-2011, paragraphs 1.63.1, 1.63.2, and 1.63.3 respectively. DOE is taking this approach because there is no definition for these motor types in MG1–2011. DOE is considering the following definition for electric motors with customer defined endshields:

> A motor with *customer defined endshields* means an electric motor with customized flanges which do not conform to NEMA MG1–2011 paragraphs 1.63.1, 1.63.2, or 1.63.3.

Encapsulated Electric Motors

Encapsulated motors have special insulation protecting the stator winding from condensation, moisture, dirt, and debris. This insulation typically consists of a special material coating that completely seals off the stator's copper windings. Encapsulation is generally found on open-frame motors, such as open drip-proof (ODP) motors, where the possibility of contaminants getting inside the motor is higher than on an enclosed-frame motor, such as a totally enclosed, fan cooled (TEFC) motor.

DOE may consider proposing a definition for "encapsulated electric motors" based on the definition of "machine with sealed windings" in paragraph 1.27.2 from NEMA MG1–2011. DOE is considering the following definition for electric motors with encapsulated stator windings:

> *Encapsulated electric motor* means an electric motor that has an insulation system which, through the use of materials, processes, or a combination of materials and processes, results in windings and connections that are sealed against contaminants. This type of machine is intended for environmental conditions and shall be capable of passing the conformance test in NEMA MG1–2011 paragraph 12.62.

IEC Design N Electric Motors

IEC Design N electric motors are similar to NEMA Design B electric motors with regards to locked-rotor limits and torque performance requirements. While IEC Design N motors are currently subject to energy conservation standards, DOE is looking to add a definition for them in order to clarifying any coverage-ambiguity.

DOE may consider proposing to set a definition for "IEC Design N electric motor" that would incorporate language from IEC Standard 60034-12 (2007 Ed. 2.1) with some modifications that would make the definition more comprehensive. The IEC Standard 60034-12 (2007 Ed. 2.1) defines IEC Design N motors as "normal starting torque three-phase cage induction motors intended for direct-on-line starting, having 2, 4, 6 or 8 poles and rated from 0,4 kW to 1,600 kW," with torque characteristics and locked-rotor characteristics described in later tables. DOE looks to modify this definition to include all references to tables for torque characteristics and locked-rotor characteristics tables to clarify the performance requirements of IEC Design N electric motors in the definition. DOE is considering the following definition for IEC Design N motors:

> *IEC design N electric motor* means an electric motor with a three-phase cage induction motor intended for direct-on-line starting, having 2, 4, 6, or 8 poles, rated from 0.4 kW to 1,600 kW and conforming to the IEC 60034-12 edition 2.1 torque characteristics found in section 6.1, locked rotor apparent power in section 6.2, and starting requirements in section 6.3.

Immersible Electric Motors

Immersible motors are motors capable of being submerged and removed from liquid without damaging or destroying the motor. Immersible motors are different than submersible motors because they are not designed to run while submerged in liquid. DOE understands that immersible motors do not rely on the cooling provided by submersion in liquid to operate continuously. DOE is also aware that industry sometimes interchanges the use of the two terms "immersible" and "submersible." Because of the potential confusion of the two terms, DOE believes it may be appropriate to provide definitions for both immersible and submersible electric motor types.

The definition DOE is considering for "immersible electric motor" is based on comments and feedback from industry experts and NEMA. DOE may consider proposing a definition for this motor type in an effort to provide clarification concerning electric motor types that may be subject to efficiency regulation and those that are exempt. The definition DOE is considering for this motor type is:

> *Immersible electric motor* means an electric motor designed to withstand complete immersion in liquid for a limited amount of time.

Inverter-Capable Electric Motors

An inverter is a device used to control the speed or torque characteristics of a motor. Inverters may also be referred to as inverter drives, drives, variable speed drives, variable frequency drives, adjustable frequency drives, alternating current (AC) drives, or microdrives. Inverters serve as special electronic controllers to help manipulate the power source of a motor. Inverters are used to slow the rotation of a motor or provide a constant torque output of the motor. Motors that can operate on an inverter may require special construction or design changes to withstand the abnormally harsh operating conditions an inverter may subject a motor to, such as increased operating temperatures or increased harmonic distortion of the motor's power supply. Inverters are considered by DOE as part of an "advanced motor system" and are discussed in more detail in chapter 2 of the preliminary TSD.

Manufacturer catalogs refer to motors capable of being run on an inverter as "inverter duty." However, DOE understands there are two distinct types of motors that may be referred to as "inverter duty" in the motor industry. The first type is a motor that has the ability to be run on an inverter drive, but can also run continuously when connected directly to a polyphase, sinusoidal line power source (i.e., it can be run continuously without an inverter). DOE plans to refer to this type of motor as an "inverter-capable" motor because it is capable of withstanding inverter duty operation, but the motor does not necessitate an inverter for continuous-duty operation. The second type of motor that the motor industry may refer to as "inverter duty" is a motor that cannot operate continuously without the use of an inverter. This motor type is discussed under the title "inverter-only electric motor" section below.

DOE wishes to create a clear understanding of each of these two motor types because it understands that there is no industry accepted definitions delineating between motors capable of running continuously on an inverter and motors that can only be run continuously on an inverter. DOE is considering creating a clear, succinct definition for this motor type in an effort to clarify which motor types may be subject to energy conservation standards. The definition DOE is considering for "inverter-capable electric motor" is based on feedback and comments from industry experts, SMEs, and NEMA and reads:

> *Inverter-capable electric motor* means an electric motor that can run continuously when directly connected to polyphase, sinusoidal line power, but is also capable of handling continuous operation on an inverter drive.

Inverter-Only Electric Motors

The section above mentions the two types of electric motors capable of being run on an inverter. The first type DOE refers to as an 'inverter-capable' electric motor. The second type of motor often referred to as "inverter duty" is a motor that cannot operate continuously without an inverter drive. This motor may have heavy insulation or other design changes to deal with operating conditions resulting from inverter operation, such as harmonic distortion of the power signal, dielectric stresses resulting from voltage spikes, or hotter-than-typical operating temperatures resulting from insufficient air cooling. This motor, unlike an "inverter capable" motor, is specifically built for the conditions resulting from inverter-fed operation, and are therefore generally more expensive to build than an "inverter capable" motor. This second motor type cannot be used for continuous duty operation on line power without an inverter. DOE plans to refer to this second type of motor as an "inverter-only electric motor" because it is specifically built to only operate continuously when operated on an inverter.

The definition DOE is considering for "inverter-only electric motor" is based on feedback and comments from industry experts, SMEs, and NEMA. As discussed above, DOE looks to create a clear, succinct definition for this motor type in an effort to clarify which electric motor types may be subject to energy conservation standards. The definition DOE plans on proposing for "inverter-only electric motor" is:

> *Inverter-only electric motor* means an electric motor designed such that it can only be run continuously when operated through an inverter drive.

Liquid-Cooled Electric Motors

Liquid-cooled electric motors rely on a special cooling apparatus that pumps liquid into and around the motor frame. The liquid is circulated around the motor to dissipate heat and prevent the motor from overheating during continuous duty operation. The user of a liquid-cooled motor may employ different liquids or liquid temperatures which could affect the measured efficiency of a motor.

DOE is considering defining "liquid-cooled electric motor" based on the definition of "totally enclosed water-cooled machine" in paragraph 1.26.5 of MG1–2011, with some changes. DOE is proposing to remove "totally enclosed" from the definition so that open-frame motors that are liquid-cooled would also be included in this definition. DOE also plans on replacing the term "water" with "liquid" to include motor types that may use other types of liquids, not just water, as a coolant. DOE is considering the following definition for "liquid-cooled electric motor":

> *Liquid-cooled electric motor* means an electric motor that is cooled by circulating liquid, with the liquid or liquid conductors coming in direct contact with the machine parts.

NEMA Design A Electric Motors

NEMA MG1–2011 defines four types of polyphase, AC induction motors, NEMA design types A, B, C, and D. As stated above, DOE has already adopted a definition for NEMA Design B electric motors. NEMA MG1–2011 establishes the same torque requirements for both NEMA Design A and NEMA Design B electric motors. However, NEMA Design B electric motors must be designed such that their locked-rotor (or starting) current is less than that established for NEMA Design A electric motors. Unless the application specifically requires a NEMA Design A electric motor design, NEMA Design B electric motors are often used instead of Design A electric motors because of the smaller spike in startup current.

DOE is considering defining “NEMA Design A electric motor” based on the definition found in NEMA MG1–2011 paragraph 1.19.1.1. DOE believes that the MG1–2011 definition of “NEMA Design A” electric motor is clear and concise and may consider proposing to define this term as:

> *NEMA design A electric motor* means a squirrel-cage motor designed to withstand full-voltage starting and developing locked-rotor torque as shown in NEMA MG1–2011 paragraph 12.38, pull-up torque as shown in NEMA MG1–2011 paragraph 12.40, breakdown torque as shown in NEMA MG1–2011 paragraph 12.39, with locked-rotor current higher than the values shown in paragraph 12.35.1 for 60 hertz and paragraph 12.35.2 for 50 hertz and having a slip at rated load of less than 5 percent for motors fewer than 10 poles.

NEMA Design C Electric Motors

Similarly, NEMA MG1-2011also establishes different torque requirements for NEMA Design C electric motors relative to NEMA Design A and B motors. NEMA Design C motors are typically used for applications that require high starting-torque applications, such as rock crushers or other crushing applications. DOE has placed NEMA Design C motors in their own equipment class group for the preliminary analysis. Therefore, DOE believes adopting a formal definition would be consistent with its potential adoption of NEMA Design B and NEMA Design A electric motor definitions.

DOE is considering a definition of “NEMA Design C electric motor” based on the definition found in NEMA MG1–2011 paragraph 1.19.1.3. DOE believes that the MG1–2011 definition of “NEMA Design C” electric motor is clear and concise and plans to propose to define this term as:

> *NEMA Design C electric motor* means a squirrel-cage motor designed to withstand full-voltage starting, developing locked-rotor torque for high-torque applications up to the values shown in NEMA MG1–2011 paragraph 12.38, pull-up torque as shown in NEMA MG1–2011 paragraph 12.40, breakdown torque up to the values shown in NEMA MG1–2011 paragraph 12.39, with locked-rotor current not to exceed the values shown in paragraph 12.35.1 for 60 hertz and paragraph 12.35.2 for 50 hertz, and having a slip at rated load of less than 5.

Partial Electric Motors

DOE understands partial motors, also called “partial ¾ motors” or “¾ motors,” as motors that are missing one or both endshields. These motors may have an endshield removed to allow the motor to be directly connected to another piece of equipment, such as a pump or gearbox. When a partial motor is mated to another piece of equipment, it is often referred to as an “integral” motor. For example, an “integral gearmotor” is the combination of a partial motor mated to a gearbox using bolts or some other means of attachment.

DOE is considering creating a standard, industry-accepted definition of the term "partial electric motor" in order to clarify its understanding of a potential expansion of scope of energy conservation standards. Additionally, DOE believes it is currently used inconsistently as an "umbrella" term to describe a wide range of electric motor types, including motor types that DOE believes should fall under the definition of "component sets" of electric motors. DOE is considering a definition of "partial electric motor" based on discussions with industry experts, SMEs, and comments from NEMA and other motor-industry groups. DOE hopes to clarify energy conservation standards coverage for this rulemaking by setting clear definitions for "partial motors." The definition DOE is considering for "partial electric motor" is:

> *Partial electric motor* means an electric motor necessitating only the addition of one or two endshields with bearings to create an operable motor. Included under this definition are integral motors and partial ¾ motors.

Submersible Electric Motors

DOE understands submersible electric motors are only capable of continuous duty operation while completely submerged in liquid. Submersible motors are similar to liquid-cooled motors because they use liquid to dissipate the heat produced during this continuous duty operation. However, submersible motors are typically submerged in a liquid as opposed to liquid-cooled electric motors that use a separate hose and pump apparatus connected to the motor. DOE believes a motor designed to operate while submerged in open water and a motor that utilizes a hose and pump apparatus could create significant design changes which would warrant separate definitions. Therefore, DOE is considering separate definitions for these two motor types to avoid any potential ambiguity between the two motor types.

DOE is considering defining "submersible electric motor" based on the description of "submersible motors for deep well pumps" in NEMA MG1–2011 part 18, page 52. The definition DOE is considering is:

> *Submersible electric motor* means an electric motor designed for continuous operation while submerged in a liquid. Such a motor is unable to operate continuously if not submerged in liquid.

Totally Enclosed Non-Ventilated Electric Motors

A majority of the medium-size electric motors shipped in the U.S. are TEFC. These motors have a fan on the outside of the end opposite the drive-end which blows air over the surface of the motor (typically the fan is enclosed by a metal fan cover). This airflow over the surface of the motor helps dissipate heat during the motor's operation. Unlike TEFC motors, totally enclosed, non-ventilated motors (TENV) are motors that have no external fan blowing air over the outside of the motor. TENV motors may be used in environments where an external fan could clog with dirt or dust. TENV motors are cooled by natural conduction and convection of the motor heat into the surrounding environment, which results in a motor that operates at higher temperatures than TEFC motors. TENV motors may deal with the higher operating temperatures by adding more frame material to dissipate excess heat or by upgrading stator winding insulation to withstand the higher operating temperatures.

DOE is considering defining the term "totally enclosed, non-ventilated electric motor" based on the definition of a "totally enclosed non-ventilated machine" in paragraph 1.26.1 in NEMA MG1–2011. DOE believes this definition is clear and concise and is considering the definition verbatim. DOE is considering the following definition of a TENV motor:

> *Totally enclosed non-ventilated (TENV) motor* means a motor that is a frame-surface cooled totally enclosed machine which is only equipped for cooling by free convection.

3.2.2 Equipment Class Groups and Equipment Classes

Within each category of electric motors it addressed, EISA 2007 set separate energy conservation standards by horsepower rating, enclosure type, and pole configuration. These standards correspond to Table 12-12 of NEMA MG 1–2011 (equivalent to NEMA Premium[a]) for general purpose electric motors (subtype I) and Table 12-11 of NEMA MG1–2011 (equivalent to EPACT 1992 values) for 1 to 200 horsepower general purpose electric motors (subtype II), fire pump electric motors, and NEMA Design B electric motors greater than 200 horsepower.[b] (42 U.S.C. 6313(b)(2))

In general, when DOE amends energy conservation standards, it divides covered equipment into classes. By statute, these classes are based on: (a) the type of energy used; (b) the capacity of the equipment; or (c) any other performance-related feature that justifies different efficiency levels, such as features affecting consumer utility. (42 U.S.C. 6295(q)) As a result of changes in EISA 2007, particularly with the addition of general purpose electric motors (subtype II) as a subset of motors covered by the term "electric motor," there are a large number of motor design features that DOE considered in this rulemaking. In the following sections, DOE discusses the design features that it is considering as part of its analysis.

Due to the number of electric motor characteristics (e.g., horsepower rating, pole configuration, and enclosure), DOE is using two constructs, at this stage, to help develop appropriate energy conservation standards for electric motors: "equipment class groups" and "equipment classes." An equipment class group is a collection of electric motors that share a common design type. Equipment class groups include motors over a range of horsepower ratings, enclosure types, and pole configurations. Essentially, each equipment class group is a collection of a large number of equipment classes with the same design type. An equipment class represents a unique combination of motor characteristics for which DOE will determine an energy efficiency conservation standard. For example, given a combination of motor design type, horsepower rating, pole configuration, and enclosure type, the motor design type dictates the

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[a] NEMA Premium efficiency levels refer to the efficiency values in NEMA MG1-2011 Table 12-12.

[b] EISA 2007 also set minimum conservation levels for subtype I motors from 201-500 horsepower at the EPACT 1992 levels.

equipment class group, while the combination of the remaining characteristics dictates the specific equipment class.

For the preliminary analysis DOE has created three equipment class groups based on two main motor characteristics: the designated NEMA design letter and whether the motor meets the definition of a fire pump electric motor. DOE's resulting equipment class groups are for NEMA Design A and B motors (including IEC-equivalent designs), NEMA Design C motors (including IEC-equivalent designs), and fire pump electric motors (including IEC-equivalent designs). Within each of these three broad groups, DOE uses combinations of other pertinent motor characteristics to enumerate its individual equipment classes. To illustrate the differences between the two terms, consider the following example. A NEMA Design B, 50 horsepower (hp), 2-pole enclosed electric motor and a NEMA Design B, 100 hp, 6-pole open electric motor would both be in the same equipment class group (for the preliminary analysis, group 1), but each motor would represent a unique equipment class, which will ultimately have its own efficiency standard. There are 478 potential equipment classes which consist of all permutations of electric motor design types (i.e., NEMA Design A and B, NEMA Design C, or fire pump electric motor), standard horsepower ratings (i.e., standard ratings from 1 to 500 horsepower), pole configurations (i.e., 2-, 4-, 6-, or 8-pole), and enclosure types (i.e., open or enclosed). Table 3.1 illustrates the relationships between equipment class groups and the characteristics used to define equipment classes. In the following sections, DOE discusses each of these design features.

Table 3.1 Electric Motor Equipment Class Groups

Equipment Class Group	Electric Motor Design	Horsepower	Poles	Enclosure
1	NEMA Design A & B*	1-500	2, 4, 6, 8	Open
				Closed
2	NEMA Design C*	1-200	2, 4, 6, 8	Open
				Closed
3	Fire Pump*	1-500	2, 4, 6, 8	Open
				Closed

*Including IEC equivalents.

DOE notes that should it establish amended energy conservation standards for electric motors with this arrangement of equipment class groups and equipment classes, it would no longer disaggregate its standards by general purpose electric motor subtype I and II. Additionally, in light of DOE's plan to expand the scope of energy conservation standards in this rulemaking, the equipment class groups listed in Table 3.1 would include motor types that previously may not have been subject to energy conservation standards, including motors that may not fall under the categories of subtype I or II motors.

3.2.2.1 Electric Motor Design

Various industry organizations, such as NEMA and IEC, publish performance criteria that provide specifications that electric motors must meet in order to be assigned different design types. As these design types represent a certain set of performance parameters, they provide electric motor users with an easy reference to use when designing their equipment and when purchasing a motor to drive their equipment. The electric motors covered under this rulemaking must meet one of three NEMA design types. For medium polyphase alternating current (AC) induction motors, the three NEMA design types considered general purpose and covered by EPCA, as amended by EISA 2007, are Design A, Design B, and Design C. The definitions for these three motor types are as follows:

In NEMA MG1–2011 paragraph 1.19.1.1, “A Design A motor is a squirrel-cage motor designed to withstand full-voltage starting and developing locked-rotor torque as shown in 12.38, pull-up torque as shown in 12.40, breakdown torque as shown in 12.39, with locked-rotor current higher than the values shown in 12.35.1 for 60 hertz and 12.35.2 for 50 hertz and having a slip at rated load of less than 5 percent.”

Under 10 CFR 431.12,[c] “NEMA Design B motor means a squirrel-cage motor that is (1) designed to withstand full-voltage starting, (2) develops locked-rotor, breakdown, and pull-up torques adequate for general application as specified in sections 12.38, 12.39 and 12.40 of NEMA Standards Publication MG1–2009 (incorporated by reference, *see* § 431.15), (3)draws locked-rotor current not to exceed the values shown in section 12.35.1 for 60 hertz and 12.35.2 for 50 hertz of NEMA Standards Publication MG1–2009, and (4) has a slip at rated load of less than 5 percent for motors with fewer than 10 poles.”

In NEMA MG1–2011 paragraph 1.19.1.3,“A Design C motor is a squirrel-cage motor designed to withstand full-voltage starting, developing locked-rotor torque for special high-torque application up to the values shown in 12.38, pull-up torque as shown in 12.40, breakdown torque up to the values shown in 12.39, with locked-rotor current not to exceed the values shown in 12.34.1 [12.35.1] for 60 hertz and 12.35.2 for 50 hertz, and having a slip at rated load of less than 5 percent.”

NEMA Design A and NEMA Design B electric motors have different locked-rotor current requirements. NEMA Design A electric motors have no locked-rotor current limits whereas NEMA Design B electric motors are required to stay below certain maximums specified in NEMA MG1-2011 paragraph 12.35.1. This tolerance for excess current will allow NEMA Design A motors to reach the same efficiency levels as NEMA Design B with fewer design changes and constraints. However, NEMA Design A and NEMA Design B motors have the same requirements for locked-rotor, pull-up, and breakdown torque and are consequently used in many of the same applications. Additionally, as is shown in section 3.2.4 below, NEMA Design

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[c] As this definition was adopted and codified into the CFR, DOE added some minor language to specify which version of NEMA MG1 should be used and DOE corrected some minor typographical errors that referred the reader to the wrong tables for locked rotor current specifications.

B motors constitute a significantly larger population of the electric motors that are shipped relative to NEMA Design A motors.

NEMA Design C electric motors, on the other hand, have different torque requirements than NEMA Design A or B motors. NEMA Design C electric motors typically have higher torque requirements. DOE believes that this performance change represents a change in utility which can also affect efficiency. Additionally, the difference in torque requirements will restrict which applications can use which NEMA Design types. As a result, NEMA Design C motors will not always be replaceable with NEMA Design A or B motors, or vice versa.

DOE notes that Congress held NEMA Design A and NEMA Design B motors to the same energy conservation standards prescribed by EPACT 1992 (42 U.S.C. 6311(13)(A)) and EISA 2007 (42 U.S.C. 6311 (13)(A)) (see requirements for general purpose electric motors (subtype I)). For the preliminary analysis, DOE has followed the precedent set by EPACT 1992 and EISA 2007 and has considered NEMA Design A and B motors in a group together, while placing NEMA Design C motors in their own equipment class group. Finally, DOE notes that all equivalent IEC design types are also covered by this energy conservation standards rulemaking and should be considered with their corresponding NEMA Design type.

3.2.2.2 Fire Pump Electric Motors

EISA 2007 prescribed energy conservation standards for fire pump electric motors. (42 U.S.C. § 6313(b)(2)(B)) Fire pump electric motors are motors with special design characteristics that make them more suitable for emergency operation. As stated previously, DOE adopted a definition of “fire pump electric motor,” which incorporated portions of the National Fire Protection Association (NFPA) Standard 20, “Standard for the Installation of Stationary Pumps for Fire Protection” (2010). Such electric motors, per the requirements of NFPA 20, are required to be marked as complying with NEMA Design B performance standards and be capable of operating even if it overheats or may be damaged due to continued operation. These additional requirements for a fire pump electric motor constitute a change in utility, apart from other general purpose electric motors, which DOE believes could also affect its performance and efficiency. Therefore, DOE has preliminarily established a separate equipment class group for fire pump electric motors.

3.2.2.3 Horsepower Rating

Horsepower is a measurement directly related to the capacity of an electric motor to perform useful work and, therefore, it is one of DOE’s primary criteria in designating equipment classes. Horsepower rating defines the output power of an electric motor, where 1 horsepower equals 745.7 Watts. It is generally true that efficiency scales with horsepower. In other words, a 50-horsepower motor is usually more efficient than a 10-horsepower motor. Also, because of its larger frame size and additional active material (e.g., copper wiring and electrical steel), the 50-horsepower motor will be able to achieve a higher, maximum level of efficiency. Horsepower is a critical performance attribute of an electric motor, and because there is a direct correlation between horsepower and efficiency, DOE is preliminarily using horsepower rating as an equipment class setting criterion.

3.2.2.4 Pole configuration

An electric motor’s pole configuration corresponds to the number of magnetic poles present in the motor. Consequently, the number of magnetic poles (or “poles”) dictates the revolutions per minute (RPM) of the rotor and shaft. For each pole configuration there is a corresponding synchronous speed, in RPMs, which is the theoretical maximum speed at which a motor might operate without a load. All of the electric motors covered by this rulemaking are asynchronous motors, meaning they cannot reach this speed. There is an inverse relationship between the number of poles and a motor’s speed. As the number of poles increases from two to four to six to eight, the synchronous speed drops from 3,600 to 1,800 to 1,200 to 900 RPMs. Because the number of poles has a direct impact on the rotational speed of a motor shaft, it also affects a motor’s utility and performance, including efficiency. Therefore, DOE is also using pole configuration as a means of differentiating equipment classes for the preliminary analysis.

3.2.2.5 Enclosure type

In general, there are two variations of enclosure types, either open or enclosed. DOE currently defines both of these terms under 10 CFR 431.12. An electric motor meets the current definition of an “enclosed motor” if it is “an electric motor so constructed as to prevent the free exchange of air between the inside and outside of the case but not sufficiently enclosed to be termed airtight.” An open motor is defined under 10 CFR 431.12 as “an electric motor having ventilating openings which permit passage of external cooling air over and around the windings of the machine.” As in EPACT 1992, EISA 2007 prescribes separate energy conservation standards for open and enclosed electric motors. (42 U.S.C. 6313 (b)(1))

DOE is aware that given two motors of the same horsepower rating, pole configuration, and frame size, an open machine is typically more efficient than an enclosed motor. This occurs because enclosure type affects an electric motor’s ability to dissipate heat (the open motor’s free air exchange allows for better thermal dissipation), which enables open motors to achieve higher efficiency levels than their enclosed counterparts. Additionally, whether an electric motor is open or enclosed affects its utility in that open motors are generally not used in harsh operating environments, whereas enclosed electric motors often are. Therefore, because of the effects on both efficiency and consumer utility, DOE is using motor enclosure as an equipment class-setting criterion for the preliminary analysis.

Table 3.2, Table 3.3, and Table 3.4 illustrate the relationship between equipment class and various motor design characteristics.

Table 3.2 NEMA Design A and B Equipment Classes

Horsepower	Enclosure	Two Poles	Four Poles	Six Poles	Eight Poles
1.0	Open	-	EC#1	EC#2	EC#3
	Enclosed	-	EC#4	EC#5	EC#6
1.5	Open	EC#7	EC#8	EC#9	EC#10
	Enclosed	EC#11	EC#12	EC#13	EC#14
2.0	Open	EC#15	EC#16	EC#17	EC#18
	Enclosed	EC#19	EC#20	EC#21	EC#22
3.0	Open	EC#23	EC#24	EC#25	EC#26

	Enclosed	EC#27	EC#28	EC#29	EC#30
5.0	Open	EC#31	EC#32	EC#33	EC#34
	Enclosed	EC#35	EC#36	EC#37	EC#38
7.5	Open	EC#39	EC#40	EC#41	EC#42
	Enclosed	EC#43	EC#44	EC#45	EC#46
10.0	Open	EC#47	EC#48	EC#49	EC#50
	Enclosed	EC#51	EC#52	EC#53	EC#54
15.0	Open	EC#55	EC#56	EC#57	EC#58
	Enclosed	EC#59	EC#60	EC#61	EC#62
20.0	Open	EC#63	EC#64	EC#65	EC#66
	Enclosed	EC#67	EC#68	EC#69	EC#70
25.0	Open	EC#71	EC#72	EC#73	EC#74
	Enclosed	EC#75	EC#76	EC#77	EC#78
30.0	Open	EC#79	EC#80	EC#81	EC#82
	Enclosed	EC#83	EC#84	EC#85	EC#86
40.0	Open	EC#87	EC#88	EC#89	EC#90
	Enclosed	EC#91	EC#92	EC#93	EC#94
50.0	Open	EC#95	EC#96	EC#97	EC#98
	Enclosed	EC#99	EC#100	EC#101	EC#102
60.0	Open	EC#103	EC#104	EC#105	EC#106
	Enclosed	EC#107	EC#108	EC#109	EC#110
75.0	Open	EC#111	EC#112	EC#113	EC#114
	Enclosed	EC#115	EC#116	EC#117	EC#118
100.0	Open	EC#119	EC#120	EC#121	EC#122
	Enclosed	EC#123	EC#124	EC#125	EC#126
125.0	Open	EC#127	EC#128	EC#129	EC#130
	Enclosed	EC#131	EC#132	EC#133	EC#134
150.0	Open	EC#135	EC#136	EC#137	EC#138
	Enclosed	EC#139	EC#140	EC#141	EC#142
200.0	Open	EC#143	EC#144	EC#145	EC#146
	Enclosed	EC#147	EC#148	EC#149	EC#150
250.0	Open	EC#151	EC#152	EC#153	EC#154
	Enclosed	EC#155	EC#156	EC#157	EC#158
300.0	Open	EC#159	EC#160	EC#161	-
	Enclosed	EC#162	EC#163	EC#164	-
350.0	Open	EC#165	EC#166	EC#167	-
	Enclosed	EC#168	EC#169	EC#170	-
400.0	Open	EC#171	EC#172	-	-
	Enclosed	EC#173	EC#174	-	-
450.0	Open	EC#175	EC#176	-	-
	Enclosed	EC#177	EC#178	-	-
500.0	Open	EC#179	EC#180	-	-
	Enclosed	EC#181	EC#182	-	-

Table 3.3 NEMA Design C Equipment Classes

Horsepower	Enclosure	Four Poles	Six Poles	Eight Poles
1.0	Open	EC#1	EC#2	EC#3
	Enclosed	EC#4	EC#5	EC#6
1.5	Open	EC#7	EC#8	EC#9
	Enclosed	EC#10	EC#11	EC#12
2.0	Open	EC#13	EC#14	EC#15

	Enclosed	EC#16	EC#17	EC#18
3.0	Open	EC#19	EC#20	EC#21
	Enclosed	EC#22	EC#23	EC#24
5.0	Open	EC#25	EC#26	EC#27
	Enclosed	EC#28	EC#29	EC#30
7.5	Open	EC#31	EC#32	EC#33
	Enclosed	EC#34	EC#35	EC#36
10.0	Open	EC#37	EC#38	EC#39
	Enclosed	EC#40	EC#41	EC#42
15.0	Open	EC#43	EC#44	EC#45
	Enclosed	EC#46	EC#47	EC#48
20.0	Open	EC#49	EC#50	EC#51
	Enclosed	EC#52	EC#53	EC#54
25.0	Open	EC#55	EC#56	EC#57
	Enclosed	EC#58	EC#59	EC#60
30.0	Open	EC#61	EC#62	EC#63
	Enclosed	EC#64	EC#65	EC#66
40.0	Open	EC#67	EC#68	EC#69
	Enclosed	EC#70	EC#71	EC#72
50.0	Open	EC#73	EC#74	EC#75
	Enclosed	EC#76	EC#77	EC#78
60.0	Open	EC#79	EC#80	EC#81
	Enclosed	EC#82	EC#83	EC#84
75.0	Open	EC#85	EC#86	EC#87
	Enclosed	EC#88	EC#89	EC#90
100.0	Open	EC#91	EC#92	EC#93
	Enclosed	EC#94	EC#95	EC#96
125.0	Open	EC#97	EC#98	EC#99
	Enclosed	EC#100	EC#101	EC#102
150.0	Open	EC#103	EC#104	EC#105
	Enclosed	EC#106	EC#107	EC#108
200.0	Open	EC#109	EC#110	EC#111
	Enclosed	EC#112	EC#113	EC#114

Table 3.4 Fire Pump Electric Motor Equipment Classes

Horsepower	**Enclosure**	**Two Poles**	**Four Poles**	**Six Poles**	**Eight Poles**
1.0	Open	-	EC#1	EC#2	EC#3
	Enclosed	-	EC#4	EC#5	EC#6
1.5	Open	EC#7	EC#8	EC#9	EC#10
	Enclosed	EC#11	EC#12	EC#13	EC#14
2.0	Open	EC#15	EC#16	EC#17	EC#18
	Enclosed	EC#19	EC#20	EC#21	EC#22
3.0	Open	EC#23	EC#24	EC#25	EC#26
	Enclosed	EC#27	EC#28	EC#29	EC#30
5.0	Open	EC#31	EC#32	EC#33	EC#34
	Enclosed	EC#35	EC#36	EC#37	EC#38
7.5	Open	EC#39	EC#40	EC#41	EC#42
	Enclosed	EC#43	EC#44	EC#45	EC#46
10.0	Open	EC#47	EC#48	EC#49	EC#50
	Enclosed	EC#51	EC#52	EC#53	EC#54
15.0	Open	EC#55	EC#56	EC#57	EC#58

	Enclosed	EC#59	EC#60	EC#61	EC#62
20.0	Open	EC#63	EC#64	EC#65	EC#66
	Enclosed	EC#67	EC#68	EC#69	EC#70
25.0	Open	EC#71	EC#72	EC#73	EC#74
	Enclosed	EC#75	EC#76	EC#77	EC#78
30.0	Open	EC#79	EC#80	EC#81	EC#82
	Enclosed	EC#83	EC#84	EC#85	EC#86
40.0	Open	EC#87	EC#88	EC#89	EC#90
	Enclosed	EC#91	EC#92	EC#93	EC#94
50.0	Open	EC#95	EC#96	EC#97	EC#98
	Enclosed	EC#99	EC#100	EC#101	EC#102
60.0	Open	EC#103	EC#104	EC#105	EC#106
	Enclosed	EC#107	EC#108	EC#109	EC#110
75.0	Open	EC#111	EC#112	EC#113	EC#114
	Enclosed	EC#115	EC#116	EC#117	EC#118
100.0	Open	EC#119	EC#120	EC#121	EC#122
	Enclosed	EC#123	EC#124	EC#125	EC#126
125.0	Open	EC#127	EC#128	EC#129	EC#130
	Enclosed	EC#131	EC#132	EC#133	EC#134
150.0	Open	EC#135	EC#136	EC#137	EC#138
	Enclosed	EC#139	EC#140	EC#141	EC#142
200.0	Open	EC#143	EC#144	EC#145	EC#146
	Enclosed	EC#147	EC#148	EC#149	EC#150
250.0	Open	EC#151	EC#152	EC#153	EC#154
	Enclosed	EC#155	EC#156	EC#157	EC#158
300.0	Open	EC#159	EC#160	EC#161	-
	Enclosed	EC#162	EC#163	EC#164	-
350.0	Open	EC#165	EC#166	EC#167	-
	Enclosed	EC#168	EC#169	EC#170	-
400.0	Open	EC#171	EC#172	-	-
	Enclosed	EC#173	EC#174	-	-
450.0	Open	EC#175	EC#176	-	-
	Enclosed	EC#177	EC#178	-	-
500.0	Open	EC#179	EC#180	-	-
	Enclosed	EC#181	EC#182	-	-

3.2.3 Expanded Scope of Coverage

During the October 18, 2010, framework public meeting, DOE received comments regarding the energy savings potential from expanding the scope of coverage beyond subtype I, subtype II, and fire pump electric motors. DOE addresses these comments in chapter 2 of the preliminary TSD DOE's discussion of expanding the scope of coverage refers to the decision to analyze energy conservation standards for electric motor types that currently do not have energy conservation standards. DOE has the statutory authority to establish such standards without first promulgating a coverage determination rulemaking based on the modifications resulting from EISA 2007, which struck the statutory definition for "electric motors." DOE recognizes the energy savings potential of scope expansion for motors previously exempt from conservation standards, as well as motors that may not fall into the subtype I, subtype II, and fire pump electric motor categories. DOE plans on expanding the scope of conservation standards to all motors with characteristics listed in Table 3.5 and then specifically naming motors for which no standards are established.

Table 3.5 Characteristics of Motors Regulated Under Expanded Scope of Coverage

Motor Characteristic
Is a single-speed, induction motor,
Is rated for continuous duty (MG1) operation or for duty type S1 (IEC),
Contains a squirrel-cage (MG1) or cage (IEC) rotor,
Operates on polyphase alternating current 60-hertz sinusoidal power,
Has a 2-, 4-, 6-, or 8-pole configuration,
Is rated 600 volts or less,
Has a three-digit NEMA frame size and is less than 500 horsepower, and
Is a NEMA Design A, B, or C motor (or an IEC equivalent)

Table 3.6 lists electric motors that are not currently subject to efficiency standards, but would be subject to minimum efficiency standards if DOE decides to expand energy efficiency standards to electric motors with all of the characteristics listed in Table 3.5 (with the exception of specifically named motors that would otherwise not be covered). Such motors would fall into the equipment class groups listed in Table 3.1 based on their respective NEMA Design type. See chapter 2 of the preliminary TSD for an in-depth discussion of the decision to include these motors in the expansion of energy conservation standards.

Table 3.6 Electric Motor Types DOE Plans on Regulating Under Newly-Expanded Scope of Conservation Standards

Electric Motors with Customer Defined Endshields or Special Flanges	Encapsulated Electric Motor
Electric Motors with Single and Double Shafts of Non-Standard Shaft Dimensions or Additions	Immersible Electric Motor
Electric Motors with Sleeve Bearings	Inverter-Capable Electric Motor
Electric Motors with Special Base or Mounting Feet	Partial Electric Motor
Electric Motors with Thrust Bearings	Totally Enclosed, Non-Ventilated Electric Motor
Vertical Hollow-Shaft Electric Motor	-

In the March 30, 2011, Request For Information related to electric motors, DOE requested comment on expanding the scope of energy conservation standards to motors that were not currently subject to standards, including some motor types listed in Table 3.6 and Table 3.7. (76 FR 17577) The motor types listed in Table 3.7 are motor types which, at this time, DOE does not plan on subjecting to energy conservation standards. While some of these motors conform to many or all of the characteristics listed in Table 3.5, DOE understands that covering such motors might not be warranted due to special operating conditions or testing difficulties as discussed below.

Table 3.7 Electric Motors Excluded from Expanded Scope of Coverage

Electric Motor Type	
Air-Over Electric Motors	Direct Current Motors
Component Sets	Single Phase Motors
Intermittent Duty Motors	Liquid-Cooled Motors
Inverter-Only Duty Motors	Submersible Motors
Multispeed Motors	-

Air-Over Electric Motors

Air-over electric motors require an external means of cooling to allow continuous duty operation. These motors may be subject to over-heating and therefore cannot run continuously without a specified amount of air flowing over the motor housing. The required air flow amount is usually determined by the manufacturer as part of the motor design and performance characteristics.

DOE is not planning on covering air-over motors because of the test setup complexities required for these motors. DOE's primary test procedure, the Institute of Electrical and Electronics Engineers, Inc. (IEEE) Standard 112–2004 Test Method B (IEEE 112B), requires certain measurements to be taken at a steady-state temperatures[d]. Reaching a steady-state temperature requires a motor to be rated and operate under continuous-duty conditions; otherwise the motor could overheat and be damaged before reaching a steady-state temperature. IEEE 112B does not provide directions on how to setup an air-over motor for testing, which would otherwise require an external cooling apparatus. DOE is not aware of test procedures that provide guidance on how to test such motors. DOE requests comment on testing non-continuous duty motors in chapter 2 of the preliminary TSD.

Liquid-Cooled Motors

Liquid-cooled electric motors rely on a special cooling apparatus that pumps liquid into and around the motor housing. The liquid is circulated around the motor to dissipate heat and prevent the motor from overheating during continuous-duty operation. The user of a liquid-cooled motor could employ different liquids or liquid temperatures which could affect the measured efficiency of a motor. IEEE 112B does not provide standardized direction for testing liquid-cooled motors, and therefore DOE does not plan on including them in the scope of coverage. DOE requests comment on the testing of liquid-cooled electric motors, including any test procedure that is capable of testing these motor types.

Submersible Motors

Submersible motors are similar to liquid-cooled motors in that they use liquid to dissipate the heat produced during continuous duty operation. However, unlike liquid-cooled motors,

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[d] Section 3.3.2 of IEEE 112B requires the conductor losses to be measured when the machine is at a specified temperature.

submersible motors are only meant to operate while completely submerged in water, as opposed to having a hose and pump apparatus circulating liquid around the motor enclosure.

DOE is not aware of any test procedures for motors that can only operate continuously in special environments, such as underwater. Therefore, DOE does not plan on including submersible motors in the expanded scope of coverage. DOE requests comment on the testing of submersible electric motors, including any test procedure that is capable of testing these motor types.

Component Sets

Component sets are comprised of any combination of motor parts, such as a stator, rotor, shaft, stator housing, shaft bearings, endshields, or other electrical parts. DOE delineated between component sets and partial motors in chapter 2 of the preliminary TSD when it called out partial motors as motors only missing one or both endshields. Component sets are typically sold to be turned into complete electric motors or installed in equipment by the end-user.

DOE believes component sets do not constitute a complete motor that could be tested under IEEE 112B. Additionally, DOE is not aware of any test procedures that would accommodate the testing of component sets of motors. While DOE is planning on including partial motors in the expansion of energy conservation standards by testing them with a custom-built endshield that could be attached as a ‘dummy’ endplate for testing, DOE believes component sets would require too many or various hardware additions to make a complete motor. Therefore, DOE does not plan on including component sets in the expanded scope of coverage. DOE requests comment on the decision not to subject these motor types to efficiency standards due to testing difficulties. DOE requests comment on any applicable testing standards that are capable of testing component sets of electric motors.

Intermittent-Duty Electric Motors

Intermittent-duty motors are motors that, by definition, are not able to operate continuously under full load. DOE does not plan to include such motors in the expanded scope for energy conservation standards because it does not believe intermittent-duty motors present significant opportunities for energy savings. Additionally, IEEE 112B requires measurements to be taken at a steady-state temperatures. Reaching a steady-state temperature requires a motor to be rated and operate under continuous-duty conditions; otherwise the motor could overheat and be damaged before reaching a steady-state temperature. Intermittent-duty motors are not capable of continuous-duty operation and, therefore, never reach a steady-state temperature which IEEE 112B requires for certain calculations. Otherwise, DOE is not aware of any test procedures which provide for testing an intermittent or non-continuous-duty motor. DOE requests comment on this matter in chapter 2 of the preliminary TSD.

Inverter-Only Electric Motors

Inverter-only motors cannot be run continuously when directly connected to a 60-hertz, AC polyphase sinusoidal power source. Therefore a separate, special electronic controller, called an inverter, is used to alter the power signal to the motor. For a more in-depth discussion of how inverter controllers work, see chapter 2 of the preliminary TSD.

Inverter controllers are not necessarily 100 percent efficient when manipulating the power signal being fed into the motor. Consequently, the IEEE 112B-measured efficiency of an inverter-only motor would not reflect the true efficiency of that motor, but would also include any losses inherent in the inverter controller. DOE believes testing an inverter-only motor with the inverter controller connected would not accurately record the efficiency of the motor per se. DOE is not planning to include inverter-only motors under the expanded scope motors covered by energy conservation standards, because it is not aware of any test procedures that recognize and differentiate losses caused by the inverter controller. DOE requests comment on this issue in chapter 2 of the preliminary TSD.

Multispeed Motors

For this rulemaking, the speed of an electric motor subject to energy conservation standards is determined by its magnetic pole configuration (2-, 4-, 6-, or 8-pole), and the frequency (60-hertz) of the motor's incoming power signal. The pole configuration is directly determined by the stator winding configuration as discussed in section 3.2.2.4.

In general, multispeed motors are motors with multiple, separate stator winding configurations that enable the motor to perform at different speeds contingent upon which winding configuration is connected to the power source. For example, a multispeed motor could be wound with a 2-pole winding configuration and a 4-pole winding configuration. When the power source is connect to the 2-pole winding configuration, the motor shaft will rotate at or near (depending on slip) 3,600 revolutions per minute (RPM), and when the 4-pole winding configuration is connected to the power source the same motor shaft will rotate at or near 1,800 RPM.

DOE is not planning to include multispeed motors in the expanded scope of motors covered under conservation standards, because it is not aware of any test procedures that provide methods for testing a motor with more than one nameplate-rated speed. DOE requests comment on any test procedures that are capable of testing multispeed electric motors.

Direct Current Motors

Direct current (DC) motors are motors that run on DC power input. For this rulemaking, DOE is covering only electric motors that operate on polyphase, sinusoidal AC power and can be tested under IEEE 112B. DC motors cannot be tested under IEEE 112B, but require testing under other methods.

Single Phase Motors

Single phase motors operate on a single phase, AC power source. For this rulemaking, DOE is covering only electric motors that operate on polyphase, sinusoidal AC power and can be tested for efficiency under IEEE 112B. DOE does not plan to include single phase motors in this rulemaking because they cannot be tested according to IEEE 112B.

3.2.4 Electric Motor Shipments

To prepare an estimate of the national impact of energy conservation standards for electric motors, DOE needed to estimate annual motor shipments. For this stage of the rulemaking, DOE used publically available shipment data from the U.S. Census Bureau, NEMA, and the Annual Energy Outlook provided by the U.S. Energy Information Administration.

DOE used this data for three main purposes. First, the shipment data and market trend information contributed to the shipments analysis and base-case forecast for electric motors (chapter 9 of the preliminary TSD). Second, DOE used the shipment and catalog data to select the representative equipment classes and units for analysis (chapter 5 of the preliminary TSD). Third, DOE used the data to develop the installed stock of equipment for the national impact analysis (chapter 10 of the preliminary TSD). Although more detailed shipments data are given in chapter 9, the shipments shown in this chapter illustrate which electric motor characteristics were the most common in 2011.

3.2.4.1 NEMA Design Type

As discussed previously, the scope of DOE's energy conservation standards for electric motors covers four design types: NEMA Design A, NEMA Design B, NEMA Design C, and fire pump electric motors.[e] In 2011, Design B motors were by far the most common electric motor type, comprising of 98.7 percent of all shipments. NEMA Design A was the second most common design type, consisting of 1.0 percent of shipments. Finally, NEMA Design C and fire pump electric motors constituted just 0.2 percent and 0.1 percent of shipments, respectively.

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[e] DOE notes that IEC-equivalent design types are also covered.

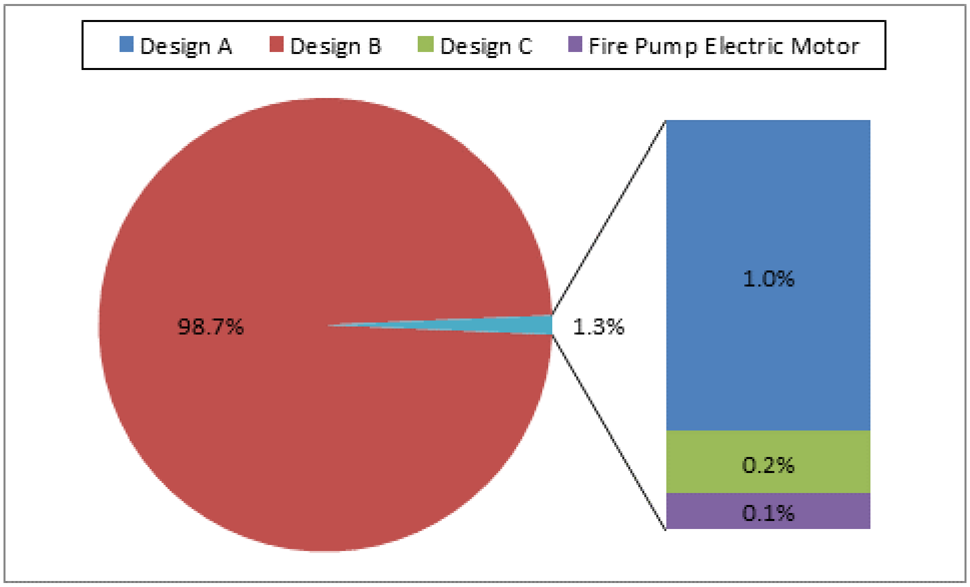


Figure 3.2.1 Electric Motor Shipments by Design Type for 2011

As will be discussed in more detail in chapter 5 of the preliminary TSD, DOE focused its engineering analysis on NEMA Design B motors based on the popularity of the design type. Although NEMA Design C motors consist of a small portion of the motor market, DOE has separately analyzed these motors because of the different utility and performance characteristics that these motors have relative to Design A and B motors.

3.2.4.2 Horsepower Ratings

For 2011 NEMA supplied shipments data broken down by horsepower rating.

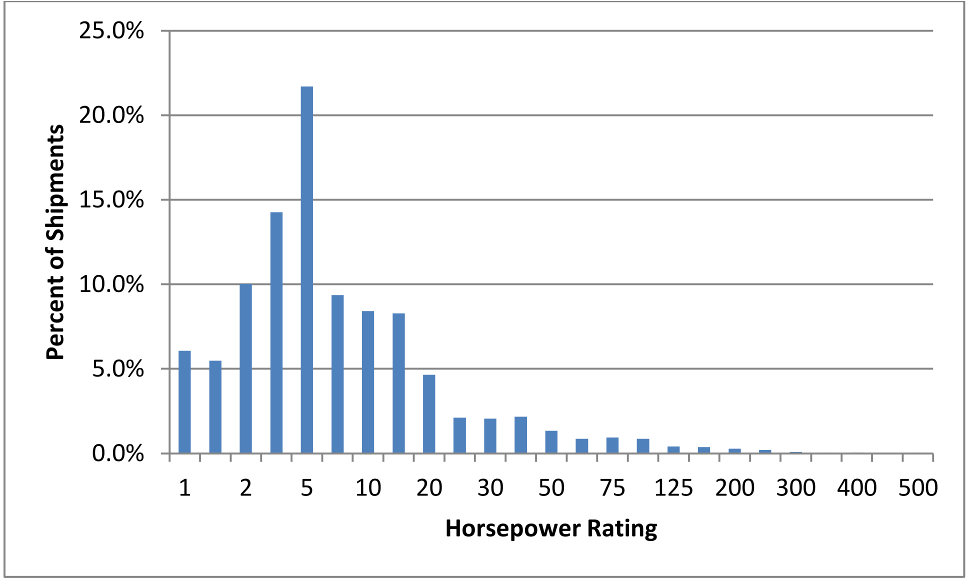


Figure 3.2.2 illustrates the total shipments of electric motors broken down by horsepower rating. As is evident by the graph, the vast majority of shipments occurred in the lower range of horsepower rating, with 5-horsepower being the most common rating.

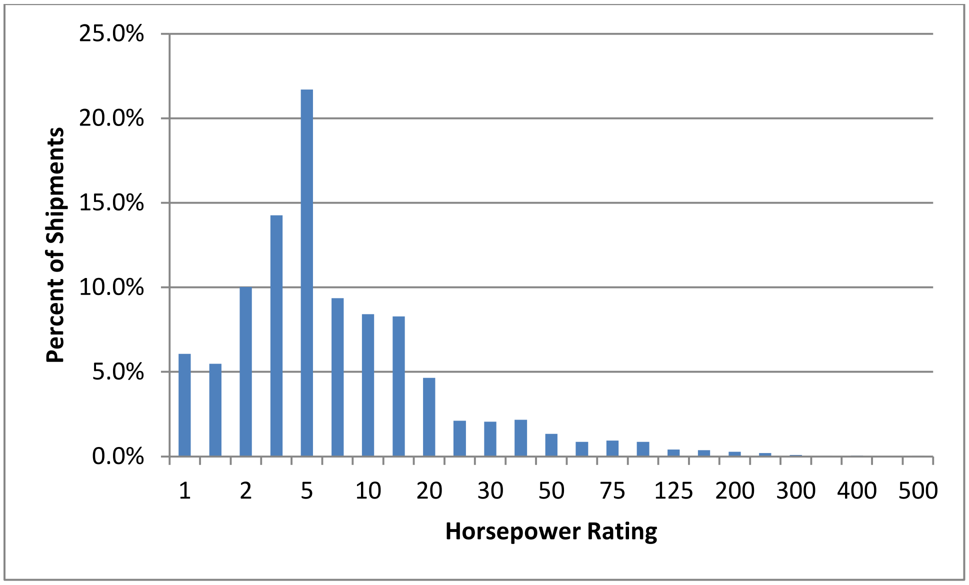
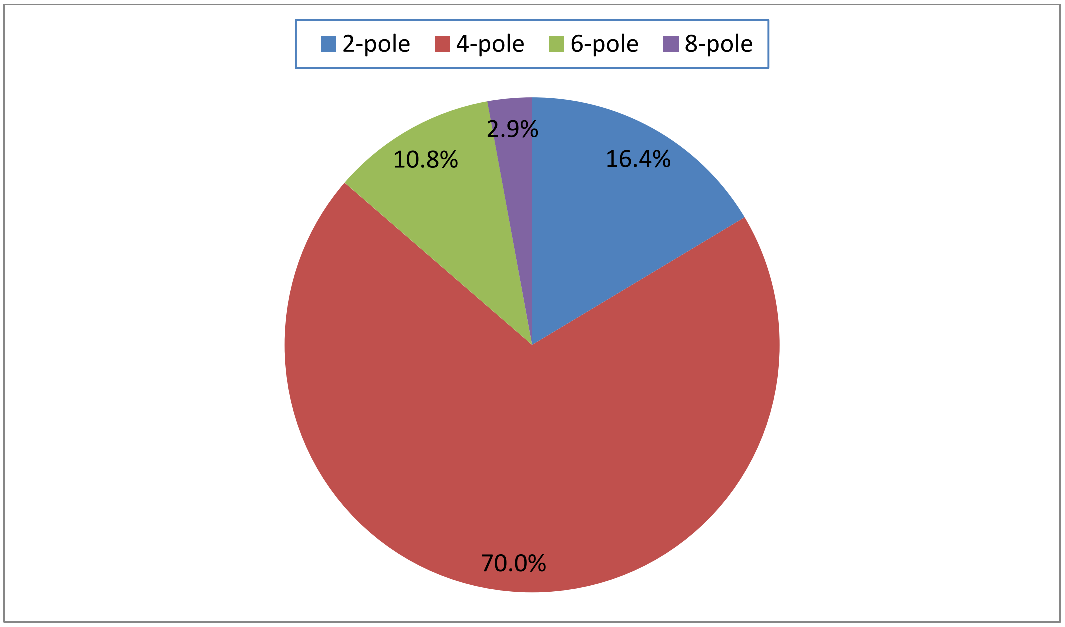


Figure 3.2.2 Electric Motor Shipments by Horsepower Rating for 2011

3.2.4.3 Pole Configuration



NEMA also supplied 2011 shipments data broken down by pole configuration. As illustrated in Figure 3.2.3, 4-pole electric motors were by far the most commonly shipped. The next highest group of shipments was 2-pole motors, constituting 18 percent of all shipments. Then, 6-pole and 8-pole motors accounted for 10 percent and 3 percent of electric motor shipments, respectively.

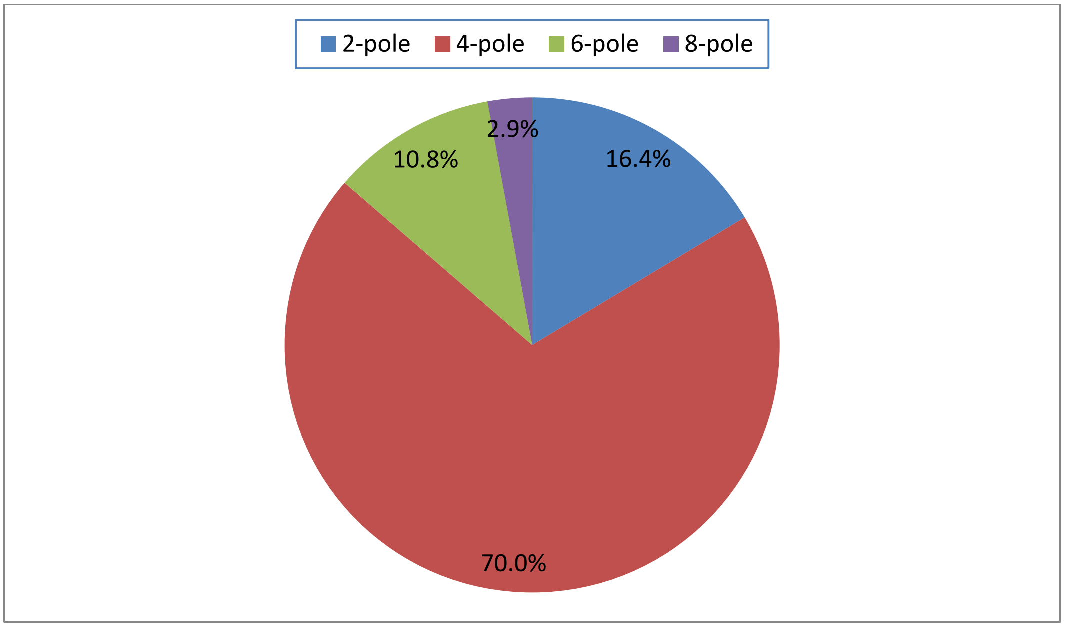


Figure 3.2.3 Electric Motor Shipments by Pole Configuration for 2011

3.2.4.4 Enclosure Types

Finally, NEMA provided shipment estimates broken down by enclosure types, that is, open or enclosed. In 2011, enclosed motors were shipped roughly three times as frequently as open motors. In 2011, enclosed consisted of about 77 percent of electric motor shipments and open electric motors consisted of about 23 percent of motor shipments.

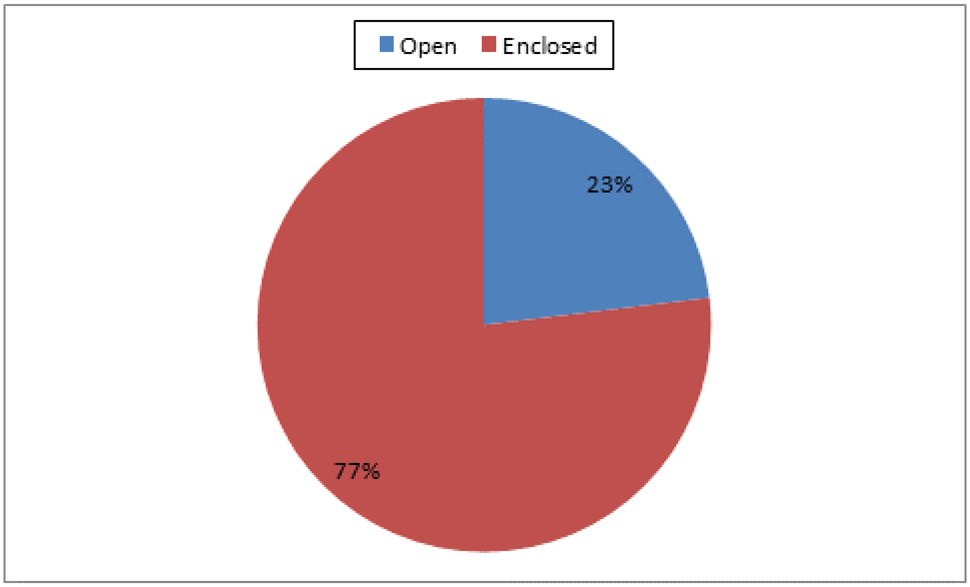


Figure 3.2.4 Electric Motor Shipments by Enclosure Type for 2011

3.2.5 Manufacturers and Market Share

The major manufacturers that dominate the electric motor market for this rulemaking, in alphabetical order, are:

- A.O. Smith Electrical Products Company;
- Baldor Electric Company;
- General Electric Company;
- Nidec Motor Corporation;
- Regal-Beloit Corporation.;
- Siemens Industry, Inc.;
- Toshiba; and
- WEG

The manufacturers identified above are all major manufacturers with diverse portfolios of equipment offerings, including electric motors covered under EPCA. Over the past decade, there has been a consolidation of motor manufacturing in the United States and this list is a result of those mergers and acquisitions.

DOE does not have empirical data on the market shares of particular manufacturers of electric motors. Nevertheless, estimates of available cumulative data indicate that shipments of electric motors from these companies constitute over a significant portion of the total U.S. market. Further, DOE believes that the cumulative shipment estimates provided by NEMA constitute a good estimate of overall national shipments.

3.2.5.1 Small Businesses

Although the electric motor market is predominantly supplied by large manufacturers, DOE will examine those small businesses that manufacture electric motors during the NOPR stage of the rulemaking. In general, the Small Business Administration (SBA) defines a small business manufacturing enterprise for "motor and generator manufacturing" as one that has 1,000 or fewer employees. The number of employees in a small business is rolled up with the total employees of the parent company; it does not represent the division manufacturing electric motors. SBA lists small business size standards for industries as they are described in the North American Industry Classification System (NAICS). For electric motors, the size standard is matched to NAICS code 335312, Motor and Generator Manufacturing.[1]

3.2.6 Application and Performance of Existing Equipment

The general purpose electric motors as well as the definite and special purpose electric motors that can be used in general purpose applications covered in the preliminary analysis are used in a wide range of applications that include the following:

- blowers
- business equipment
- commercial food processing
- compressors
- conveyors
- crushers
- fans
- farm equipment
- general industrial applications
- grinders
- heating, ventilation, and air-conditioning equipment
- machine tools
- milking machines
- pumps
- winches
- woodworking machines

3.2.7 Trade Associations

DOE is aware of one trade association for manufacturers of medium electric motors, the National Electrical Manufacturers Association (NEMA).

3.2.7.1 National Electrical Manufacturers Association

NEMA was established as a trade association in 1926, and has since been divided into five core departments that provide different functions for its members. Those departments are:

- Technical Services

- Government Relations
- Industry Operations
- Business Information Services
- Medical

Through these groups, NEMA establishes voluntary standards for the performance, size, and functionality of electrical equipment to facilitate communication among motor manufacturers, original equipment manufacturers, engineers, purchasing agents, and users. An example of NEMA's role in standardization is the NEMA Standards Publication MG-1, "Motors and Generators," (MG 1) document,[f] which is a reference document for motor and generator manufacturers and users. MG 1 provides guidance to motor manufacturers on performance and construction specifications for a broad range of electric motors. By standardizing around certain parameters, NEMA makes it easier for users to identify and purchase electric motors. MG 1 is a complete industry reference document for standardizing the motors offered in the market. The groups above also set up work that NEMA, as a whole, does to contribute to U.S. public policy and the economic data analysis it performs.[2]

In addition to MG 1, NEMA established and promoted a high efficiency standard through a "NEMA Premium®" label for qualifying motors.[g] NEMA motor manufacturers attach a label to motors that are built to high efficiency standards. These standards exceed those set by EPACT 1992, which requires general-purpose motors from 1 to 200 horsepower to meet certain minimum efficiency levels. See section 3.2.2 and 3.2.9 for more discussion on these minimum efficiency levels.

3.2.8 Regulatory Programs

EPCA, 42 U.S.C. 6311, *et seq.*, as amended by EPACT 1992, established energy conservation standards and test procedures for certain commercial and industrial electric motors manufactured (alone or as a component of another piece of equipment) after October 24, 1997. Then, in December 2007, Congress passed into law EISA 2007. (Pub. L. No. 110–140) Section 313(b)(1) of EISA 2007 updated the energy conservation standards for those electric motors already covered by EPCA and established energy conservation standards for a larger scope of motors not previously covered. (42 U.S.C. 6313(b)(2))

EPCA also directs that the Secretary [of Energy] shall publish a final rule no later than 24 months after the effective date of the previous final rule to determine whether to amend the standards in effect for such product. Any such amendment shall apply to electric motors manufactured after a date which is five years after –

(i) the effective date of the previous amendment; or
(ii) if the previous final rule did not amend the standards, the earliest date by which a previous amendment could have been effective. (42 U.S.C. 6313(b)(4))

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[f] NEMA's MG 1 document can be purchased online at www.nema.org/stds/MG 1.cfm.
[g] NEMA's Premium® Motors program can be reviewed at www.nema.org/gov/energy/efficiency/premium.

As described earlier, EISA 2007 constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. Because these amendments became effective on December 19, 2010, DOE is required by statute to publish a determination by December 19, 2012, whether to further amend the EISA 2007 energy conservation standards for electric motors. As such, DOE will determine whether to promulgate amended energy conservation standards for electric motors and, if so, at what levels. Sections 325(o)-(p) of EPCA require any such levels to be technologically feasible, economically justified, and save a significant amount of energy. (42 U.S.C. 6295(o)-(p), 6316(a)) Any such amended standards that DOE establishes would require compliance two years after publication of a final rule.

3.2.9 Non-Regulatory Programs

DOE reviewed voluntary programs that promote energy efficient electric motors in the United States, including the DOE Motor Challenge and Best Practices programs, NEMA Premium energy efficient motors program, and Consortium for Energy Efficiency (CEE) Premium Efficiency motors program.

3.2.9.1 Department of Energy Motor Challenge Program

In general, motor-driven equipment accounts for almost 70 percent of all electricity consumption by U.S. industries. In 1993, DOE launched its industry/government partnership, Motor Challenge Program with the goals of increasing the energy-efficiency of electric motor-driven systems in domestic industry and enhancing environmental quality. The program uses a market-driven approach to promote the design, purchase, installation, and management of energy-efficient electric motors and motor-driven systems and equipment, such as pumps, fans, and compressors. It was designed to help industry capture 5 billion kilowatt-hours per year of electricity savings and 1.2 million metric tons of carbon-equivalent by the year 2000, with projections of much larger and longer-term national energy savings opportunities of over 100 billion kilowatt-hours per year by the year 2010.[h]

The Motor Challenge program encompasses three-phase 60 Hertz motors rated 1 horsepower and above. Its elements and offerings include: DOE Energy Efficiency and Renewable Energy (EERE) Information Center, which provides up-to-date information about the practicality and profitability of electric motor system strategies; design decision tools, such as MotorMaster+ software; Showcase Demonstration projects; training; workshops; and conferences. In general, the response to the program from industry has been overwhelmingly favorable. The Motor Challenge program is no longer active; however, the DOE Energy Efficiency and Renewable Energy (EERE) Information Center and the MotorMaster+ database of industrial motors remain viable.

The EERE Information Center answers questions on energy efficient products and services and refers callers to the most appropriate DOE/EERE resources. Industrial callers are eligible for an advanced level of service that includes engineering assistance, research, and

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[h] For more information about DOE "Best Practices," under the DOE Industrial Technologies Program, and Motor Challenge, visit http://www1.eere.energy.gov/industry/bestpractices/index.html.

software support for plant staff and industrial service providers working on industrial energy savings projects.[i]

MotorMaster+ is an energy-efficient motor selection and management tool, which includes a database of over 20,000 AC motors. It features motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.[j]

3.2.9.2 National Electrical Manufacturers Association Premium Efficiency Motor Program

On January 11, 1989, NEMA established voluntary energy efficiency levels for 1 through 200 horsepower, polyphase squirrel-cage induction motors. For an electric motor to be classified as “energy efficient,” it was required to meet certain levels of efficiency in NEMA Standards Publication MG 1–1987 (Revised March 1991). In 1992, the NEMA efficiency levels were incorporated into section 342(b) of EPACT 1992 and subsequently codified in 10 CFR 431.25. In 2001, the NEMA Premium Efficiency Motor Program was established to provide special recognition to electric motors that exceed the required efficiency levels established by EPACT 1992. NEMA Premium-labeled motors help purchasers identify more efficient motors and optimize motor system efficiency commensurate with a particular application.[3][k]

Going a step beyond EPACT, NEMA Premium applies to single-speed, polyphase; 1 to 500 horsepower; 2-, 4-, and 6-pole; squirrel-cage; induction motors; NEMA Designs A or B; 600 volts or less; and rated for continuous duty operation.[4] Such electric motors are typically used in industrial applications operating more than 2000 hours per year.

3.2.9.3 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is a nonprofit corporation that develops initiatives for its North American members to promote the manufacture and purchase of energy efficient equipment, including electric motors and services. Its members include utilities, statewide and regional market transformation administrators, environmental groups, research organizations and state energy offices in the U.S. and Canada. Also included in the CEE collaborative process are manufacturers, retailers, and government agencies.

In 1996, CEE began its Premium-Efficiency Motors Initiative to promote the production, distribution, and adoption of premium efficiency motors over motors meeting the minimum efficiency levels established under EPACT 1992. In 1999, CEE took a systems approach to energy savings and launched its Motor Systems Initiative that viewed the motor as a component of a larger system, where efficient motors, adjustable-speed drives, and system-specific design strategies would provide the greatest opportunity for savings. Then, in 2001, CEE launched its

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[i] For more information about the EERE Information Center, visit http://www1.eere.energy.gov/industry/bestpractices/info_center.html.

[j] For more information about MotorMaster+, visit www1.eere.energy.gov/industry/bestpractices/software.html#mm.

[k] For more information about the NEMA Premium Efficiency Motor Program, visit http://www.nema.org/gov/energy/efficiency/premium/.

Motor Decisions Matter to promote greater awareness of the benefits of motor systems efficiency. In June 2001, CEE and NEMA aligned to promote NEMA Premium motor efficiency levels that are roughly .5 to 3 percentage points above EPACT 1992 requirements.[5]

In May 2007, CEE published the Energy-Efficiency Incentive Programs – Premium-Efficiency Motors & Adjustable Speed Drives in the U.S and Canada, which provides information about the incentive-based programs in North America. These programs concentrate on 1 to 200 horsepower motors, but some include 201 to 500 horsepower motors. It appears that the programs cover commercial and industrial motors rated from 1 to 500 horsepower.[1] There are a number of different programs broken down by region. For more information on these programs, download the report from CEE.[6]

3.3 TECHNOLOGY ASSESSMENT

The electric motors covered in the framework document are all AC induction motors. Induction motors have two core components: a stator and a rotor. The components work together to convert electrical energy into rotational mechanical energy. This is done by creating a rotating magnetic field in the stator, which induces a voltage across the rotor-stator air gap which in turn causes current to flow within the squirrel cage of the rotor. The squirrel cage of the rotor is so named because without the core steel stack, the rotor conductor bars and end rings resemble the exercise wheels that domesticated squirrels would run in. The stator and rotor magnetic fields interact to create torque. This torque provides the rotational force delivered to the load via a shaft.

The purpose of the technology assessment is to develop a preliminary list of technology options that may improve the efficiency of electric motors. For the electric motors covered in this rulemaking, energy efficiency losses are grouped into five main categories: stator I^2R losses, rotor I^2R losses, core losses, friction and windage losses, and stray load losses.

Designers have to balance the five basic losses to optimize the various motor performance criteria. There are numerous trade-offs that have to be considered. Efficiency is only one parameter that has to be met. Reducing one loss may increase another. What may be desirable on a 4-pole motor may not be on a 2-pole motor. Increasing the air gap is a good example: a larger air gap may reduce the stray loss but may increase the losses associated with the magnetizing current. A complete discussion of these trade-offs is beyond the scope of this report. Different companies utilize different approaches for minimizing motor losses.

3.3.1 Technology Options for I^2R Losses

I^2R losses are produced from either the current flow through the copper windings in the stator (stator I^2R losses) or the squirrel cage of the rotor (rotor I^2R losses). Stator I^2R losses are

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[1] For more information about CEE motor and motor systems programs, visit http://www.cee1.org/ind/mot-sys/mtr-ms-main.php3.

reduced by decreasing resistance to current flow in the electrical components of a motor. These losses are manifested as heat, which can shorten the service life of a motor. Another way to decrease stator I^2R losses is to increase the cross sectional area of the stator winding conductors (e.g., copper wire diameter). This can also be accomplished by either increasing the slot fill and/or increasing the size of the stator slots. However, this method replaces some of the stator magnetic cross sectional area and increases the flux density in the stator. Increasing the flux density may increase core losses. The motor designer must make a trade-off between these two options to streamline the motor design.

There are also various ways to reduce rotor I^2R losses. Rotor conductor bars are the areas in the rotor where current flows. These bars are usually made of aluminum in electric motors. However, one method of increasing the efficiency of the motor is to substitute copper bars for aluminum bars. Aluminum has a higher electrical resistivity (2.65×10^{-8} ohm-m) than copper (1.68×10^{-8} ohm-m). Copper's 63 percent lower electrical resistance compared to aluminum would result in reduced rotor I^2R losses if copper bars are used instead of aluminum.

Manipulation of the rotor's geometrical design is another approach to reduce rotor I^2R losses. The conductor bars of the rotor cage may be skewed. This means the conductor bars are slightly offset from one end of the rotor to the other. By skewing the rotor bars, motor designers can reduce harmonics that add cusps to the speed-torque characteristics of the motor. The cusps in the speed-torque curves mean that the acceleration of the motor will not be completely smooth. The degree of skew matters because reducing the skew will help reduce the rotor resistance and reactance, thereby providing gains in efficiency. However, reducing the skew may have adverse impacts on the speed-torque characteristics.

Another change to the rotor bar geometry that can reduce resistance is increasing the cross-sectional area of the conductor bars. Resistance is inversely proportional to the cross-sectional area of the material through which current is flowing. By increasing the cross-sectional area, rotor bar resistance will decrease which may reduce rotor I^2R losses.

Manufacturers may also alter the end rings of the rotor to increase efficiency. Current flows through the end rings of the rotor and increasing the size of the end ring may decrease resistance and reduce the associated rotor I^2R losses.

Another approach to improve motor efficiency is increasing the number of steel laminations to the rotor and stator (i.e., increasing the "stack" length). Increasing the stack length reduces the flux densities and therefore the iron loss. However, usually other parameters in the motor design must be modified to achieve an efficiency improvement with a longer stack length. Improving the grade of electrical steel used in the motor laminations will also reduce the iron losses.

Another way manufacturers may improve efficiency is to reduce the air gap between the stator and rotor. Within limits, decreasing the air gap decreases the magneto-motive force drop across the air gap. This will improve the motor's power factor and reduce stator I^2R losses. Reducing the air gap has some manufacturing limitations and it may also increase other loss components, so again design optimization is a must.

3.3.2 Technology Options for Core Losses

Core losses are losses created in the electrical steel components of a motor. These losses, like I^2R losses, manifest themselves as heat. Core losses are generated in the steel by two electromagnetic phenomena: hysteresis losses and eddy currents. Hysteresis losses are caused by magnetic domains resisting reorientation to the alternating magnetic field (i.e., 60 times per second, or 60 hertz). Eddy currents are currents that are induced in the steel laminations by the pulsating magnetic flux.

Another common technique for reducing steel losses is using a higher quality, more efficient electrical steel in the core. Hysteresis losses are reduced because the magnetic permeability improves and grain size increases, reducing the magnetic domain resistance. Eddy currents are reduced because the resistivity of the laminations is higher, reducing the magnitude of the currents. In studying the techniques used to reduce steel losses, DOE considered two types of materials: conventional silicon steel and so-called “exotic” steels, which contain a relatively high percentage of boron or cobalt.

Conventional steels are commonly used in electric motors manufactured today. There are three types of steel that DOE considers “conventional” or cold-rolled magnetic laminations (CRML), fully processed non-oriented electrical steel, and semi-processed non-oriented electrical steel. Each steel type is sold in a range of grades. In general, as the grade number goes down, so does the amount of loss associated with the steel (i.e., watts of loss per pound of steel). The induction saturation level also drops, causing the need for increased stack length. Of these three types, CRML steels are the most commonly used, but also the least efficient. The fully processed steels are annealed before punching and therefore do not require annealing after being punched and assembled, and are available in a range of steel grades from M56 through M15. Semi-processed electrical steels are designed for annealing after punching and assembly.

The exotic steels are generally not manufactured for specific use in electric motors. However, these steels offer a lower loss level than the best electrical steels, but are more expensive per pound. From a manufacturing perspective, these steels also present problems because they come in non-standard thicknesses that are harder to manufacture.

Another possible option for reducing core loss is to use thinner laminations. Thinner laminations generally have less eddy current losses and this contributes toward improving motor efficiency.

Manufacturers may also reduce eddy currents by using improved insulating coatings between the steel laminations. Improved coatings increase the resistance between the steel laminations, which makes it more difficult for eddy currents to flow from lamination to lamination.

Annealing the core steel is another technique manufacturers use to reduce hysteresis losses. Annealing is a heating process that alters the grain structure of the steel and alleviates any stresses introduced during punching and assembly. After being annealed, the material becomes much easier to magnetize, which means the magnetic domains reorient more easily. Manufacturers will incur more cost if they anneal the steel because they are adding another step to the manufacturing process and that increases production time. The necessary annealing equipment also requires a large capital investment.

Table 3.8 presents the core steels used in manufacturing electric motors, including some more efficient steels that are not as common, which DOE considered in its analysis. In addition to the steel grade name, the table presents nominal thickness and core losses at a fixed magnetic flux density.

Table 3.8 Core Steel Grades, Thicknesses, and Associated Losses

Steel Grade	Nominal Thickness (inches)	Core Loss at 60 Hz Watts per Pound at Magnetic Flux Density	Remarks
24 M56*	0.025	4.30 Watts/lb at 1.5 T†	Cold-rolled magnetic laminations (semi-processed)
26 M47*	0.019	2.80 Watts/lb at 1.5 T	Non-oriented electrical steel (fully processed)
24 M36*	0.025	2.35 Watts/lb at 1.5 T	Non-oriented electrical steel (fully processed)
24 M19*	0.025	2.00 Watts/lb at 1.5 T	Non-oriented electrical steel (fully processed)
29 M15*	0.014	1.45 Watts/lb at 1.5 T	Non-oriented electrical steel (fully processed)
Hiperco 50	0.006	1.00 Watts/lb at 1.5 T	Iron-cobalt-vanadium soft magnetic alloy

* Denotes a steel used in the engineering analysis.

†Watts of loss per pound of core steel are only comparable at the same magnetic flux density, measured in tesla. The tesla (symbol T) is the SI-derived unit of magnetic field, which is also known as "magnetic flux density."

3.3.2.1 Plastic Bonded Iron Powder

Recently, DOE became aware of a new technology that Lund University researchers in Sweden developed in the production of magnetic components for electric motors from plastic bonded iron powder (PBIP). The technique has the potential to cut production costs by 50 percent while doubling motor output.

The method uses two main ingredients: metal powder and plastics. Combining the ingredients creates a material with low conductivity and high permeability. The metal particles are surrounded by an insulating plastic, which prevents electric current from developing in the material. This is critical because it essentially eliminates losses in the core due to eddy currents. Properties of PBIP can differ depending on the processing. If the metal particles are too closely compacted and begin to touch, the material will gain electrical conductivity, counteracting one of its most important features.

Another advantage of PBIP is a reduction in the number of production steps. The number of steps in manufacturing a rotor and stator is reduced from roughly 60 to just a few. A second way to increase savings is to build an inductor with PBIP. During processing, the plastic and metal are molded together using a centrifugal force. During this process, the inductor core consisting of PBIP and pre-wound windings are baked into the core. This inductor is then used as a filter for grid power application. The filter then reduces the use of cooling equipment in the motor design.[7]

3.3.3 Technology Options for Friction and Windage Losses

Bearing friction and the cooling fan system create what is called "friction and windage losses" in AC induction motors. The bearing friction also adds heat to the motor's system which adds losses and decreases the motor's efficiency.

To decrease the losses caused by motor bearings, manufacturers can change the bearings or bearing lubricant. Less friction, and thus less heat, is produced when manufacturers use a better bearing structure or bearing lubricant, but manufacturers must also consider issues such as temperature rating and speed.

Another way to reduce heat in an induction motor is to use a better cooling system. Changing the fan or adding baffles to the ventilation system can help reduce the motor temperature rise and therefore losses. Baffles help redirect airflow through the motor, creating better circulation and an overall cooler-running motor. With a well-designed cooling system, the motor should run more efficiently.

3.3.4 Technology Options for Stray-Load Losses

Stray-load loss is defined as the difference between the total motor loss and the sum of the other four losses referred to above. Stray-load loss is caused by many factors. Manufacturers alter different design parameters to reduce stray-load losses, including slot combination, skew, rotor cage insulation, etc. Stator and rotor lamination design can contribute toward reducing the high frequency losses that occur to some degree in all induction motors. Careful attention to the design and manufacturing processing of the motor can significantly reduce the stray-load loss.

3.3.5 Summary of the Technology Options Under Consideration

Table 3.9 summarizes the technology options discussed in this preliminary TSD technology assessment and those that DOE will consider in the screening analysis (see chapter 4). The options that pass all four screening criteria are considered "design options" and are used in the engineering analysis (see preliminary TSD chapter 5) as a means of improving the efficiency of electric motors.

Table 3.9 Summary of Technology Options for Improving Efficiency

Type of Loss to Reduce	Technology Option Applied
Stator I^2R Losses	Increase copper wire diameter to maximize slot fill
	Reduce end turn length
	Increase stator slot size
Rotor I^2R Losses	Reduce rotor resistance by a change in volume or material conductivity
	Increase rotor slot size
	Manipulation rotor slot configuration
Core Losses	Select lamination with less watts loss/pound
	Optimize air gap
	Improve annealing process
	Add stack height (i.e., add electrical steel)
Friction and Windage Losses	Optimize bearing or lubrication selection
	Improve cooling system design
Stray-Load Losses	Optimize selection of rotor/stator slot combination
	Improve stator/rotor slot lamination designs
	Improve rotor surface machining

Most of the design changes suggested in Table 3.9 produce interacting effects on the motor's breakdown torque, locked rotor torque, locked rotor current, and so forth. Therefore, motor designers making a specific design change must evaluate the effects against all of a motor's performance characteristics and not just focus on efficiency.

REFERENCES

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[1] U.S. Small Business Administration. *Small Business Size Standards Matched to North American Industry Classification System.* 2007. (Last accessed November 09, 2011.) <http://www.sba.gov/sites/default/files/Size_Standards_Table.pdf> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

[2] National Electric Manufacturers Association. (Last accessed November 09, 2011.) <http://www.nema.org/about/upload/NEMACorpBrochure05.pdf> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

[3] National Electric Manufacturers Association. *NEMA Premium Efficiency Electric Motors Program.* 2008. (Last accessed November 09, 2011.) <http://www.nema.org/gov/energy/efficiency/premium/upload/nemaprem1p.doc> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

[4] National Electric Manufacturers Association. *NEMA Premium Product Scope and Nominal Efficiency Levels.* (Last accessed November 09, 2011.) <http://www.nema.org/stds/complimentary-docs/upload/MG1premium.pdf> The April November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

[5] Consortium for Energy Efficiency. *Industrial Programs Premium-Efficiency Motors*. 2008. (Last accessed November 09, 2011.) <http://www.cee1.org/ind/mot-sys/mtr-ms-main.php3> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

[6] Consortium for Energy Efficiency. *Energy-Efficiency Incentive Programs, Premium-Efficiency Motors and Adjustable Speed Drives in the U.S. and Canada*. May 2009. (Last accessed November 09, 2011.) < http://www.motorsmatter.org/tools/2009MotorsProgramSummaryv2.xls> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

[7] Horrdin, H., Olsson, E. *Technology Shifts in Power Electronics and Electric Motors for Hybrid Electric Vehicles: A Study of Silicon Carbide and Iron Powder Materials.* 2007. Chalmers University of Technology. Göteborg, Sweden.

CHAPTER 4. SCREENING ANALYSIS

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CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

The purpose of the screening analysis is to identify design options that improve electric motor efficiency and determine which options the Department of Energy (DOE) will either evaluate or screen out. DOE consults with industry, technical experts, and other interested parties in developing a list of design options for consideration. Then DOE applies the following set of screening criteria to determine which design options are unsuitable for further consideration in the rulemaking (1 Title 10 of the Code of Federal Regulations, Part 430, Subpart C, Appendix A at 4(a)(4) and 5(b)):

(1) *Technological feasibility*. Technologies incorporated in commercial products or in working prototypes will be considered technologically feasible.

(2) *Practicability to manufacture, install, and service*. If mass production of a technology in commercial products 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 DOE will consider that technology practicable to manufacture, install, and service.

(3) *Adverse impacts on product utility or product availability*. If DOE determines that a technology will have significant adverse impacts on the utility of the product to significant subgroups or consumers or result in the unavailability of any covered product type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products generally available in the United States at the time, that technology will not be considered further.

(4) *Adverse impacts on health or safety*. If DOE determines that a technology will have significant adverse impacts on health or safety, that technology will not be considered further.

This chapter discusses the design options that DOE considered for improving the energy efficiency of electric motors and describes how DOE applied the screening criteria.

4.2 DISCUSSION OF DESIGN OPTIONS

Several well-established engineering practices and techniques exist for improving the efficiency of an electric motor. Improving the construction materials (*e.g.*, the core steel, winding material, cooling system) and modifying the motor's geometric configuration (*i.e.*, the core and winding assemblies, the rotor, and stator) can make an electric motor more energy efficient.

As discussed in the market and technology assessment (chapter 3), there are four general areas of efficiency loss in electric motors: I^2R, core, friction and windage, and stray load. In the framework document DOE presented an initial list of technology options used to reduce energy consumption and thus improve the efficiency of general purpose induction motors. Unfortunately, methods of reducing electrical losses in the equipment are not completely independent of one another. This means that some technology options that decrease one type of loss may cause an increase in a different type of loss in the motor. Thus, it takes a great degree of engineering skill to maximize the efficiency gains in a motor design overall, balancing out the loss mechanisms. In some instances, motor design engineers must make design tradeoffs when finding the appropriate combination of materials and costs. However, there are multiple design pathways to achieve a given efficiency level.

Although I^2R and core losses account for the majority of the losses in an induction motor, friction and windage losses and stray load losses also contribute to the total loss. In an induction motor, friction and windage losses can manifest in the bearings, bearing lubricant, and cooling fan system. Any losses that are otherwise unaccounted for and not attributed to I^2R losses, steel losses, or frictional and windage losses are considered stray-load losses. General process changes to the manufacturing of rotors and stators could somewhat reduce these losses, such as removing the skew on the rotor bars, or improving the rotor bar insulation. However, these various technologies can constrain the design parameters of a motor and thus limit the improvement in efficiency.

Table 4.2.1 presents a general summary of the methods that a manufacturer may use to reduce losses in electric motors. The approaches presented in this table refer either to specific technologies (*e.g.*, aluminum versus copper die-cast rotor cages, different grades of electrical steel) or physical changes to the motor geometries (*e.g.*, cross-sectional area (CSA) of rotor conductor bars, additional stack height).

Table 4.2.1 Summary List of Options from Technology Assessment

Type of Loss to Reduce	Design Options Considered
I^2R Losses	Use copper die-cast rotor cage
	Decrease the length of coil extensions
	Increase cross-sectional area of rotor conductor bars
	Increase end ring size
	Increase the amount of copper wire in stator slots
	Increase the number of stator slots
Core Losses	Improve grades of electrical steel
	Use thinner steel laminations
	Add stack length (*i.e.*, add electrical steel laminations)
	Increase flux density in air gap
Friction and Windage Losses	Use bearings and lubricant with lower losses
	Install a more efficient cooling system
Stray Load Losses	Reduce skew on conductor cage
	Improve rotor bar insulation

4.3 DESIGN OPTIONS NOT SCREENED OUT OF THE ANALYSIS

This section discusses the technology options that DOE considers viable means of improving the efficiency of electric motors.

4.3.1 Copper Die-Cast Rotor Cage

Aluminum is the most common material used today to create die-cast rotor bars in electric motors. Some manufacturers that focus on producing high-efficiency designs have started to offer electric motors with die-cast rotor bars made of copper. Copper offers better performance than aluminum because, per unit area, copper has a higher electrical conductivity (*i.e.*, a lower electrical resistance). However, copper has a higher melting point than aluminum, so the casting process becomes more difficult and is likely to increase both production time and cost for manufacturing a motor.

Considering the four screening criteria for this technology option, DOE did not screen out copper as a die-cast rotor cage conductor material. Because this material is in commercial use today, DOE concluded that this material is technologically feasible and practicable to manufacture, install, and service. DOE is aware of the higher melting point of copper (1084 degrees Celsius versus 660 degrees Celsius for aluminum) and the potential impacts this may have on the health or safety of plant workers. However, DOE does not believe this impact is sufficiently adverse to screen out copper as a die cast material for rotor conductors. DOE understands many plants already deal with molten aluminum die casting processes and believes similar processes could be adopted for copper.

4.3.2 Decrease the Length of Coil Extensions

One method of reducing resistance losses in the stator is decreasing the length of the coil extensions at the end turns. Reducing the length of copper wire in the stator slots not only reduces the resistive losses, but also reduces the material cost of the electric motor because less copper is being used.

Considering the four screening criteria for this technology option, DOE did not screen out decreasing the length of the coil extensions as a means of improving efficiency. Motor design engineers adjust this particular variable when manufacturing to obtain performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with decreasing the length of coil extensions to obtain increased efficiency.

4.3.3 Increase Cross-Sectional Area of Rotor Conductor Bars

Increasing the cross-sectional area of the rotor conductor bars, either by making the diameter of the conductor bars larger or changing the cross-sectional geometry of the rotor, can improve motor efficiency. Increasing the cross-sectional area of the rotor conductor bars will decrease the resistance, increase current flow, and lower losses. However, changing the shape of the rotor bars may affect the size of the end rings and can also change the torque characteristics of the motor.

Considering the four screening criteria for this technology option, DOE did not screen out increasing the cross-sectional area of rotor conductor bars as a means of improving efficiency. Motor design engineers adjust this particular variable when manufacturing to obtain performance and efficiency targets. The rotor conductor bars are created by automated production equipment that have certain tolerances and allow variance in this parameter. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with increasing the cross-sectional area of rotor conductor bars to obtain increased efficiency.

4.3.4 Increase End Ring Size

The end rings create an electrical connection between the rotor bars. Increasing the size of the end rings reduces the resistance and thus lowers the I^2R losses in the end rings.

Considering the four screening criteria for this technology option, DOE did not screen out increasing end ring size as a means of improving efficiency. As with some of the previous technology options, motor design engineers adjust this variable when manufacturing an electric motor to achieve performance and efficiency targets. Automated production and casting equipment, which allow some degree of variability, determine the end ring size. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with increasing the size of the rotor end rings to obtain increased efficiency.

4.3.5 Increase the Amount of Copper Wire in the Stator Slots

Increasing the slot fill by either adding windings or changing the gauge of wire used in the stator winding can also increase motor efficiency. Motor design engineers can achieve this by manipulating the wire gauges to allow for a greater total cross-sectional area of wire to be incorporated into the stator slots. This could mean either an increase or decrease in wire gauge, depending on the dimensions of the stator slots and insulation thicknesses. As with the benefits associated with larger cross-sectional area of rotor conductor bars, using more total cross-sectional area in the stator windings decreases the winding resistance and associated losses. However, this change could affect the packing factor of the wire in the stator slots. The stator slot openings must be able to fit the wires so that automated machinery or manual labor can pull (or push) the wire into the stator slots.

Considering the four screening criteria for this technology option, DOE did not screen out changing gauges of copper wire in the stator as a means of improving efficiency. Motor design engineers adjust this technology option in fractions of a half a gauge when manufacturing an electric motor to achieve desired performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with changing the wire gauges in the stator to obtain increased efficiency.

4.3.6 Increase the Number of Stator Slots

Increasing the number of stator slots associated with a given motor design can improve motor efficiency. Similar to increasing the amount of copper wire in a particular slot, increasing the number of slots can allow the motor design engineer to incorporate more overall copper into the stator slots. This decreases the losses in the windings, but can also affect motor torque and performance (including efficiency).

Considering the four screening criteria for this technology option, DOE did not screen out increasing the number of stator slots as a means of improving efficiency. Motor design engineers modify this technology to achieve desired performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with changing stator slot sizes to obtain increased efficiency.

4.3.7 Higher Quality Electrical Steel in Core

Losses generated in the electrical steel in the core of an induction motor can be significant. Generally, these losses are classified as either hysteresis or eddy current. Hysteresis losses are caused by magnetic domains resisting reorientation to the alternating magnetic field. Eddy currents are physical currents that are induced in the steel laminations by the magnetic flux produced by the current in the windings. Both of these losses generate heat in the electrical steel.

In studying the techniques used to reduce steel losses, DOE considered two types of materials: conventional silicon steel and “exotic” steels, which contain a relatively high percentage of boron or cobalt. Conventional steels are commonly used in electric motors manufactured today. There are three types of steel that DOE considers “conventional:” cold-rolled magnetic laminations, fully processed non-oriented electrical steel, and semi-processed non-oriented electrical steel.

One way to reduce hysteresis losses is to incorporate a higher grade of core steel into the electric motor design (*e.g.*, switching from an M56 to an M19). Even for the same thickness (*i.e.*, gauge) of core steel lamination, losses are reduced as the grain size increases, thus reducing magnetic resistance to reorientation by the alternating current.

The exotic steels are not generally manufactured for use specifically in the electric motors covered in this rulemaking. These steels include vanadium permendur and other alloyed steels containing a high percentage of boron or cobalt. These steels offer a lower loss level than the best electrical steels, but are more expensive per pound. In addition, these steels can present manufacturing challenges because they come in non-standard thicknesses that are difficult to manufacture.

Considering the four screening criteria for this technology option, DOE did not screen out higher quality, more efficient electrical steel in the core as a means of improving efficiency. Design engineers use this approach to achieve desired performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with improving the electrical steel.

4.3.8 Thinner Steel Laminations

DOE can use thinner laminations of core steel to reduce eddy currents. DOE can either change grades of electrical steel as described above, or use a thinner gauge of the same grade of electrical steel. The magnitude of the eddy currents induced by the magnetic field becomes smaller in thinner laminations, making the motor more energy efficient.

Considering the four screening criteria for this technology option, DOE did not screen out thinner steel laminations as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with using thinner steel laminations.

4.3.9 Additional Stack Length

Adding electrical steel to the rotor and stator to lengthen the motor can also reduce the efficiency losses in steel. Lengthening the motor by increasing stack length reduces the magnetic flux density, which reduces hysteresis losses. However, increasing the stack length affects other performance attributes of the motor, such as starting torque. Issues can arise when installing a more efficient motor with additional stack height because the motor becomes longer and therefore may not fit into applications with dimensional constraints.

Considering the four screening criteria for this technology option, DOE did not screen out additional stack height as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option technologically feasible. Regarding the second screening criterion–practicable to manufacture, install, and service–DOE is concerned that increasing motor length makes installation of these motors too problematic. However, DOE recognizes that many motor applications are not constrained by motor length. Thus, DOE believes that this technology option meets the second screening criterion. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with increased stack height.

4.3.10 Increase Flux Density in Air Gap

Another technology option to improve electric motor efficiency is to increase the flux density across the air gap. Typically, the efficiency will increase as the air gap flux density increases as long as the steel laminations are not saturated. Once saturation is reached, core losses increase at a much faster rate than rotor losses thereby negating any efficiency increases beyond the saturation point. Additionally, increasing the flux density also increases the in-rush current. Electric motor designers need to take these limitations into account when using increased air gap flux density to increase overall electric motor efficiency.

Considering the four screening criteria for this technology option, DOE did not screen out increasing the air gap flux density as a means of improving efficiency. DOE recognizes that increasing the air gap flux density is a means design engineers use to achieve desired performance and efficiency targets. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with increasing the air gap flux density.

4.3.11 Better Bearings and Lubricant

Another technology option to improve the efficiency of electric motors is using better ball bearings and a lower-friction lubricant. Using improved bearings and lubricants minimizes mechanical resistance to the rotation of the rotor, which also extends motor life.

Considering the four screening criteria for this technology option, DOE did not screen out better ball bearings and lubricants as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with better ball bearings and lubricant.

4.3.12 More Efficient Cooling System

Using a more efficient cooling system that circulates air through the motor is another technology option to improve the efficiency of electric motors. Improving the cooling system reduces air resistance and associated frictional losses and decreases the operating temperature (and associated electrical resistance) by cooling the motor during operation. This can be accomplished by changing the fan or adding baffles to the current fan to help redirect airflow through the motor.

Considering the four screening criteria for this technology option, DOE did not screen out a more efficient cooling system as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with improved cooling systems for electric motors.

4.3.13 Reduce Skew on Conductor Cage

In the rotor, the conductor bars are not straight from one end to the other, but skewed or twisted slightly around the axis of the rotor. Decreasing the degree of skew can improve a motor's efficiency. The conductor bars are skewed to help eliminate harmonics that add cusps, losses, and noise to the motor's speed-torque characteristics. Reducing the degree of skew can help reduce the rotor resistance and reactance, which helps improve efficiency. However, overly reducing the skew also may have adverse effects on starting, noise, and the speed-torque characteristics.

Considering the four screening criteria for this technology option, DOE did not screen out adjusting rotor skew as a means of improving efficiency. Rotor skew is one of the variables that motor design engineers can manipulate to obtain certain performance and efficiency targets. The rotor skew is part of the overall motor design, which is input into automated production equipment that punches and stacks the steel to create a rotor with the desired skew. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with properly manipulating the rotor skew to obtain improved performance.

4.3.14 Improved Rotor Bar Insulation

One major source of stray losses in electric motors is inter-bar currents flowing through the laminations between rotor bars. These currents can be reduced by using improved insulation materials between the rotor bars and the steel laminations.

Considering the four screening criteria for this technology option, DOE did not screen out improved rotor bar insulation as a means of improving efficiency. Design engineers use this approach to achieve desired improvements in performance and efficiency. Because this design technique is in commercial use today, DOE considers this technology option both technologically feasible and practicable to manufacture, install, and service. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with improved rotor bar insulation.

4.3.15 Summary of Technology Options Not Screened Out

Table 4.3.1 summarizes the design options that DOE did not screen out of the analysis.

Table 4.3.1 Summary List of Options from Technology Assessment

Type of Loss to Reduce	Design Options Considered
I^2R Losses	Use copper die-cast rotor cage
	Decrease the length of coil extensions
	Increase cross-sectional area of rotor conductor bars
	Increase end ring size
	Increase the amount of copper wire in stator slots
	Increase the number of stator slots
Core Losses	Improve grades of electrical steel
	Use thinner steel laminations
	Add stack length (*i.e.*, add electrical steel laminations)
	Increase flux density in air gap
Friction and Windage Losses	Use bearings and lubricant with lower losses
	Install a more efficient cooling system
Stray Load Losses	Remove skew on conductor cage
	Improve rotor bar insulation

4.4 DESIGN OPTIONS SCREENED OUT OF THE ANALYSIS

DOE screened out the following design options from further consideration because they do not meet the screening criteria.

4.4.1 Amorphous Metal Laminations

Using amorphous metals in the rotor laminations is another technology option to improve the efficiency of electric motors. Amorphous metal is extremely thin, has high electrical resistivity, and has little or no magnetic domain definition. Because of amorphous steel's high resistance it exhibits a reduction in hysteris and eddy current losses, which reduce overall losses in electric motors. However, amorphous steel is a very brittle material which makes it difficult to punch into motor laminations.[a]

Considering the four screening criteria for this technology option, DOE screened out amorphous metal laminations as a means of improving efficiency. Although amorphous metals have the potential to improve efficiency, DOE does not consider this technology option technologically feasible, because it has not been incorporated into a working prototype of an electric motor. Furthermore, DOE is uncertain whether amorphous metals are practicable to manufacture, install, and service, because a prototype amorphous metal electric motor has not been made and little information is available on the ability to manufacture this technology to make a judgment. DOE is not aware of any adverse impacts on consumer utility, reliability, health, or safety associated with improved cooling systems for electric motors.

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[a] S.R. Ning, J. Gao, and Y.G. Wang. *Reviewon Applications of Low Loss Amorphous Metals in Motors.* 2010. ShanDong University. Weihai, China.

4.4.2 Plastic Bonded Iron Powder

Plastic bonded iron powder (PBIP) could cut production costs while increasing the output of electric motors. Although other researchers may be working on this technology option, DOE is aware of a research team at Lund University in Sweden that published a paper about PBIP. This technology option is based on an iron powder alloy that is suspended in plastic, and is used in certain motor applications such as fans, pumps, and household appliances.[1] The compound is then shaped into motor components using a centrifugal mold, reducing the number of manufacturing steps. Researchers claim that this technology option could cut losses by as much as 50 percent. The Lund University team already produces inductors, transformers, and induction heating coils using PBIP, but has not yet produced an electric motor. In addition, it appears that PBIP technology is aimed at torus, claw-pole, and transversal flux motors, none of which fall under DOE's scope of analysis as defined by the Energy Policy and Conservation Act, as amended by the Energy Independence and Security Act.

Considering the four screening criteria for this technology option, DOE screened out PBIP as a means of improving efficiency. Although PBIP has the potential to improve efficiency while reducing manufacturing costs, DOE does not consider this technology option technologically feasible, because it has not been incorporated into a working prototype of an electric motor. Also, DOE is uncertain whether the material has the structural integrity to form into the necessary shape of an electric motor steel frame. Furthermore, DOE is uncertain whether PBIP is practicable to manufacture, install, and service, because a prototype PBIP electric motor has not been made and little information is available on the ability to manufacture this technology to make a judgment. However, DOE is not aware of any adverse impacts on product utility, product availability, health, or safety that may arise from the use of PBIP in electric motors.

4.4.3 Summary of Technology Options Screened Out of the Analysis

Table 4.4.1 shows the criteria DOE used to screen amorphous metal laminations and plastic bonded iron powder (PBIP) out of the analysis.

Table 4.4.1 Design Options Screened Out of the Analysis

Design Option	Screening Criteria
Amophous Metals	Technological feasibility
PBIP	Technological feasibility

REFERENCES

[1] Horrdin, H., and E. Olsson. *Technology Shifts in Power Electronics and Electric Motors for Hybrid Electric Vehicles: A Study of Silicon Carbide and Iron Powder Materials.* 2007. Chalmers University of Technology. Göteborg, Sweden.

CHAPTER 5. ENGINEERING ANALYSIS

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LIST OF ACRONYMS AND ABBREVIATIONS

A	ampere
AC	alternating current
AWG	American wire gauge
BOM	bill of materials
CSL	candidate standard level
DOE	United States Department of Energy
EISA	Energy Independence and Security Act of 2007
IEC	International Electrotechnical Commission
in	inch
lbs	pounds
M*	M15, M19, M36, M47, M56 - grade of core steel
MSP	manufacturer selling price
Nm	Newton meter
NCI	Navigant Consulting, Inc.
NEMA	National Electrical Manufacturers Association
NIA	national impact analysis
RPM	revolutions per minute
SEC	Securities and Exchange Commission
SME	subject matter expert
TSD	technical support document
U.S.	United States
V	volt

CHAPTER 5. SCREENING ANALYSIS

5.1 INTRODUCTION

The engineering analysis estimates the increase in manufacturer selling price (MSP) associated with technological design changes that improve the efficiency of an electric motor. This chapter presents the U.S. Department of Energy's (DOE's) assumptions, methodology and findings for the electric motor engineering analysis. The output from the engineering analysis is a "cost-efficiency" relationship for each electric motor analyzed which describes how its cost changes as efficiency increases. The output of the engineering analysis is used as an input to the life-cycle cost analysis (preliminary Technical Support Document (preliminary TSD) chapter 8) and the national impact analysis (preliminary TSD chapter 10).

The engineering analysis takes input from the market and technology assessment (see preliminary TSD chapter 3) and the screening analysis (see preliminary TSD chapter 4). These inputs include equipment classes, baseline electric motor performance, methods for improving efficiency, and design options that have passed the screening criteria. The engineering analysis uses these inputs, coupled with material price estimates, design parameters, and other manufacturer inputs to develop the relationship between the MSP and nominal full-load efficiency of the representative electric motors studied.

At its most basic level, the output of the engineering analysis is a curve that estimates the MSP for a range of efficiency values. This output is subsequently marked-up to determine the end-user prices based on the various distribution channels (see preliminary TSD chapter 6). After determining customer prices by applying distribution chain markups, sales tax, and contractor markups, the data is combined with the energy-use and end-use load characterization (see preliminary TSD chapter 7) and used as a critical input to the customer's life-cycle cost and payback period analysis (see preliminary TSD chapter 8).

The results presented in this chapter do not provide a full assessment of a manufacturer's costs associated with increasing efficiency levels for an electric motor. The relationship presented in this chapter assumes an ideal situation, where the manufacturer does not incur any costs associated with retooling, product redesign, training, or marketing associated with incorporating design changes to its equipment lines to achieve the efficiency levels presented. In the notice of proposed rulemaking stage of the rulemaking, DOE will attempt to quantify the additional costs that the manufacturer would incur when complying with mandatory efficiency standards. For discussion of these costs and DOE's methodology for quantifying them, see preliminary TSD chapter 12, the preliminary manufacturer impact analysis.

In this chapter, DOE discusses the equipment classes analyzed and the representative electric motors selected from all motors considered for energy conservation standards. As discussed in chapters 2 and 3 of this TSD, the electric motors in the scope of coverage of this rulemaking include single-speed, squirrel-cage induction, alternating current (AC), polyphase motors from 1 to 500 horsepower and National Electrical Manufacturers Association (NEMA) Design A, B, and C electric motors, including fire pump electric motors. The engineering analysis selected three NEMA Design B electric motors to analyze the NEMA Design A and B equipment class group and two NEMA Design C electric motors to analyze the NEMA Design C equipment class group. The fire pump electric motor equipment class group will be based on the three NEMA Design B electric motors. DOE also presents the methodology, inputs, and results associated with the development of MSP versus efficiency curves for each of the representative electric motors. Finally, DOE discusses the approach used to scale the engineering analysis to all other equipment classes for the national impact analysis.

5.2 EQUIPMENT CLASSES AND REPRESENTATIVE UNITS ANALYZED

Due to the large number of equipment classes, DOE did not directly analyze all covered electric motors. Instead, DOE selected certain equipment classes to directly analyze after reviewing electric motors shipments, examining manufacturers' catalog data, and soliciting feedback from interested parties. The equipment classes that DOE directly analyzes and focuses its engineering analysis on are referred to as representative units. Table 5.1 shows the equipment class groups discussed in preliminary TSD chapter 3 and the corresponding electric motor designs they encompass. As mentioned above, DOE selected three representative units to analyze in equipment class group 1 and two representative units in equipment class group 2. For equipment class group 3, DOE plans on developing any potential amended energy conservation standards based off of its analysis of equipment class group 1 because fire pump electric motors are required to meet National Electrical Manufacturers Association (NEMA) Design B performance standards.

Table 5.1 Electric Motor Equipment Class Groups

Equipment Class Group	Electric Motor Design Type	Horsepower Rating	Pole Configuration	Enclosure
1	NEMA Design A & B*	1-500	2, 4, 6, 8	Open
				Closed
2	NEMA Design C*	1-200	2, 4, 6, 8	Open
				Closed
3	Fire Pump*	1-500	2, 4, 6, 8	Open
				Closed

*Includes International Electrotechnical Commission (IEC) equivalent design types.

DOE considered each of the characteristics listed in Table 5.1when selecting its representative units. The sections that follow describe the decisions that DOE made with respect to each of these electric motor characteristics.

5.2.1 Electric Motor Design Type

For equipment class group 1 that includes NEMA Design A and B electric motors, DOE only selected NEMA Design B motors as representative units to analyze in the engineering analysis. DOE chose NEMA Design B electric motors because NEMA Design A electric motors can generally meet NEMA Design B efficiency levels due to their less stringent locked-rotor current limits. In other words, NEMA Design B motors slightly limit the incremental increase in energy conservation standards that could be technologically feasible. However, by directly analyzing NEMA Design B motors, it ensures that any potential amendments to the current energy conservation standards could be met by all motors covered in equipment class group 1. Additionally, NEMA Design B units have much higher shipment volumes than NEMA Design A motors. Figure 5.1 shows the relative shipments of each electric motor design type, which demonstrates that NEMA Design B motors constitute the vast majority of all shipments with a market share of 98.7 percent. Finally, by choosing NEMA Design B motors, DOE could also apply the results of its equipment class group 1 analysis to its equipment class group 3 analysis because fire pump motor designs are held to very similar design constraints as NEMA Design B motors.

For equipment class group 2, DOE selected two representative units to analyze directly. Because Design C is the only NEMA design type covered by this equipment class group, DOE only selected NEMA Design C motors for analysis as its representative units.

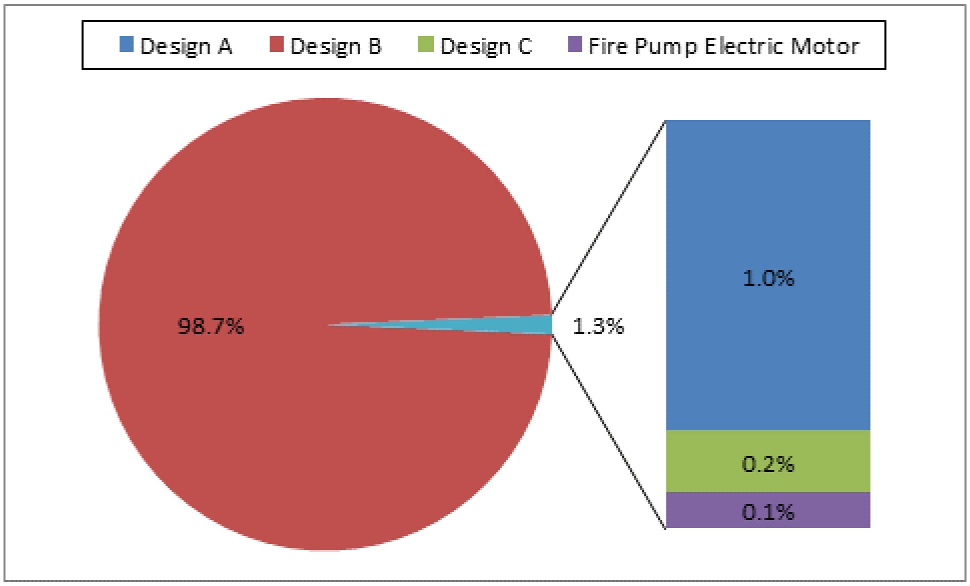

Figure 5.1 Electric Motor Shipments by Design Type for 2011

5.2.2 Horsepower Rating

Horsepower rating is an important equipment class setting criterion, which DOE received multiple comments about when developing its representative units. When DOE selected its preliminary analysis representative units, DOE chose those horsepower ratings that constitute a high volume of shipments in the market and provide a sufficiently wide range upon which DOE could reasonably base a scaling methodology. For NEMA Design B motors, for example, DOE chose 5-, 30-, and 75-horsepower-rated electric motors to analyze as representative units. DOE selected the 5-horsepower rating because it is the rating with the highest shipment volume of the electric motors considered. Figure 5.2 shows shipments of electric motors broken down by horsepower rating and demonstrates that the 5-horsepower rating constituted nearly 15 percent of shipments in 2011. DOE selected the 30-horsepower rating as an intermediary between the small and large frame number series electric motors. For the largest frame number series, DOE elected to analyze a 75-horsepower rated electric motor. DOE believes that this rating is an appropriate choice to represent the highest horsepower ratings because there tends to be minimal change in efficiency at the highest horsepower ratings. For consecutive horsepower ratings above 75, the nominal efficiencies that motors must meet in order to be deemed NEMA Premium tend to repeat.

For NEMA Design C electric motors, DOE only selected two horsepower ratings because of the relatively low shipment volumes. As with NEMA Design B motors, DOE elected to analyze the 5-horsepower rating because of its relatively high market share. For an upper bound, DOE selected the 50-horsepower rating.

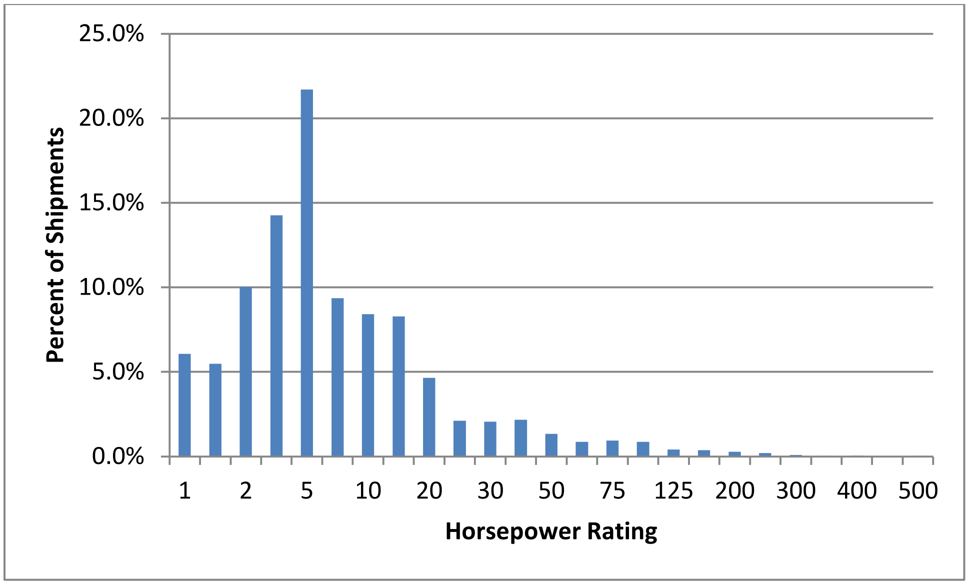

Figure 5.2 Electric Motors Shipments by Horsepower Rating for 2011

5.2.3 Pole-Configuration

Pole-configuration is another important equipment class setting criterion which DOE had to consider when selecting its representative units. For the preliminary analysis, DOE selected 4-pole motors for all of its representative units. DOE chose not to vary the pole configuration of the various representative units it analyzed because it believed that doing so would provide the strongest relationship upon which to base its scaling. By keeping as many design characteristics constant as possible, DOE could more accurately identify how design changes affect efficiency across horsepower ratings. For example, if DOE compared the NEMA Premium efficiencies of a 5-horsepower, 4-pole electric motor and 50-horsepower, 6-pole electric motor it would be difficult to determine how much of the difference was due to the change in horsepower rating and how much was due to the change of pole configuration. Additionally, DOE believes that the horsepower rating-versus-efficiency relationship is the most important (rather than pole configuration and enclosure-type versus efficiency) because there are significantly more horsepower ratings to consider. Finally, as illustrated in Figure 5.3, 4-pole electric motors constitute the largest fraction of the electric motors market. Electric motors built with 4-poles accounted for 69 percent of shipments in 2011, which was more than 2-pole, 6-pole, and 8-pole motor shipments combined.

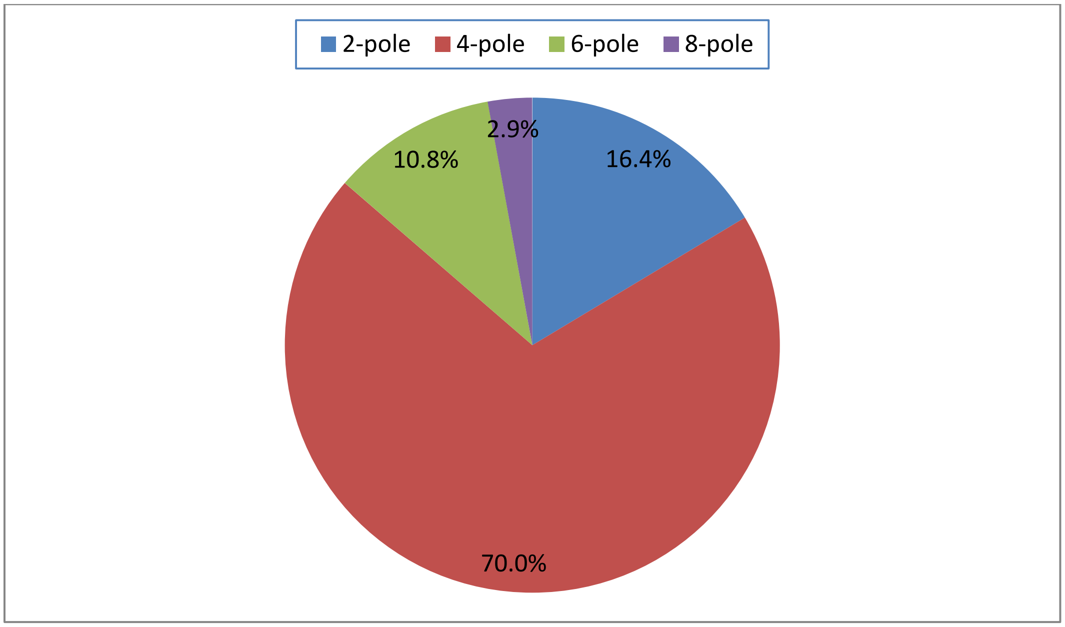

Figure 5.3 Electric Motor Shipments by Pole Configuration for 2011

5.2.4 Enclosure Type

The final equipment class setting criterion that DOE had to consider when selecting its representative units was enclosure type. For the preliminary analysis, DOE elected to only analyze electric motors with totally enclosed, fan-cooled (TEFC) designs rather than open designs for all of its representative units. DOE selected TEFC motors because, as with pole configurations, DOE wanted as many design characteristics to remain constant as possible. Again, DOE believed that such an approach would allow it to more accurately identify the reasons for efficiency improvements. Finally, TEFC electric motors represented more than three times the shipment volume of open motors. Figure 5.4 shows the relative shipments of open and enclosed motors in the year 2011.

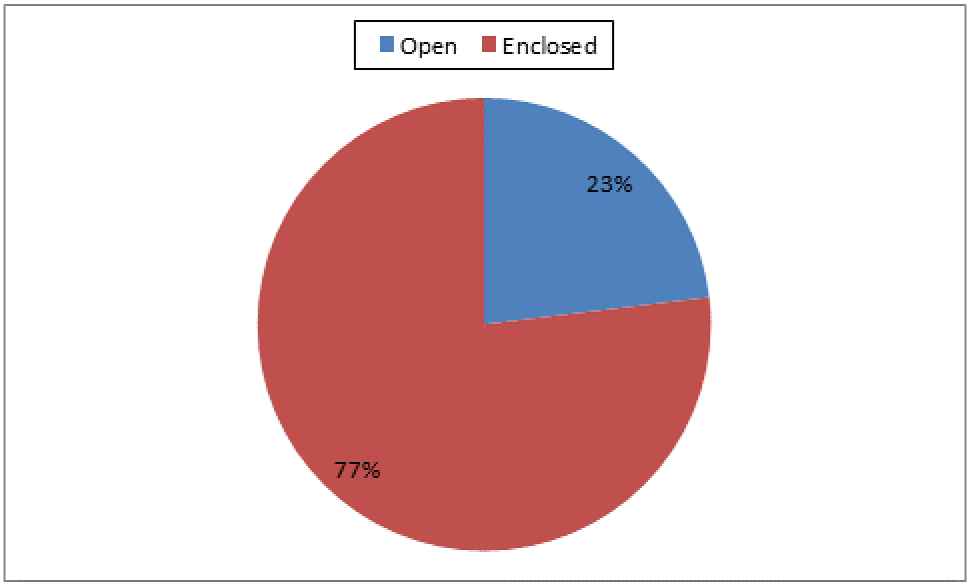

Figure 5.4 Electric Motor Shipments by Enclosure Type for 2011

As addressed above, when identifying which electric motors to evaluate, DOE considered equipment classes that represented motors with a significant volume of shipments. DOE also considered the necessity for scaling its engineering results. Therefore, DOE selected electric motors that would minimize any error that might be introduced through extrapolating between horsepower ratings, pole configurations, and enclosure types. As is discussed in section 5.7, DOE scaled the engineering analysis results of its analyzed representative units to all of the other, not-analyzed, equipment classes. Such scaling is necessary for the national impacts analysis (NIA). For more information on the NIA, please see preliminary TSD chapter 10. Table 5.2 presents the major design characteristics of the five representative units that DOE analyzed and will discuss in detail throughout this engineering analysis.

Table 5.2 Design Characteristics of the Five Representative Units Analyzed

Equipment Class Group Represented	Electric Motor Design Type	Horsepower Rating	Pole Configuration	Enclosure
1 and 3	NEMA Design B	5	4	Totally Enclosed, Fan Cooled
1 and 3	NEMA Design B	30	4	Totally Enclosed, Fan Cooled
1 and 3	NEMA Design B	75	4	Totally Enclosed, Fan Cooled
2	NEMA Design C	5	4	Totally Enclosed, Fan Cooled
2	NEMA Design C	50	4	Totally Enclosed, Fan Cooled

5.2.5 Equipment Class Group 1 (NEMA Design A and B Electric Motors)

DOE decided to focus the analysis of NEMA Design A and NEMA Design B electric motors on three representative units. When selecting these representative units, DOE used the data in Figure 5.2 and Figure 5.11 to select three representative units with high shipping volume that also evenly cover the entire range of horsepower ratings in the scope of this analysis. The graph in Figure 5.11 shows the average efficiencies of 4-pole, enclosed electric motors versus horsepower rating. This data was based on DOE’s electric motor database which was compiled from the most current electric motor manufacturer catalog data available. DOE analyzed this curve and segmented the graph into three primary sections.

5.2.6 Equipment Class Group 2 (NEMA Design C Electric Motors)

When selecting the representative units for equipment class group 2 (NEMA Design C electric motors), DOE referred again to Figure 5.2 which also represents the shipment volumes of NEMA Design C electric motors. Based on Figure 5.2, DOE selected a 5-horsepowerelectric motor again because of its high volume of shipments. To cover the higher horsepower ratings, DOE selected a 50-horsepower electric motor. DOE chose to base the analysis on the NEMA Design C equipment class group on two electric motors instead of three due to the lower production volumes of NEMA Design C electric motors and therefore somewhat limited equipment selection. DOE selected the 50-horsepowerrating because it falls between the 30-horsepower and 75-horsepowerratings selected as representative units for equipment class group 1.

5.2.7 Equipment Class Group 3 (Fire Pump Electric Motors)

According to National Fire Protection Association (NFPA) 20,*Standard for the Installation of Stationary Pumps for Fire Protection*, a motor that is used with a fire pump system must comply with NEMA MG1, comply with NEMA Design B standards, and be listed for fire pump service. So, with a few exceptions, fire pump electric motors are very similar to NEMA Design B electric motors. Namely, fire pump electric motors are not required to shut off if they are overheating, and they require more rigorous start/stop capabilities than general purpose NEMA Design B electric motors. Aside from these operating differences, fire pump electric motors are electromechanically similar to NEMA Design B electric motors. Therefore, DOE decided to base the analysis of fire pump electric motors on the engineering data produced from the representative units chosen for equipment class group1.

5.3 BASELINE AND CANDIDATE STANDARD LEVELS OF EFFICIENCY

For each representative unit selected, DOE identified a specific baseline electric motor as a fundamental design against which it would apply design changes to improve the electric motor's efficiency. DOE chose the baseline electric motors to represent the typical characteristics of electric motors in the equipment class of the corresponding representative unit. The baseline efficiency level is used to determine energy savings and changes in price associated with moving to higher efficiency levels. Energy efficiency levels are termed "candidate standard levels" (CSLs) and are intended to help characterize the cost-efficiency relationship. Table 5.3 shows these efficiency levels for each of DOE's selected representative units.

Table 5.3 Baseline Efficiency Ratings of Representative Units

Basic Characteristics of Electric Motors Analyzed	Baseline Efficiency %	Equipment Class Group
Design B, 5-horsepower, 4-pole, enclosed frame	82.5	1*
Design B, 30-horsepower, 4-pole, enclosed frame	89.5	1*
Design B, 75-horsepower, 4-pole, enclosed frame	93.0	1*
Design C, 5-horsepower, 4-pole, enclosed frame	87.5	2
Design C, 50-horsepower, 4-pole, enclosed frame	93.0	2

*Analysis of equipment class group 3 will be based on these representative units.

As discussed in chapters 2 and 3, DOE intends to expand the scope of energy conservation standards to include motors that were not previously covered by regulation. Those motor types not previously covered and that are now within the scope of coverage are listed in chapter 3 of the preliminary TSD. DOE used a motor database of efficiencies and up-to-date manufacturer motor catalogs to find motors with the lowest market efficiency. Since the expanded scope of energy conservation standards includes motors not previously subject to efficiency standards, DOE selected motors whose baseline efficiencies were below the lowest energy conservation levels currently enforced for any motors (levels most recently prescribed by EISA 2007). DOE observed NEMA Design B vertical, hollow-shaft motors, currently outside the scope of regulation, with efficiency levels listed in Table 5.3. For the NEMA Design C equipment class group, DOE selected NEMA MG1-2011 Table 12-11 values as baseline efficiency levels. This approach is based on the lowest efficiency values DOE observed in motor catalogs for NEMA Design C motors. The NEMA Design C representative motors with the lowest observed efficiencies are also listed in Table 5.3.

Should DOE not find any economic justification for amended energy conservation standards above the baseline efficiency level, subtype I and subtype II motors would remain subject to the same efficiency levels (i.e., different from each other) mandated by EISA 2007. Additionally, DOE notes that although the efficiencies in Table 5.3 represent the baseline, DOE's efficiency distribution for equipment class group 1 shows a significant portion of motors already above the baseline efficiency level.

5.3.1 Candidate Standard Levels of Efficiency

NEMA MG1-2011 contains a table of standardized "nominal" full load efficiency values, Table 12-10, from which manufacturers may choose a value to label and market their electric motors. NEMA uses these standardized values of efficiency because of the variability in the performance of materials used in electric motors, such as electrical steel and copper, and the laboratory to laboratory test variation that can occur. Because of these possible sources of performance variation, NEMA and its members in industry use these standardized values of efficiencies, with associated guaranteed minimum values of efficiencies, to represent a specific electric motor model's efficiency with a "band" of efficiency. The standardized values of NEMA nominal efficiencies found in Table 12-10 of NEMA MG1-2011 are fairly evenly spaced in terms of motor losses.[a] Each higher, incremental level of nominal efficiency represents a reduction in motor losses of roughly 10 percent. DOE followed a similar pattern when developing its higher CSLs (i.e., those above NEMA MG1-2011 Table 12-12 and Table 12-11).

As mentioned earlier, DOE selected a baseline model for each representative unit as a reference point against which to measure changes that may result from increasing an electric motor's efficiency. Each increase in efficiency over the baseline level that DOE analyzed was assigned a CSL number. For the preliminary analysis, DOE based its baseline efficiency level, or CSL 0, on the lowest efficiency levels observed in motor catalog data for the motors DOE plans on including in the expanded scope of conservation standards. DOE selected five additional incremental CSLs for equipment class group 1 and three additional incremental CSLs for equipment class group 2 based on other industry specifications, market data, and software modeling.

Table 5.4 shows the CSLs for equipment class group1that DOE used for electric motors during the preliminary analysis. DOE based its first incremental CSL (CSL 1) on NEMA MG1-2011, Table 12-11 and Table 20-A[b], which specify the nominal efficiency levels for motors that NEMA classifies as "energy efficient." Table 12-11 is equivalent to the EPACT 1992 levels for 1 to 200 horsepower NEMA Design B electric motors and the EISA 2007 levels for NEMA Design B electric motors with a horsepower rating greater than 200. EISA 2007 also mandated that general purpose electric motors (subtype I) from 1 to 200 horsepower meet efficiency levels

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[a] Motor losses are calculated with the formula $(1/\eta)-1$, where η represents the value of efficiency.

[b] NEMA MG1-2011 Table 20-A includes efficiency levels for 6- and 8-pole motors at higher horsepower ratings (between 300 and 500 horsepower) that are omitted from Table 12-11. Table 20-A is a new addition to NEMA MG1-2011, and therefore the efficiency levels it specifies are not part of the most recent conservation standards set by EISA 2007.

that correspond to NEMA MG1-2011, Table 12-12 (i.e., equivalent to NEMA Premium levels). However, equipment class group 1 includes motors that are considered general purpose electric motors (subtype II). For these electric motors, EISA 2007 mandated efficiency standards equivalent to Table 12-11, which is why DOE believes Table 12-11 is the appropriate CSL 1 to represent equipment class group 1.

Table 5.4 Candidate Standard Levels

CSL Number	CSL Name	NEMA MG1-2011 Table	Note
0	Baseline	--	Lowest observed efficiency under expanded scope
1	Standard	12-11 & 20-A	EPACT 1992 requirement, with additional efficiency levels added in NEMA MG1-2011
2	Premium	12-12 & 20-B	EISA 2007 requirement for general purpose electric motors (subtype I), with additional efficiency values added in NEMA MG1-2011
3	Best-in-Market	--	One NEMA nominal efficiency level improvement relative to the Premium level
4	Incremental	--	One NEMA nominal efficiency level improvement relative to the Best-in-Market
5	Maximum Technology	--	One NEMA nominal efficiency level improvement relative to CSL 3

DOE based its second incremental CSL (CSL 2) on the NEMA Premium efficiency levels, found in NEMA MG1-2011 Tables 12-12 and 20-B. These tables typically represent a two or three NEMA band improvement above the previously mandated EPACT 1992 levels displayed in NEMA MG1-2011 Table 12-11. The third incremental CSL (CSL 3) is based on motors with the highest efficiencies observed in DOE's motor database and up-to-date motor catalogs. Therefore CSL 3 motors have the "best-in-market" efficiencies for equipment class group 1 (ECG 1). This level was generally one NEMA band above the NEMA Premium level, or CSL 2. This level represents the best or near best efficiency level at which current manufacturers are producing electric motors. CSL 4 represents an incremental level between the maximum available efficiency and the maximum technology ("max-tech") CSL. CSL 4 is based on a theoretical efficiency achievable using technologically feasible design options that were not screened out. CSL 5 represents the maximum technologically available or "max-tech" efficiency level. CSL 5 is based on a motor which incorporates a combination of the best materials potentially available for high-production motor manufacturing. This includes low-loss electrical steel and copper rotor motor technology. DOE based its value of efficiencies for CSL 4 and 5 on computer-modeled designs and subject matter expert (SME) feedback.

The CSLs for NEMA Design C motors (equipment class group 2) were selected differently than for equipment class group 1. For equipment class group 2, DOE selected the NEMA MG1-2011 Table 12-11 values as the baseline efficiency level. This approach is based on the lowest efficiency values DOE observed in manufacturer catalogs for NEMA Design C motors, which apparently are the EPACT 1992 equivalent efficiency levels (as mandated by EISA 2007 under 'general purpose electric motor (subtype II)'). Further CSLs for ECG 2 were selected based on computer modeling results, and are displayed in Table 5.5.

Table 5.5 shows the nominal efficiency values for each representative unit and each CSL. Cells with a '†' indicate the efficiency number is a NEMA nominal nameplate efficiency rating of a physical electric motor which DOE purchased and tore down. Cells with a '*' indicate the efficiency levels are from software modeling data gathered from DOE's SME which were derived using various technology, material, and geometry changes. Cells with a '-' indicate that DOE was not able to further increase efficiency levels for these representative units and still keep an electric motor design within the proper specifications.

Table 5.5 Candidate Standard Levels for each Representative Unit

Candidate Standard Level	5-Horsepower Design B Efficiency (%)	30-Horsepower Design B Efficiency (%)	75-Horsepower Design B Efficiency (%)	5-Horsepower Design C Efficiency (%)	50-Horsepower Design C Efficiency (%)
0	82.5†	89.5†	93.0†	87.5†	93.0†
1	87.5†	92.4†	94.1†	89.5*	94.1*
2	89.5†	93.6*	95.4†	90.2*	94.5*
3	90.2†	94.1†	95.8†	91.0*	95.0*
4	91.0*	94.5*	96.2*	-	-
5	91.7*	-	96.5*	-	-

†Indicates the efficiency of a purchased and physically torn-down electric motor
*Indicates the efficiency of a software-modeled electric motor

5.4 ENGINEERING ANALYSIS METHODOLOGY

As stated, the engineering analysis estimates the cost increment for the efficiency improvement potential of individual design options or combinations of design options that pass the four criteria in the screening analysis. DOE uses this cost-efficiency relationship, developed in the engineering analysis, in the LCC analysis.

DOE can use three methodologies to generate the manufacturing costs needed for the engineering analysis. These methods are:

1. the design-option approach – reporting the incremental costs of adding design options to a baseline model;

2. the efficiency-level approach – reporting relative costs of achieving improvements in energy efficiency; and

3. the reverse engineering or cost assessment approach – involving a "bottom up" manufacturing cost assessment based on a detailed bill of materials derived from electric motor teardowns.

Because DOE targeted certain nominal efficiency levels when improving baseline efficiencies and relied on tear-downs of electric motors, DOE's analysis for the electric motor rulemaking is a combination of the efficiency-level approach and the reverse engineering approach. DOE created baseline costs from bills of materials of electric motor tear-downs and then determined the costs of increasing efficiency levels based on material or technology changes.

5.4.1 Subcontractor Tear-downs

Due to limited manufacturer feedback concerning cost data and production costs, DOE derived its production and material costs by having a professional motor laboratory[c] disassemble and inventory the physical electric motors purchased. DOE performed tear-downs on the electric motors representing CSL 0 through 3 for equipment class group 1as well as electric motors representing CSL 0 for equipment class group 2. These tear-downs provided DOE the necessary data to construct a bill of materials, which DOE could normalize using a standard cost model and markup to produce a projected manufacturer selling price. DOE used the MSP derived from the engineering tear-down paired with the corresponding nameplate nominal efficiency to report the relative costs of achieving improvements in energy efficiency. DOE derived material prices from a consensus of current, publicly available data, manufacturer feedback, and conversations with its subject matter experts. DOE supplemented the findings from its tests and tear-downs through: (1) a review of data collected from manufacturers about prices, efficiencies, and other features of various models of electric motors, and (2) interviews with manufacturers about the techniques and associated costs used to improve efficiency.

DOE's engineering analysis documents the design changes and associated costs when improving electric motor efficiency from the baseline level up to a max-tech level. This includes considering improved electrical steel for the stator and rotor, interchanging aluminum and copper rotor bar material, increasing stack length, and any other applicable design options remaining after the screening analysis. As each of these design options are added, the manufacturer's cost generally increases and the electric motor's efficiency improves.

5.4.2 Subcontractor Software Designs

DOE worked with technical experts to develop the highest efficiency levels (i.e., the max-tech levels) technologically feasible for each representative unit analyzed. DOE used a combination of electric motor software design programs and SME input. DOE retained an electric motor expert[d] with design experience and software, who prepared a set of designs with increasing efficiency. Additionally, DOE purchased another software modeling suite for the SME to check against his personal modeling software. The SME also checked his designs against tear-down data and made alterations to some of his designs to create the most practical designs possible. As new designs were created, careful attention was paid to the critical performance characteristics defined in NEMA MG-1 2009 Tables 12-2, 12-3, 12-4, and paragraph 12.35.1, which define locked rotor torque, breakdown torque, pull-up torque and maximum locked rotor currents, respectively. For a given representative unit, DOE ensured that the modeled electric motors met the same set of constraints (i.e., performance standards) as the purchased electric motors. This was done to ensure that the utility of the baseline unit was conserved as efficiency was improved through the application of various design options.

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[c] The Center for Electromechanics University of Texas at Austin, a 140,000 sq. ft. lab with 40 years of operating experience with teardowns overseen by Dr. Angelo Gattozzi, an electric motor expert with previous industry experience.

[d] Dr. Howard Jordan, Ph.D, an electric motor design expert with over 40 years of industry experience.

Additionally, DOE limited its modeled stack length increases based on tear-down data and the maximum "C" dimensions found in manufacturer's catalogs.[e]

DOE limited the amount by which it would increase the stack length of its software-modeled electric motors to preserve the utility of the baseline model torn down. The maximum stack lengths used in the software-modeled CSLs were determined by first analyzing the stack lengths and C dimensions of torn-down electric motors. Then, DOE analyzed the C dimensions of various electric motors in the marketplace conforming to the same design constraints as the representative units (same NEMA design type, horsepower rating, NEMA frame number, enclosure type, and pole configuration). For each representative unit, DOE found the largest C dimension currently available on the marketplace and estimated a maximum stack length based on the stack length to C dimension ratios of motors it tore down. The resulting product was the value that DOE chose to use as the maximum stack length in its software modeled designs. Table 5.6 shows the stack lengths of torn down CSLs and stack lengths used in the software modeled CSLs. The efficiency levels of the software modeled CSLs are displayed in Table 5.5.

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[e] The C dimension of an electric motor is the length of the electric motor from the end of the shaft to the end of the opposite side's fan cover guard. Essentially, the C dimension is the overall length of an electric motor for proper mounting and interface with the driven equipment.

Table 5.6 Stack Length and C Dimension Measurements of Torn Down and Modeled Motors

Representative Unit	CSL	Stack Length (in)
5 HP, Design B	0	2.8*
	1	3.47
	2	5.14
	3	4.65
	4	5.32**
	5	5.32**
30 HP, Design B	0	7.88*
	1	5.53
	2	6.00**
	3	6.74
	4	7.00**
75 HP, Design B	0	8.15*
	1	10.23
	2	10.58
	3	11.33
	4	12.0**
	5	13.0**
5 HP, Design C	0	4.75
	1	4.25**
	2	5.32**
	3	5.32**
50 HP, Design C	0	8.67
	1	9.55**
	2	9.55**
	3	9.55**

*Represents stack length of a vertical, hollow-shaft motor.
**Represents stack length of a software modeled motor.

5.5 COST MODEL

DOE uses a standard method of cost accounting to determine the costs associated with manufacturing. This methodology is illustrated in Figure 5.5, where production costs and non-production costs are combined to determine the full cost of a product.

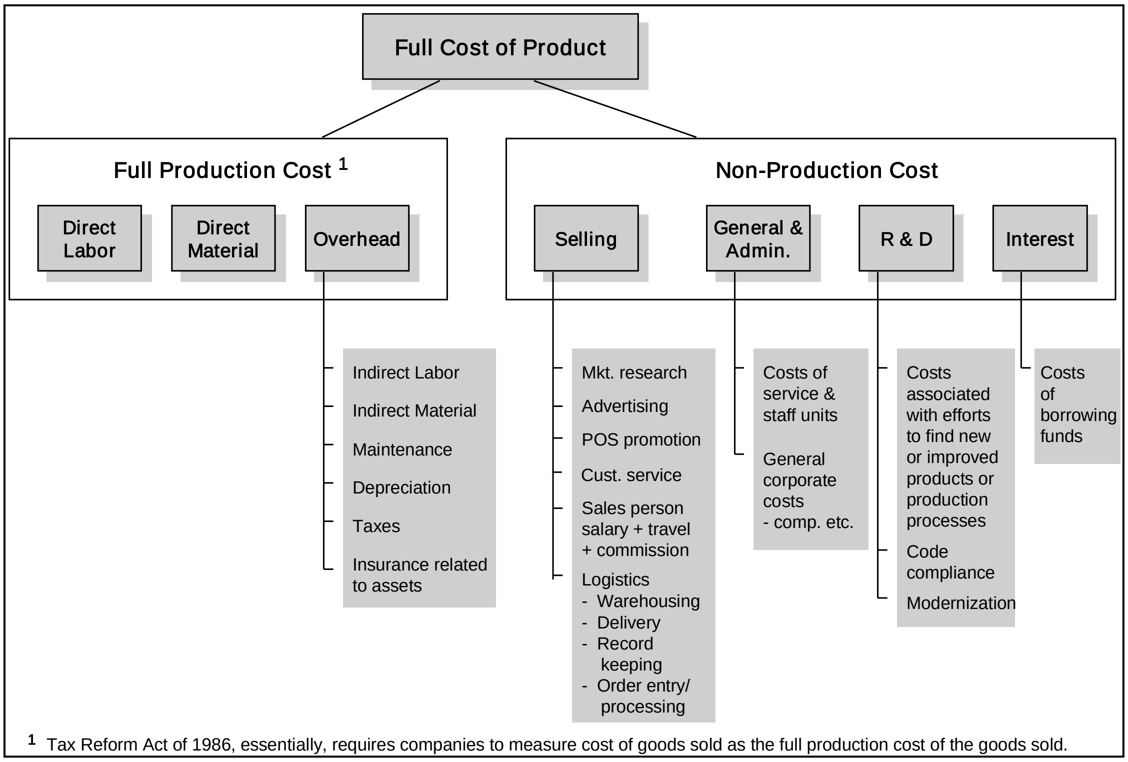

Figure 5.5 Standard Method of Cost Accounting for Standards Rulemaking

DOE developed estimates of some of the cost multipliers shown in Figure 5.5 by reviewing Security and Exchange Commission (SEC) SEC-10K reports from electric motor manufacturers, and examining previous, relevant, rulemakings, and through conversations with industry experts. Together, the full production cost and the non-production costs equal the full cost of the product. Full production cost is a combination of direct labor, direct materials, and overhead. The overhead contributing to full production cost includes indirect labor, indirect material, maintenance, depreciation, taxes, and insurance related to company assets. Non-production costs include the cost of selling (market research, advertising, sales representatives, logistics), general and administrative costs, research and development, interest payments and profit factor (not shown in the figure).

After the designs examined by DOE's motor experts were completed or the electric motors were torn down and the parts were inventoried, the next step was applying a consistent cost model to all of them. A standard bill of materials (BOM) was constructed that includes direct material costs. From this BOM, labor time estimates (along with associated costs) were added and various manufacturer markups were applied to create an MSP. DOE presents a summary of the production costs and non-production costs for each of the representative units analyzed in Appendix 5A.

5.5.1 Constructing a Bill of Materials

The BOM calculated for each design contained three types of material costs: variable, insulation, and hardware. The variable costs considered are those portions of the BOM that vary based on the cost of the material and the amount of that material used in the design. For example, stator and rotor lamination costs are variable costs because the material price for the different steel grades changes as does the volume of steel needed for each design. The insulation cost was aggregated due to the difficulty in pricing out all components of the insulation system. Based on SME feedback, DOE assumed increased efficiency does not incur notable increases in insulation system costs. Therefore, insulation costs increase as representative unit horsepower increases, but remain constant across all CSLs for each representative unit. The total price for insulation was also derived from SME input. Finally, hardware costs are an aggregate cost for all electric motor hardware components. This includes nuts, bolts, gaskets, washers and other miscellaneous hardware components. As with the insulation costs, the hardware cost was aggregated due to the difficulty of pricing individual components. DOE believes hardware costs account for a small percentage of the total material costs of an electric motor and therefore does not believe this aggregation method will have a detrimental impact on the accuracy of the MSP. Additionally, because the motors (within a representative unit) all come from the same manufacturer, DOE believes these costs are likely to be very similar and have minimal variation. The aggregate hardware cost, which is unique for each horsepower rating, was also derived based on SME input and information received about the teardowns.

Each item in the BOM is organized by the type of cost (i.e., variable, insulation, and hardware) and the component of the electric motor to which they apply. The variable costs portion of the BOM includes the following subheadings, each with an itemized parts list: stator assembly, rotor assembly, and other major costs. The insulation cost section of the BOM includes subheadings for each individual component identified during teardown, however they are not priced out individually. As discussed above, an aggregate price is used to cover this entire section. This aggregate price is unique for different horsepower ratings. The hardware cost section of the BOM includes subheadings for individual hardware items identified during the teardown, but again like the insulation costs, they are not individually priced. There is one aggregate price used that covers all of the hardware components. This aggregate price is unique for each horsepower rating.

The subheadings that have an itemized list of components include the stator assembly, rotor assembly, and other major costs. The stator assembly's itemized lists include prices for steel laminations and copper wire. The rotor assembly portion of the BOM includes prices for laminations, rotor conductor material, (either aluminum or copper) and shaft extension material. The other major costs heading contains items for the frame material and base, terminal housing components, bearing-type, and end-shield material.

DOE presents a detailed BOM for one design from each of the electric motor categories analyzed in Appendix 5B. The discussion below describes the level of detail contained in the bill of materials presented in the appendix.

5.5.2 Labor Costs and Assumptions

Due to the varying degree of automation used in manufacturing electric motors, labor costs differ for each representative unit. DOE analyzed teardown results to determine which electric motors were machine wound and which electric motors were hand wound and based on this analysis, DOE applied a higher labor hour amount for the hand-wound electric motors. For the max-tech software modeled electric motors, DOE always assumed hand-winding and therefore a higher labor hour amount. Labor hours for each of the representative units were based on SME input and manufacturer interviews.

DOE used the same hourly labor rate for all electric motors analyzed. The base hourly rate was developed from the 2007 Economic Census of Industry,[f] published by the U.S. Census Bureau, as well as manufacturer and SME input. The base hourly rate is an aggregate rate of a foreign labor rate and a domestic labor rate. DOE weighed the foreign labor rate more than the domestic labor rate due to manufacturer feedback indicating off-shore production accounts for a majority of electric motor production by American-based companies. Several markups were applied to this hourly rate to obtain a fully burdened rate which was intended to be representative of the labor costs associated with manufacturing electric motors. Table 5.7 shows the markups that were applied, their corresponding markup percentage, and the new burdened labor rate.

Table 5.7 Labor Markups for Electric Motor Manufacturers

Item description	Markup percentage	Rate per hour
Labor cost per hour		$ 10.87
Indirect Production	33 %	$ 14.46
Overhead	30 %	$ 18.79
Fringe†	24 %	$ 23.40
Assembly Labor Up-time††	43 %	$ 33.46
Cost of Labor Input to Spreadsheet		**$ 33.46**

Cost per hour is an aggregate number drawn from U.S. Census Bureau, *2007 Economic Census of Industry,* published December 2010 and foreign labor rate estimates based on manufacturer feedback.

Indirect Production Labor (Production managers, quality control, etc.) as a percent of direct labor on a cost basis. Navigant Consulting, Inc. (NCI) estimate.

Overhead includes commissions, dismissal pay, bonuses vacation, sick leave, and social security contributions. NCI estimate.

† Fringe includes pension contributions, group insurance premiums, workers compensation. Source: U.S. Census Bureau, *2007 Economic Census of Industry,* published December 2010. Data for NAICS code 335312 "Electric Motor and Generator Manufacturer" total fringe benefits as a percent of total compensation for all employees (not just production workers).

†† Assembly labor up-time is a factor applied to account for the time that workers are not assembling product and/or reworking unsatisfactory units. The markup of 43 percent represents a 70 percent utilization (multiplying by 100/70). NCI estimate.

5.5.3 Manufacturer Markups

DOE used the three markups described below to account for non-production costs that are part of each electric motor leaving a manufacturer's facility. Handling and scrap factor,

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[f] U.S. Census Bureau, 2007 Economic Census of Industry

overhead, and non-production markups will vary from manufacturer to manufacturer because their profit margins, overheads, prices paid for goods, and business structures vary. DOE prepared estimates for these three non-production cost manufacturer markups from Securities and Exchange Commission (SEC) Form 10K annual reports, and conversations with manufacturers and experts.

- Handling and scrap factor: 2.5 percent markup. This markup was applied to the direct material production costs of each electric motor. It accounts for the handling of material (loading into assembly or winding equipment) and the scrap material that cannot be used in the production of a finished electric motor (e.g., lengths of wire too short to wind).

- Factory overhead: 17.5 percent markup. Factory overhead includes all the indirect costs associated with production, indirect materials and energy use, taxes, and insurance. DOE only applies factory overhead to the direct material production costs (including the handling and scrap factor). The overhead increases to 18.0 percent when copper die casting is used in the rotor. This accounts for additional energy, insurance, and other indirect costs associated with the copper die-casting process.

- Non-production: 37 – 45 percent markup. This markup reflects costs including sales and general administrative, research and development, interest payments, and profit factor. DOE applies the non-production markup to the sum of the direct material production, the direct labor, and the factory overhead. For the analyzed electric motors at or below 30-horsepower this markup was 37 percent and for electric motors above 30-horsepower this markup was 45 percent. This increase accounts for the extra profit margin manufacturers may receive on larger electric motors that are sold in smaller volumes.

5.6 RESULTS OF ENGINEERING ANALYSIS

DOE used the five representative units to develop five manufacturer selling price versus nominal full-load efficiency curves, three for equipment class group 1 (also used for equipment class group 3), and two for equipment class group 2. Figure 5.6 through Figure 5.10 provide the manufacturer selling price versus efficiency curves and Table 5.8 through Table 5.21present the tabulated results.

5.6.1 NEMA Design B, 5-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.6 presents the relationship between MSP and nominal full-load efficiency for the 5-horsepower, Design B, 4-pole, enclosed electric motor that was analyzed. Using the tear-down results for CSLs 0 to 3, DOE determined that the manufacturer of these electric motors increased the stack length and used various combinations of increasing the stator copper, electrical steel, or rotor conductor, as well as design changes, to improve the electric motor’s efficiency.

DOE used software modeling to develop CSLs 4 and 5. DOE increased the efficiency level of these representative units and all other representative units by employing a combination of changing the slot fill, increasing stator copper or electrical steel amounts, changing the type or amount of rotor conductor material, and changing specifications of the motor design such as rotor cage geometry or rotor skew. For CSL 5, which is the max-tech efficiency level, DOE used a die-cast copper rotor conductor design while keeping the stack length the same as the motor design used for CSL 4. For CSL 5, DOE assumed a 10 percent labor hour increase above CSL 4.

Material cost increases, such as low loss electrical steel and increased stator copper, account for the relatively large increase in MSP from CSL 3 to CSL 4. Additionally, DOE assumed a hand-wound labor hour assumption for CSL 4 and 5 which adds to the relatively large jump in MSP when moving to CSL 4. All of the motors torn down and used for CSLs 0 through 3 were observed to have machine-wound stators.

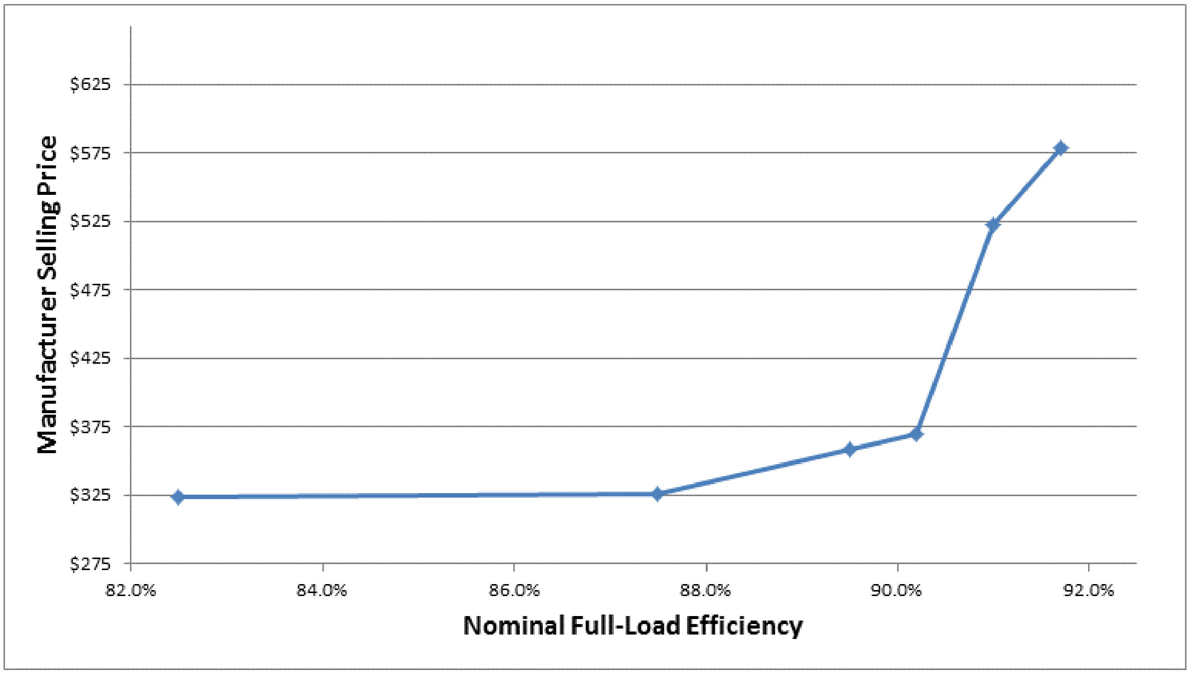

Figure 5.6 NEMA Design B, 5-Horsepower, 4-Pole, Enclosed Electric Motor Engineering Analysis Curve

Table 5.8presents the same engineering analysis results in tabular form, including the nominal full-load efficiency values and the MSPs. From CSL 0 through CSL 3, MSP increases by amounts varying up to 10 percent. When moving from CSL 3 to 4 and from CSL 4 to 5, MSP increases by $153 or about 41 percent and $56 or 11 percent, respectively, for consecutive loss reductions of roughly10 percent. Again, the large price increases when moving to CSLs 4 and 5 are a result of the use of increased labor hour and material increases. Additionally, CSL 5 employs a die-cast copper conductor in the rotor, which accounts for some of the MSP increase of CSL 5. At the time of publishing, copper was approximately 2.7 times more expensive than aluminum per pound and is three times denser. Therefore, filling an equal volume space with cast copper is almost nine times more expensive than filling the same volume with cast aluminum.

Table 5.8 Efficiency and Manufacturer Selling Price Data for the NEMA Design B, 5-Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	82.5	324
1	87.5	326
2	89.5	358
3	90.2	370
4	91.0	523
5	91.7	579

Table 5.9 presents some of the design and performance specifications associated with the six 5-horsepower NEMA Design B electric motors presented above including stator copper weight, rotor conductor weight, and electrical steel weight. Table 5.10 shows the NEMA MG1-2011 Design B performance criteria as well as those design parameters for the two software-modeled electric motors.

Table 5.9 NEMA Design B, 5-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4*	CSL 5*
Efficiency	**%**	82.5	87.5	89.5	90.2	91.0	91.7
Line Voltage	**V**	460	460	460	460	460	460
Full Load Speed	**RPM**	1,745	1,745	1,760	1,755	1,773	1,776
Full Load Torque	**Nm**	20.3	20.4	20.3	20.4	20.1	20.1
Current	**A**	6.9	6.5	6.3	6.2	6.3	6.0
Steel	**-**	M56	M47	M47	M47	M36	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	43.5%	57.2%	70.0%	68.6%	82.4%	85.2%
Stator Wire Gauge	**AWG**	19	19	19	20	20	20
Stator Copper Weight	**lbs**	8.4	10.1	10.1	12.2	14.4	14.4
Rotor Conductor Weight	**lbs**	2.63	2.87	2.6	3.42	2.7	9.1
Stack Length	**In**	2.8	3.47	5.14	4.65	5.32	5.32
Housing Weight	**lbs**	8	9	22	12	14	14

* Software modeled motor

Table 5.10 NEMA Design B, 5-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design B Limit	CSL 4	CSL 5
Efficiency	%	-	91.0	91.7
Breakdown Torque	% of full-load	225 (minimum)	323	305
Pull-Up Torque	% of full-load	130 (minimum)	245	214
Locked-Rotor Torque	% of full-load	185 (minimum)	245	214
Locked-Rotor Current	A	46 (maximum)	41.6	43.9

5.6.2 NEMA Design B, 30-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.7 presents the relationship between the MSP and nominal full-load efficiency for the 30-horsepower, Design B, 4-pole, enclosed polyphase motor analyzed. Using tear-down results for CSLs 0, 1, and 3, DOE determined that the manufacturer of these motors used a combination of material grade, material quantities, and design changes to increase the electric motor's efficiency.

Although motors are available at the CSL 2 efficiency level (93.6 percent), DOE used software modeling to simulate this motor because the CSL 2 motor DOE purchased for tear-down had a nameplate and catalog efficiency rating that did not match the efficiency found on the manufacturer's website. Additionally, tear-down results of the CSL 2 motor revealed it to have more stack length, electrical steel, and rotor aluminum as well as lower-loss electrical steel than the CSL 3 motor, which has a nameplate efficiency of 94.1 percent. CSL 2 also had 8 percent lower losses than CSL 3 based on IEEE 112B test results. Results of the IEEE 112B test, as well as tear-down results, are illustrated in Table 5.11.

Table 5.11 30-Horsepower CSL 2 and CSL 3 Testing and Tear-down Results

Parameter	CSL 2	CSL 3	Percent change over CSL 3
Nameplate and Catalog efficiency (%)	93.6	94.1	-
Website efficiency (%)	94.1	94.1	-
Tested efficiency (%)	94.29	93.88	8†
Stack length (in)	8.21	6.74	22
Electrical steel grade*	M36	M47	-
Weight of electrical steel (lbs)	201	156	29
Weight of stator copper (lbs)	37	47	-21
Weight of rotor-slot aluminum (lbs)	6.6	5.9	12

* Estimate based on DOE's metallurgical analysis
† Based on losses

DOE decided that its purchased CSL 2 motor had incorrect nameplate efficiency. This decision is based on comparing the test and tear-down results to the CSL 3 motor. Therefore, DOE decided to use software modeling to replace the CSL 2 motor tear-down, for the preliminary analysis. The CSL 2 software modeled motor is based on measurements taken from the CSL 1 and CSL 3 tear-down results, such as stack length, material weights, and electrical steel grades. The resulting CSL 2 motor specifications are listed in Table 5.13.

DOE also used software modeling to develop CSL4. For this design DOE used a copper rotor and low-loss electrical steel to achieve efficiencies higher than the purchased electric motors. Using a die-cast copper conductor in the rotor also reduced the stack length of CSL 4 compared to the other 30 horsepower CSLs analyzed. Shortening the stack length helps lower the cost of this max-tech design. CSL 4's primary cost increases arise from an increased labor hour amount based on a hand-wound labor assumption as well as other material quantity increases.

Unlike the 5-horsepower and 75-horsepower Design B representative units, the 30-horsepower Design B representative unit does not have a CSL 5. DOE attempted to improve the design of CSL 4 in an effort to reach the next highest NEMA nominal efficiency level. However, DOE was unable to reduce losses by at least 10 percent (one NEMA nominal efficiency band), and therefore DOE was not able to achieve the next NEMA nominal efficiency level.

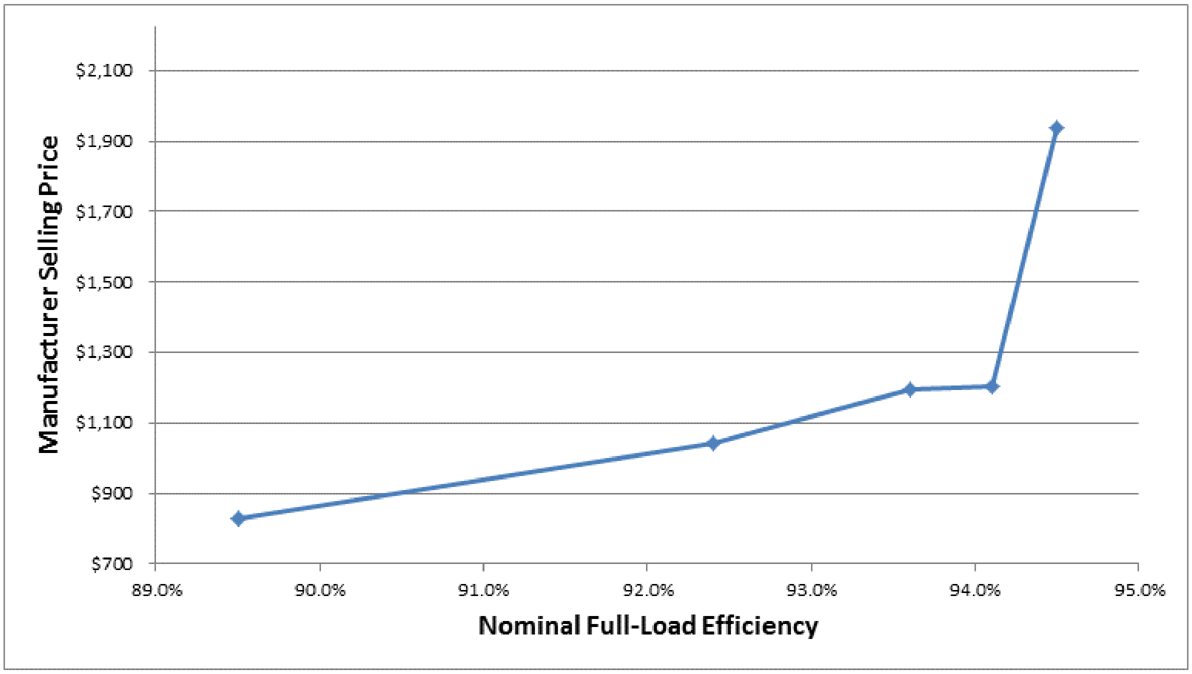

Figure 5.7 NEMA Design B, 30-Horsepower, 4-Pole, Enclosed Electric Motor Engineering Analysis Curve

Table 5.12 presents the engineering analysis results in a tabular form, including the full-load efficiency values and the MSPs. From CSL 0 to 3, DOE found that the full-load efficiency would increase 5.6 nominal percentage points over the baseline, CSL 0, which represents about a 47 percent reduction in electric motor losses. The increase in MSP to move from CSL 0 to CSL 3 is $377, or about a 46 percent increase in MSP over CSL 0. Moving from CSL 0 to CSL 4 provides a 50 percent reduction in electric motor losses for a MSP increase of $1,109 or about a 135 percent MSP increase over CSL 0.

Table 5.12 Efficiency and Manufacturer Selling Price Data for the NEMA Design B, 30-Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	89.5	827
1	92.4	1,044
2	93.6	1,193
3	94.1	1,204
4	94.5	1,936

Table 5.13 presents some of the design and performance specifications associated with the five 30-horsepower designs presented above, including stator copper weight, rotor conductor weight, and electrical steel weight. Table 5.14 shows the NEMA MG1-2009 Design B performance criteria as well as those design parameters for the software modeled electric motor.

Table 5.13 NEMA Design B, 30-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2*	CSL 3	CSL 4*
Efficiency	**%**	89.5	92.4	93.6	94.1	94.5
Line Voltage	**V**	230	460	460	460	460
Full Load Speed	**RPM**	1,755	1,765	1,768	1,770	1,784
Full Load Torque	**Nm**	121.6	121.4	120.8	120.6	119.6
Current	**A**	37	37	36	36	37
Steel	**-**	M56	M56/M47	M47	M47	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	48.4	84.0	70.0	70.0	83.2
Stator Wire Gauge	**AWG**	18	17	16	18	18
Stator Copper Weight	**lbs**	20.2	43.5	45.2	47.7	74.5
Rotor Conductor Weight	**lbs**	8.25	9.5	7.5	13.66	42.6
Stack Length	**In**	7.88	5.53	6.00	6.74	7.00
Housing Weight	**lbs**	21	130	131	147	152

* Software modeled motor

Table 5.14 NEMA Design B, 30-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design B Limit	CSL 2	CSL 4
Efficiency	%	-	93.6	94.5
Breakdown Torque	% of full-load	200 (min.)	265.6	202
Pull-up Torque	% of full-load	105 (min.)	173.3	139
Locked Rotor Torque	% of full-load	150 (min.)	183.2	154
Locked Rotor Amps	A	217.5(max.)	204	208

5.6.3 NEMA Design B, 75-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.8 presents the relationship between the MSP and nominal full-load efficiency for the 75-horsepower, Design B, 4-pole enclosed electric motor analyzed. Using tear-down results for CSLs 0 through 3, DOE determined that the manufacturer of these electric motors increased the stack length and other material amounts to increase the electric motor's efficiency levels from 93.0 percent to 95.8 percent. The torn-down electric motor representing CSL 3 used increased rotor aluminum and stator copper as well as an increased stack length to achieve 95.8 percent efficiency.

DOE used software modeling to develop CSL 4. For this design, DOE used a die-cast copper conductor in the rotor and low-loss electrical steel in the rotor and stator to achieve efficiencies higher than commercially available electric motors. The stack length of the electric motor for CSL 4 is higher than the stack length of lower CSLs for the 75-horsepower Design B electric motors analyzed, but shorter than the electric motor for CSL 5.

To develop the max-tech efficiency level, CSL 5, DOE again used software modeling. DOE continued to use a die-cast copper rotor conductor design, but increased the stack length to an estimated maximum stack length. This maximum stack length was calculated based on the method described previously in section 5.4.2. The assumption of manual-labor hour amounts and the use of die-cast copper conductors in CSL 4 and 5's rotors account for the larger-than-typical price increase between CSL 3 and CSL 4 for the 75-horsepower Design B representative units.

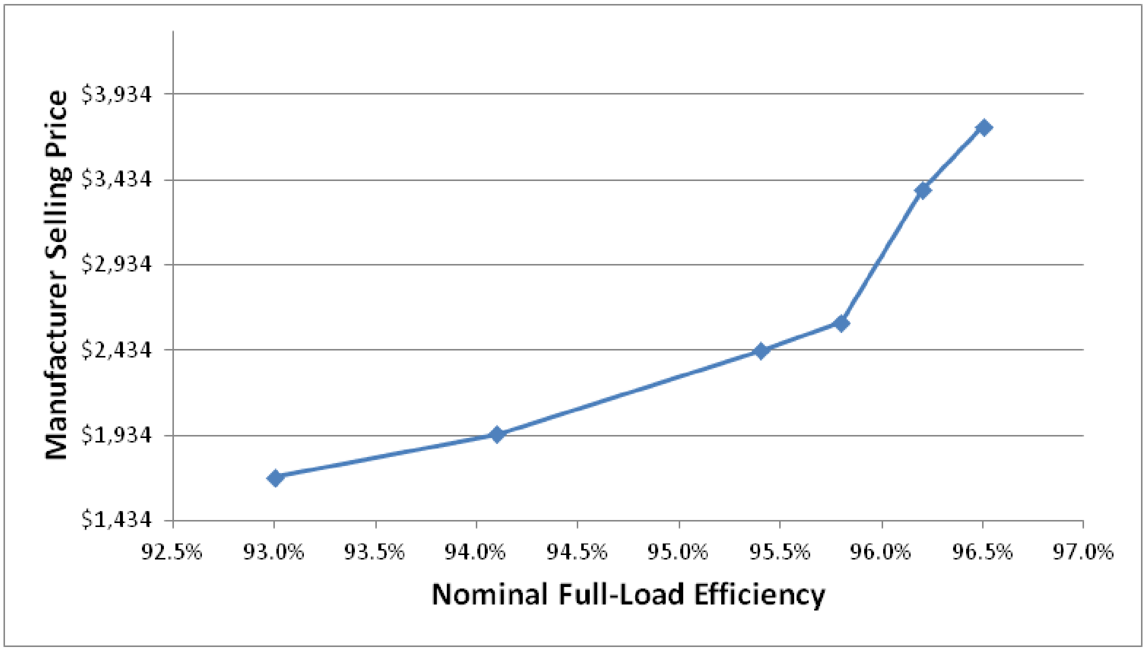

Figure 5.8 NEMA Design B, 75-Horsepower, 4-Pole, Enclosed Motor Engineering Analysis Curve

Table 5.15 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from CSL 0 to CSL 3, DOE found that the full-load efficiency would increase 2.4 nominal percentage points over the baseline, CSL 0, which represents about a 42 percent reduction in electric motor losses. The increase in MSP to move from CSL 0 to CSL 3 is about $748 or about a 41 percent increase in MSP over CSL 0. Moving from CSL 0 to CSL 4 provides a 47 percent reduction in electric motor losses for a MSP increase of $1,520, which constitutes an 83 percent MSP increase over the CSL 0 electric motor.

To increase the efficiency from CSL 0 to the max-tech efficiency of CSL 5 there is a 52 percent reduction in motor losses for about a 102 percent increase in MSP of $1,879.

Table 5.15 Efficiency and Manufacturer Selling Price Data for the NEMA Design B, 75-Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	93.0	1,833
1	94.1	1,994
2	95.4	2,270
3	95.8	2,581
4	96.2	3,353
5	96.5	3,712

Table 5.16 presents some of the design and performance specifications associated with the six 75-horsepower designs presented above, including stator copper weight, rotor conductor weight, and electrical steel weight. Table 5.17 shows the NEMA MG1-2011 Design B performance criteria as well as those design parameters for the two software modeled electric motors.

Table 5.16 NEMA Design B, 75-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4*	CSL 5*
Efficiency	**%**	93.0	94.1	95.4	95.8	96.2	96.5
Line Voltage	**V**	460	460	460	460	460	460
Full Load Speed	**RPM**	1,775	1,785	1,781	1,785	1,788	1,789
Full Load Torque	**Nm**	299.8	299.8	302.3	300.8	299.6	299.6
Current	**A**	88	91.8	89.4	88.6	89.8	91.9
Steel	**-**	M56	M47	M47	M47	M36	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Copper	Copper
Approximate Slot Fill	**%**	48.0	44.5	70.0	70.0	85.1	83.4
Stator Wire Gauge	**AWG**	17	12	12	15	14	14
Stator Copper Weight	**lbs**	77.8	71	82	136	127	160
Rotor Conductor Weight	**lbs**	31.0	20.7	27.3	38.5	79	84.3
Stack Length	**In**	8.15	10.23	10.58	11.37	12.00	13.00
Housing Weight	**lbs**	130	79	168	180	190	206

* Software modeled motor

Table 5.17 NEMA Design B, 75-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design B Limit	CSL 4	CSL 5
Efficiency	%	-	96.2	96.5
Breakdown Torque	% of full-load	200 (min.)	218.2	202.0
Pull-up Torque	% of full-load	100 (min.)	135	139.3
Locked Rotor Torque	% of full-load	140 (min.)	163.8	163.7
Locked Rotor Amps	A	542.5(max.)	530.7	541.3

5.6.4 NEMA Design C, 5-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.9 presents the relationship between the MSP and nominal full-load efficiency for the 5-horsepower, NEMA Design C, 4-pole, enclosed electric motor analyzed. DOE purchased only one NEMA Design C electric motor for its tear-down analysis. The remaining three CSLs were based on software modeled electric motors. Therefore, discussion of the NEMA Design C revolves around the design changes DOE's software modeling expert chose to implement to increase the efficiency levels of the electric motors.

DOE achieved the CSL 1 efficiency level by using a lower loss grade of electrical steel and increasing the slot fill higher than that of the CSL 0 electric motor. The CSL 1 electric motor also boasts a smaller stack length and a lower slot fill percentage than the CSL 0 electric motor. DOE increased the efficiency of the CSL 2 motor design by keeping an aluminum die-cast rotor conductor cage, but increasing the stack length to the maximum stack length calculated via the methodology described in section 5.4.2. This increased the amount of electrical steel and stator copper material by 25 and 52 percent, respectively. DOE achieved the CSL 3 efficiency by employing a copper die-cast rotor conductor and while maintaining the same stack length as the CSL 2 motor. The die-cast copper rotor conductor allowed the CSL 3 design to reduce its stator copper winding by almost 15 percent while still achieving a higher efficiency than CSL 2.

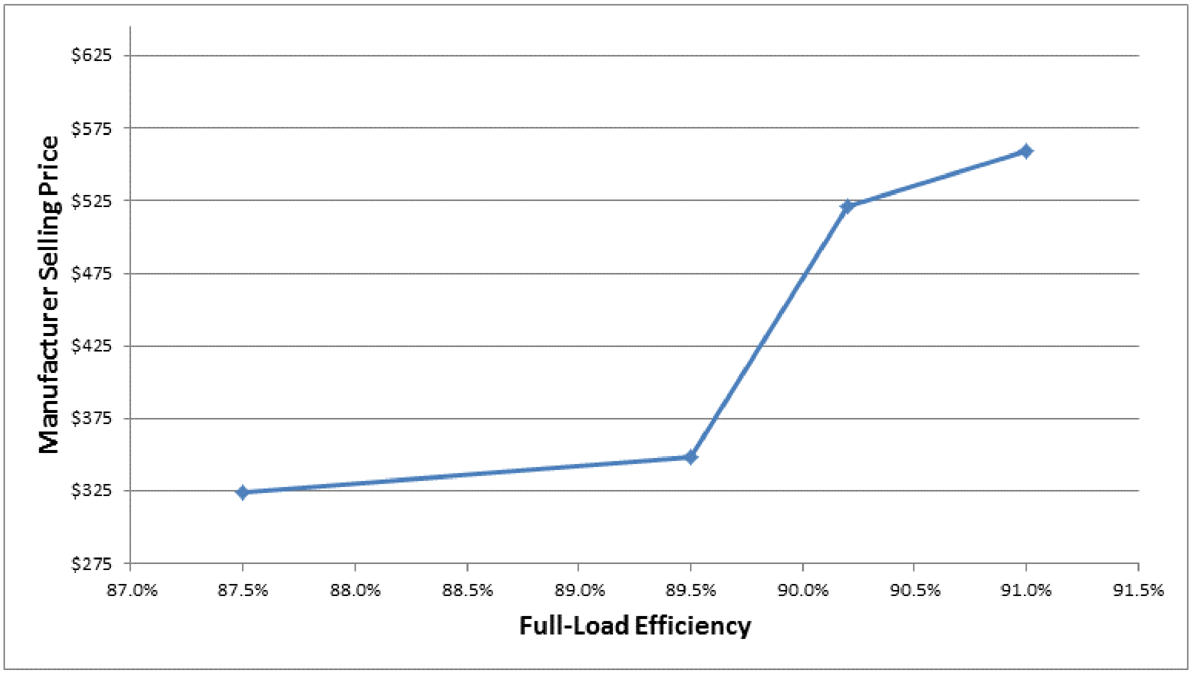

Figure 5.9 NEMA Design C, 5-Horsepower, 4-Pole, Enclosed Motor Engineering Analysis Curve

Table 5.18 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from CSL 0 to CSL 2, DOE found that the nominal full-load efficiency would increase 2.7 percentage points over the baseline, CSL 0, which represents a 24 percent reduction in electric motor losses. The increase in MSP to move from CSL 0 to CSL 2 is $198, or about a 61 percent increase in MSP over CSL 0. Increasing from CSL 2 to CSL 3 would result in a 10 percent reduction in losses and a 7 percent increase in MSP.

Table 5.18 Efficiency and Manufacturer Selling Price Data for the NEMA Design C, 5-Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	87.5	324
1	89.5	348
2	90.2	522
3	91.0	559

Table 5.19 presents some of the design and performance specifications associated with the four Design C, 5-horsepower electric motors presented above. The table includes stator copper weight, rotor conductor weight, and electrical steel weight. Table 5.20 shows the NEMA MG1-2009 Design C performance criteria as well as those design parameters for the three software modeled electric motors.

Table 5.19 NEMA Design C, 5-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3
Efficiency	**%**	87.5	89.5	90.2	91.0
Line Voltage	**V**	460	460	460	460
Full Load Speed	**RPM**	1,750	1,762	1,767	1,776
Full Load Torque	**lb-ft**	15	14.9	14.9	14.8
Current	**A**	7.1	8.4	7.1	6.5
Steel	**-**	M47	M36	M36	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	67.9	79.9	83.9	82.9
Stator Wire Gauge	**AWG**	18	18	18	18
Stator Copper Weight	**lbs**	10	9.9	15	12.8
Rotor Conductor Weight	**lbs**	2.2	2.0	2.4	7.8
Stack Length	**in**	4.75	4.25	5.32	5.32
Frame Weight	**lbs**	12	11	14	14

Table 5.20 NEMA Design C, 5-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design C Limit	CSL 1	CSL 2	CSL 3
Efficiency	%	-	89.5	90.2	91.0
Breakdown Torque	% of full-load	200 (min.)	293	260.2	260.8
Pull-up Torque	% of full-load	180 (min.)	283.9	243.6	260.8
Locked Rotor Torque	% of full-load	255 (min.)	344.1	297.9	260.8
Locked Rotor Amps	A	46 (max.)	38.5	38.3	41.7

5.6.5 NEMA Design C, 50-Horsepower, 4-Pole, Enclosed Electric Motor

Figure 5.10 presents the relationship between the MSP and nominal full-load efficiency for the 50-horsepower, NEMA Design C, 4-pole, enclosed electric motor analyzed. DOE purchased only one NEMA Design C electric motor for its tear-down analysis. The remaining three CSLs were based on software-modeled electric motors. Therefore, discussion of the NEMA Design C revolves around the design changes DOE's software modeling expert chose to implement to increase the efficiency levels of the electric motors.

DOE achieved the CSL 1 efficiency level by using a higher grade electrical steel and the maximum-calculated stack length found by using the method discussed in section 5.4.2. DOE then increased the efficiency level to CSL 2 by increasing slot fill and the amount of stator copper. To achieve the CSL 3 efficiency level, DOE decreased the slot fill and the amount of stator copper but changed the rotor conductor material to die-cast copper.

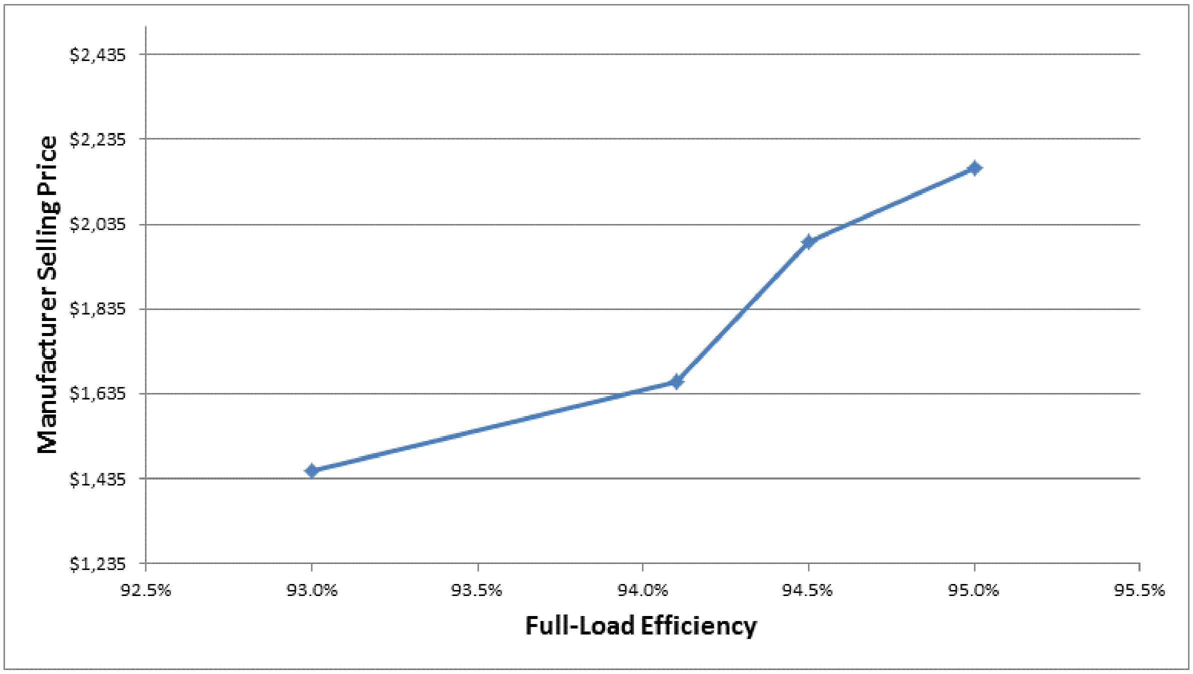

Figure 5.10 NEMA Design C, 50-Horsepower, 4-Pole, Enclosed Motor Engineering Analysis Curve

Table 5.21 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from the CSL 0 to CSL 2, DOE found that the nominal full-load efficiency would increase 1.5 nominal percentage points over the baseline, CSL 0, which represents about a 23 percent reduction in electric motor losses. The increase in MSP to move from CSL 0 to CSL 2 is $540, or about a 37 percent increase in MSP over CSL 0. To increase from CSL 2 to CSL 3, about a 10 percent reduction in electric motor losses, results in an 8.8 percent increase in MSP.

Table 5.21 Efficiency and Manufacturer Selling Price Data for the NEMA Design C, 50-Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	93.0	1,452
1	94.1	1,664
2	94.5	1,992
3	95.0	2,168

Table 5.22 presents some of the design and performance specifications associated with the four 50-horsepower electric motor designs presented above including stator copper weight, rotor conductor weight, and electrical steel weight. Table 5.23 shows the NEMA MG1-2009 Design C performance criteria as well as those design parameters for the software modeled electric motors.

Table 5.22 NEMA Design C, 50-Horsepower, 4-Pole, Enclosed Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3
Efficiency	**%**	93.0	94.1	94.5	95.0
Line Voltage	**V**	460	460	460	460
Full Load Speed	**RPM**	1,770	1,775	1,775	1,782
Full Load Torque	**lb-ft**	148	148	148	147.3
Current	**A**	59.4	63.9	63.7	61.3
Steel	**-**	M47	M36	M36	M19
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	79.6	74.8	85.3	81.3
Stator Wire Gauge	**AWG**	17	17	17	17
Stator Copper Weight	**lbs**	66	78	90	85
Rotor Conductor Weight	**lbs**	16.5	11	11	36.6
Stack Length	**In**	8.67	9.55	9.55	9.55
Frame Weight	**lbs**	125	138	138	138

Table 5.23 NEMA Design C, 50-Horsepower, 4-Pole, Enclosed Motor Modeled Characteristics

Parameter	Units	Design C Limit	CSL 1	CSL 2	CSL 3
Efficiency	%	-	94.1	94.5	95.0
Breakdown Torque	% of full-load	190 (min.)	255.2	193.5	233.5
Pull-up Torque	% of full-load	150 (min.)	254.8	165.1	202.9
Locked Rotor Torque	% of full-load	200 (min.)	254.8	258.6	202.9
Locked Rotor Amps	A	362.5 (max.)	353.6	356.2	359.6

5.7 SCALING METHODOLOGY

Due to the large number of equipment classes, DOE was not able to perform a detailed engineering analysis on each one. Instead, DOE focused its analysis on three NEMA Design B equipment classes and two NEMA Design C equipment classes. From these results, DOE scaled to other equipment classes not directly analyzed in the engineering analysis. For the preliminary analysis, DOE considered two methods of scaling, one based on the incremental improvement of motors losses and one that develops a set of power law equations based on the relationships found in the NEMA "Energy Efficient" and NEMA "Premium Efficient"[g] tables of efficiency. Ultimately, DOE did not find a large discrepancy between the two methods and elected to use the, simpler, incremental improvement of motor losses approach.

5.7.1 Scaling Approach Using Incremental Improvements of Motor Losses

Scaling electric motor efficiencies is a complicated proposition that has the potential to result in efficiency standards that are not evenly stringent across all equipment classes. Among DOE's three ECGs, there are several hundred combinations of horsepower rating, pole

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[g] NEMA MG1-2011 specifies that motors classified as "energy efficient" shall meet or exceed the efficiency values listed in Table 12-11 (or Table 20-A for certain larger horsepower ratings). Motors classified as "premium efficiency" shall meet or exceed the efficiency values listed in Table 12-12 (or Table 20-B for certain larger horsepower ratings).

configuration, and enclosure. Within these combinations there is a large number of standardized frame number series. Given this sizable number of frame number series, DOE cannot feasibly analyze all of these variants – hence, the need for scaling. Scaling across horsepower ratings, pole configurations, enclosures, and frame number series is a necessity. For DOE's first approach to scaling, it relied on a relatively simple method of analyzing the motor losses of each of its representative units from CSL to CSL and applying those same losses to various segments of the market.

As discussed previously, DOE based the first four of its CSLs for ECG 1 on torn-down motors. As these motors were marketed and sold with NEMA nominal efficiencies, DOE used those values to denote each of those CSLs. Consequently, the efficiency levels that DOE scaled to for the non-representative units were also selected from the NEMA nominal efficiency levels. DOE also used the NEMA nominal efficiency values for the CSLs that were achieved for the representative units using software modeling.

For CSL 1 and CSL 2, DOE only had to do minimal scaling. CSL 1 is based on NEMA MG 1-2011 Tables 12-11 and 20-A, which were left unchanged for all electric motors. However, Table 12-11 does not specify an efficiency level for 1 horsepower, 2 pole, open motors. DOE scaled the missing value by using the same efficiency level as that of 1 horsepower, 2 pole, enclosed motors. By observing that 1 horsepower, 2 pole, both open and enclosed motors had the same Table 12-12 efficiency levels, DOE inferred that the 1 horsepower, 2 pole, open configuration could also meet the Table 12-11 efficiency level of its enclosed counterpart.

CSL 2 is based on NEMA MG 1-2011 Tables 12-12 and 20-B, which specify the nominal efficiencies of electric motors that NEMA classifies as "premium efficiency." The 2011 version of NEMA MG1 omits NEMA Premium efficiency levels for 6-pole motors at 300- and 350-horsepower, leaving a gap in the NEMA Premium efficiency tables where there was no gap in the 2009 version of NEMA MG1. To keep CSL 2 continuous from 1- to 500-horsepower, DOE scaled the missing values from then next closest horsepower ratings (250- and 400-horsepower). Conveniently, the NEMA Premium efficiency levels for 6-pole motors at 250- and 400-horsepower were equivalent, so DOE assumed that 6-pole motors at 300- and 350-horsepower were also at the same efficiency level.

For the higher CSLs, namely 3, 4, and 5, DOE's conservation of motor losses approach relies on NEMA MG1-2011's table of nominal efficiencies and the relative improvement in motor losses of the representative units. As has been discussed, each incremental improvement in NEMA nominal efficiency (or NEMA band) corresponds to roughly a 10 percent reduction in motor losses. After CSLs 3, 4, and 5 were developed for each representative unit, DOE applied the same reduction in motor losses (or the same number of NEMA band improvements) to various segments of the market based on the representative units. DOE assigned a segment of the electric motors market, based on horsepower ratings, to each representative unit analyzed. DOE's assignments of these segments of the markets were in part based on the standardized NEMA frame number series that NEMA MG1 assigns to horsepower and pole configuration combinations. That segmentation of the market is shown in Figure 5.11.

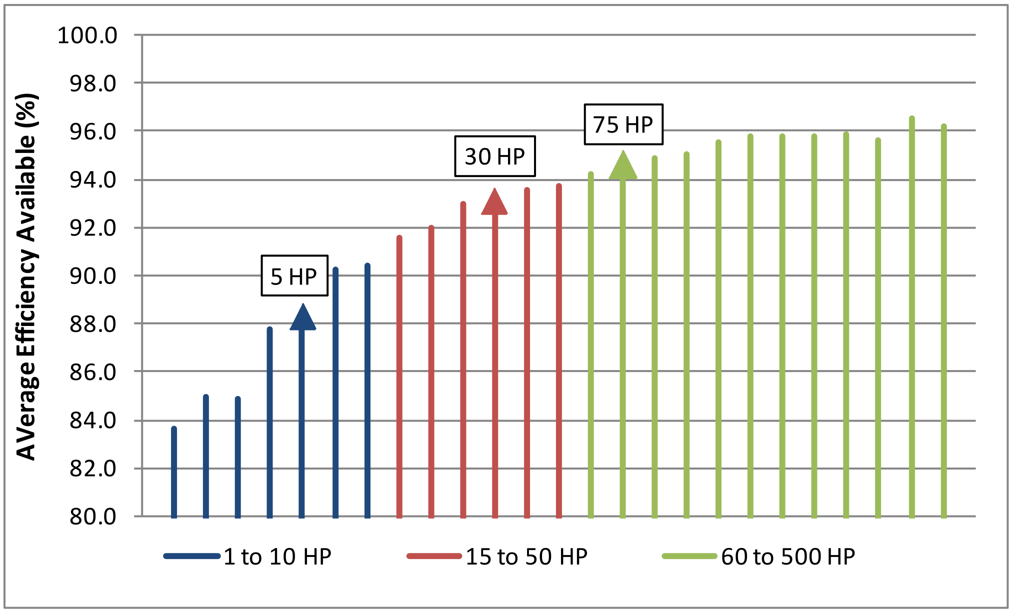

Figure 5.11 Segmentation of Electric Motor Market for Representative Units

The first section, shaded blue in Figure 5.11, consists of smaller frame electric motors whose efficiencies increase at a quicker rate than larger frame electric motors. A 5-horsepower electric motor was selected to represent the electric motors on this section of the graph based on high shipment volume and the fact that this electric motor's efficiency is in middle of this steep section of the graph. The electric motors whose analysis is based on the 5-horsepower electric motor are electric motors between 1-horsepower and 10-horsepower.

DOE then analyzed the mid-section of the graph, or electric motors whose efficiencies do not change as drastically as the blue-shaded region and determined that a 30-horsepower electric motor falls in the middle of this region of the graph. Consequently, DOE selected the 30-horsepower rating to analyze for the red shaded region of the graph, which represents electric motors from 15-horsepower to 50-horsepower.

For the third section, DOE observed the electric motor efficiencies exhibited a fairly "flat" characteristic as frame sizes increase beyond 60-horsepower. DOE selected a 75-horsepower electric motor to represent the electric motors on the final part of the graph because it was large enough to represent electric motors in this horsepower range yet small enough to facilitate various aspects of the engineering analysis, such as physical teardowns of the electric motor. The 75-horsepower electric motor represents electric motors on the large end of the scope of coverage, from 60-horsepower to 500-horsepower.

In the end, for ECG 1, each CSL above CSL 2 was one NEMA band above the previous CSL for each representative unit -- i.e., CSL 3 exceeded Table 12-12 by one band, CSL 4 by two, and CSL 5 by three. The following bulleted line items summarize each CSL for ECG 1:

- CSL 0: Lowest-in-scope efficiencies for all equipment classes
- CSL 1: NEMA MG1-2011 Tables 12-11 and 20-A for all equipment classes
- CSL 2: NEMA MG1-2011 Tables 12-12 and 20-Bfor all equipment classes

- CSL 3: One NEMA band above CSL 1 for all equipment classes
- CSL 4: One NEMA band above CSL 2 for all equipment classes
- CSL 5: One NEMA band above CSL 3 for all equipment classes[h]

The scaling results for ECG 2 were slightly different. As discussed, there is limited equipment selection of NEMA Design C motors, and CSL 0 was the only CSL based on tear-down results. Consequently, CSLs 1 through 3 were modeled using a computer software program. Relative to the baseline CSL, Table 12-11, DOE was able to achieve a max-tech efficiency level that corresponded to an improvement of four NEMA bands for both representative units. Going from CSL 0 to the first modeled design for both representative units constituted an initial jump of two NEMA bands. Each incremental CSL above CSL 1 corresponded to a one NEMA band improvement, totaling four NEMA bands of improvement relative to the baseline at CSL 3. As the improvements in NEMA bands were the same for both representative units, DOE broadly applied these improvements to all equipment classes covered by this ECG. The following bullets summarize each CSL for ECG 2.

- CSL 0: NEMA MG1-2011 Table 12-11 for all equipment classes
- CSL 1: Two NEMA bands above CSL 0 for all equipment classes
- CSL 2: One NEMA band above CSL 1 for all equipment classes
- CSL 3: One NEMA band above CSL 2 for all equipment classes

5.7.2 Scaling Approach Using Regression Equations

DOE developed a second approach for scaling to CSL 3, CSL 4 and CSL 5 which relied on regression equations to predict electric motor losses. The first step DOE took in this approach was to create a model that describes electric motor losses as a function of the electric motor's rated horsepower. To do this, DOE examined the standards adopted by EISA 2007. For polyphase general-purpose electric motors built in a three digit frame size EISA adopted the NEMA Premium Standards, shown in NEMA MG 1-2006 in Table 12-12, as the minimum efficiency levels. This table has standards for electric motors ranging in horsepower from 1 to 200-horsepower, in two-, four-, and six-pole configurations, and in open and enclosed constructions. DOE plotted this data to observe any trends:

- Electric motor losses (defined as $\frac{1}{efficiency} - 1$) versus horsepower

If plotted on logarithmic scales, DOE observed that as horsepower increased, electric motor losses decreased following a power law function,as shown in Figure 5.12. That is:

- $MotorLosses(HP) = a \times HP^{-b}$, where *a* and *b* vary by pole configuration and electric motor category combination.

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[h] DOE notes that the segment of the market based on the 30-horsepower NEMA Design B representative unit has the same set of nominal efficiencies at CSL 3 and 4 because DOE only developed three CSLs for that representative unit.

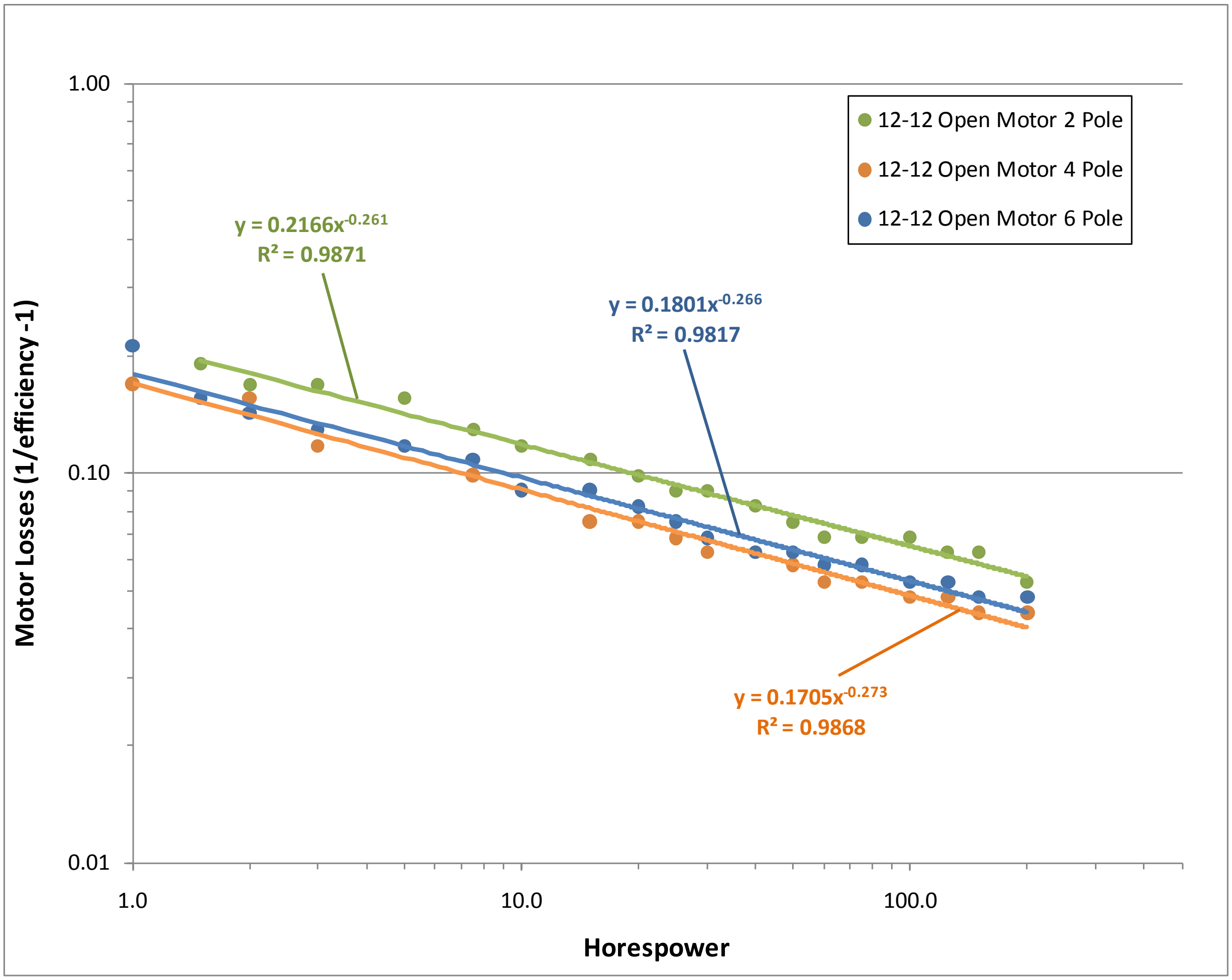


Figure 5.12 NEMA Premium Motor Losses versus Horsepower Rating

As mentioned in section 5.3, for ECG 1 CSL 3 represents a best-in-market efficiency level, CSL 5 represents the maximum technology efficiency level, and CSL 4 is an incremental efficiency level between the two. For the representative units, the efficiency levels at CSL 3, CSL 4 and CSL 5 were already known, either through purchased electric motors or software modeling. Therefore, the DOE scaled the CSLs from the representative units to the equipment classes that were not analyzed. This was done by using the power law function observed in Figure 5.12. Since DOE directly analyzed three horsepower ratings (5-horsepower, 30-horsepower and 75-horsepower), the electric motor losses continuum was split up into three ranges: 1- to 10-horsepower, 15- to 50-horsepower, and 60- to 500-horsepower (as shown in Figure 5.11). A power law function was derived for CSL 1 and CSL 2 for each range in the representative ECGs as shown in Figure 5.13.

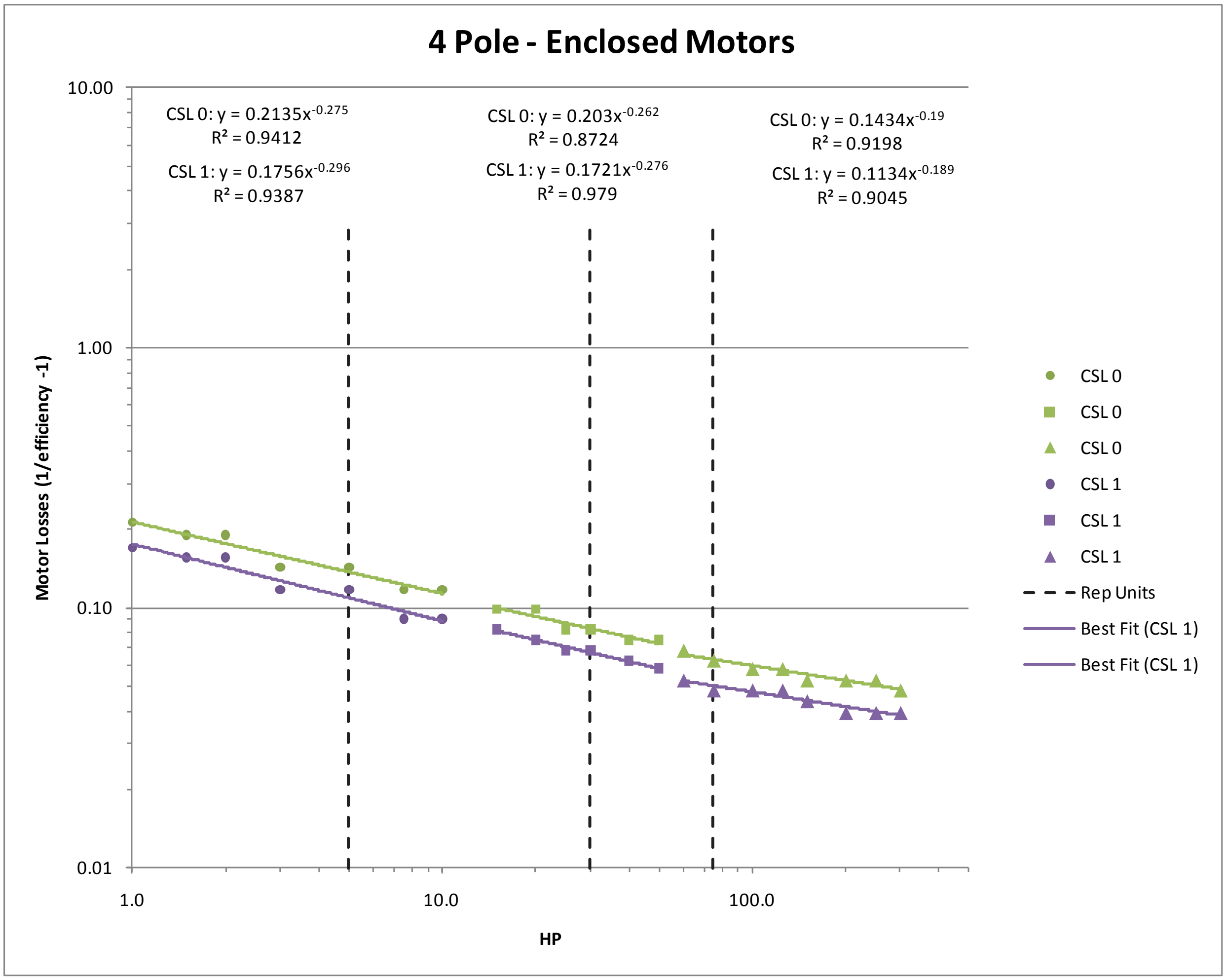


Figure 5.13 Function of Electric Motor Losses with Horsepower for 4-Pole, Enclosed Electric Motors

For each range, the exponents of CSL 1 and CSL 2 were averaged to derive the following three power law equations:

$$MotorLosses(HP) = a \times HP^{-.286} \text{ for 1 horsepower to 10-horsepower}$$

$$MotorLosses(HP) = a \times HP^{-.269} \text{ for 15-horsepower to 50-horsepower}$$

$$MotorLosses(HP) = a \times HP^{-.190} \text{ for 60-horsepower and greater}$$

where ‘*a*’ is a constant that that differs for CSL 3, CSL 4 and CSL 5. As previously mentioned, the efficiency values for CSL 3, CSL 4 and CSL 5 are known at 5-horsepower, 30-horsepower and 75-horsepower as they are the efficiency levels of the representative equipment classes. The value of ‘*a*’ for CSL 3, CSL 4 and CSL 5 can be solved for using these known efficiency values. With the constants and exponents derived for the CSL 3, CSL 4 and CSL 5 power functions, the equations can be used to derive the CSL 3, CSL 4 and CSL 5 efficiency levels for the unanalyzed horsepower ratings. The results of this calculation are shown in Figure 5.14.

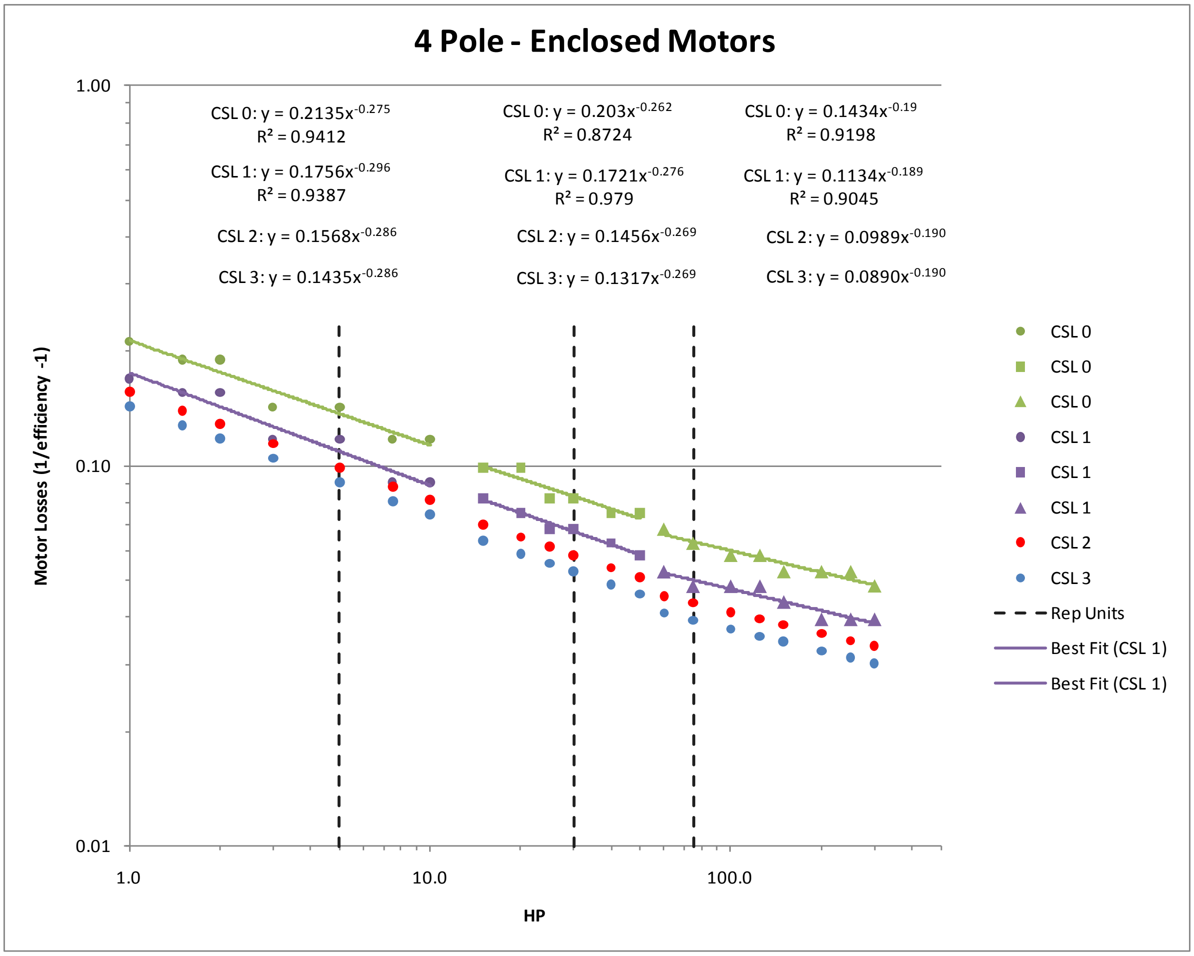


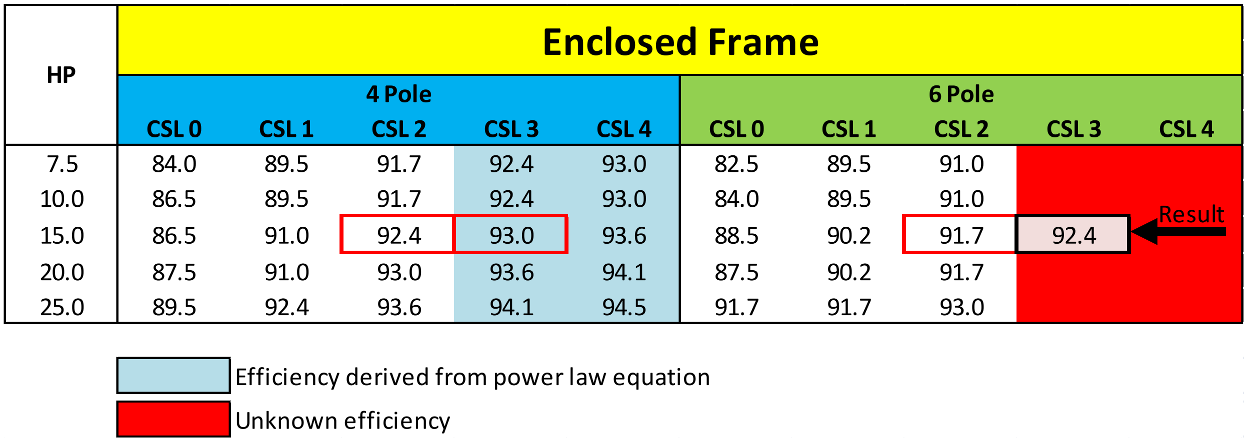
Figure 5.14 Function of Electric Motor Losses with Horsepower Derived for CSL 2 and CSL 3 for 4-Pole, Enclosed Electric Motors of NEMA Design A & B

With CSL3, CSL 4 and CSL 5 determined for the 4-pole enclosed electric motors, DOE then had to scale these CSLs to the other electric motor pole configurations and enclosures. To do this, DOE compared the efficiencies, at a given horsepower rating, of the 4-pole enclosed motors with the efficiencies of other pole configurations and enclosures at the Table 12-12 levels. The ratio of those efficiencies was multiplied by the scaled efficiency (at CSL 3, 4, or 5) of the 4-pole enclosed electric motor efficiency. The resulting product was a scaled efficiency, at a given horsepower rating, of the equipment class not analyzed. To do this, DOE had to assume that the ratio of efficiencies of different equipment classes at CSL 2stayed constant for CSL 3, CSL 4 and CSL 5. The following equation was used to derive the scaled efficiencies:

$$Efficiency(hp) = \frac{Efficiency_{NP}(hp)}{Efficiency_{NP4E}(hp)} Efficiency_{4E}(hp)$$

where

- *Efficiency*- is the resulting scaled efficiency of the desired equipment class at the new CSL (3, 4, or 5).
- $Efficiency_{NP}$-is the NEMA Premium efficiency of the desired equipment class.
- $Efficiency_{NP4E}$-is the NEMA Premium efficiency of a 4-pole enclosed electric motor.
- $Efficiency_{4E}$- is the scaled efficiency of a 4-pole enclosed electric motor at the CSL being scaled to (3, 4, or 5).



HP	Enclosed Frame									
	4 Pole					6 Pole				
	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4
7.5	84.0	89.5	91.7	92.4	93.0	82.5	89.5	91.0		
10.0	86.5	89.5	91.7	92.4	93.0	84.0	89.5	91.0		
15.0	86.5	91.0	92.4	93.0	93.6	88.5	90.2	91.7	92.4	
20.0	87.5	91.0	93.0	93.6	94.1	87.5	90.2	91.7		
25.0	89.5	92.4	93.6	94.1	94.5	91.7	91.7	93.0		

🟦 Efficiency derived from power law equation

🟥 Unknown efficiency

Figure 5.15 Scaling Across Electric Motor Configurations

For example, in order to calculate the efficiency of a 15-horsepower,6-pole, enclosed electric motor at CSL 3, see the equation below along with Figure 5.15.

$$Efficiency(15) = \frac{Efficiency_{NP}(15)}{Efficiency_{NP4E}(15)} Efficiency_{4E}(15) = \frac{91.7}{92.4} \times 93.0 = 92.3$$

As shown above, this method results in an efficiency level of 92.3 percent for a 6-pole NEMA Design A or B electric motor of enclosed construction. However, 92.3 percent falls just short of the NEMA nominal efficiency (see NEMA MG 1-2009 Table 12-10) of 92.4 percent. Therefore, it would have to be “rounded” down to the closest NEMA nominal efficiency level which in this case was 91.7 percent. By having to convert the calculated scaled efficiency levels to NEMA nominal efficiency levels, DOE observed that some of the efficiency levels that were scaled were the same efficiency as the lower CSL. For instance, in the example above CSL 1 and CSL 2 would be equal to each other at 15-horsepower since the 92.3 percent efficiency would have to be rounded down to the closest NEMA nominal efficiency level. As a result, DOE elected not to use this as the primary methodology for scaling the engineering results of its representative units.

CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUPS ANALYSIS

6.1 INTRODUCTION

This chapter of the technical support document (TSD) presents the U.S. Department of Energy’s (DOE's) method for deriving electric motor prices. The objective of the equipment price determination is to estimate the price paid by the customer or purchaser for an installed electric motor. Purchase price and installation cost are necessary inputs to the life-cycle cost (LCC) and payback period (PBP) analyses. Chapter 8 presents the LCC calculations; section 8.2.1 describes how the LCC uses purchase price and installation cost as inputs.

Purchase prices for electric motors are not generally known. Electric motors are often sold as part of a project, sometimes custom-built with unlisted prices. The engineering analysis (Chapter 5) provides the manufacturer selling prices (MSPs) for the representative units included in the LCC analysis. DOE derived a set of prices, for each electric motor representative unit produced by the engineering analysis, by applying markups to the manufacturer selling price in the form of markup equations.

6.1.1 Distribution Channels

The appropriate markups for determining the end-user equipment price depend on the type of distribution channels through which equipment moves 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.

Distribution channels vary depending on the size of the electric motor. Because smaller electric motors used as components in larger pieces of equipment constitute the majority of the market, much of the market passes through original equipment manufacturers (OEMs) who design, assemble, and brand equipment that contain electric motors. OEMs in turn obtain their motors either directly from the motor manufacturers or from manufacturers via distributors. In larger horsepower ranges (more than 50 horsepower), direct sales to the end-user and sales to contractors become more significant.

Based on market research[1] and input from interested parties, DOE identified six main distribution channels for electric motors and estimated their respective shares of shipments per electric motor horsepower range. The six channels are from the manufacturer to:

(1) OEMs and then to end-users (50 percent of sales);
(2) distributors to end-users (24 percent of sales);
(3) distributors to OEM and then to end-users (23 percent of sales);
(4) contractors and then to end-users (less than one percent of sales);
(5) distributors to end-users through contractors (less than one percent of sales); and
(6) end-users (less than two percent of sales).

Other distribution channels exist (e.g., from manufacturer to OEMs, to end-users through distributors) but are estimated to account for a minor share of the motor sales (less than one percent).

In addition to these distribution chain markups, DOE estimated the shipping costs of the motors and added these to the end-user equipment prices. These costs are a significant factor because more efficient motors are often larger and heavier than less efficient motors, so this is a cost that needs to be included in an accurate cost analysis.

6.2 MARKUP CALCULATION METHODOLOGY

As addressed above, 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). Inputs for calculating the gross margin are all corporate costs, including: overhead costs (sales, general, and administration), research and development (R&D), interest expenses, depreciation, taxes, and profits. For sales of equipment to contribute positively to company cash flow, the markup of the equipment must be greater than the corporate gross margin. Individual pieces of equipment may command a lower or higher markup, depending on their perceived added value and the competition they face from similar equipment in the market.

In developing markups for OEMs and distributors, DOE obtained data about the revenue, CGS, and expenses of firms that produce and sell the equipment of interest. DOE determined that markups are neither fixed-dollar nor proportional to all direct costs, which means that the selling price of a piece of equipment may not be strictly proportional to the purchase price of the equipment. Using the available data, DOE has found measurable differences between incremental markups on direct equipment costs and the average aggregate markup on direct business costs. Additionally, DOE discovered significant differences between average and incremental markups for electric motor OEMs and distributors. Section 6.3 and Section 6.4 further discusses the differences between average and incremental markups.

The main reason that the selling price of a piece of equipment may not be strictly proportional to the purchase price of the equipment is that businesses incur a wide variety of costs. When the purchase price of equipment and materials increases, only a fraction of the business expenses increase, while the remainder of the businesses' expenses stays relatively constant. For example, if the unit price of an electric motor increases by 30 percent, it is unlikely that the cost of secretarial support in an administrative office will increase by 30 percent also. Certain business expenses are uncorrelated with the cost of equipment or cost of goods.

DOE's approach categorizes the expenses into two categories: invariant costs (IVC), which are those costs that are not expected to vary in proportion to the change in manufacturer selling price, and variant costs (VC), which are the costs that scale with the change in manufacturer selling price. Together, IVC and VC represent the gross margin.

For each step in equipment distribution, DOE estimated both a baseline markup and an incremental markup. For electric motors, DOE understands that no increase in distribution labor is necessary for the distribution of more-efficient equipment, while the non-labor-scaling cost does increase with increasing equipment costs. This allowed DOE to estimate the incremental markup given a breakdown of distribution and manufacturing business expenses for a particular industry.

6.2.1 Assumptions

DOE derived the OEM and motor distributor markups from three key assumptions about the costs associated with motor-related industrial series. DOE used the financial data from the 2007 U.S. Economic Census's manufacturing industrial series and 2007 Business Expenses Survey to determine OEM and motor distributor markups, respectively. These income statements break down the components of all costs incurred by firms that assemble and distribute electric motors. The key assumptions used to estimate markups using these financial data are:

1. The firm income statements faithfully represent the various average costs incurred by firms designing, assembling, and distributing electric motors.

2. These costs can be divided into two categories: (1) costs that vary in proportion to the manufacturer selling price (MSP) of electric motors (variant costs); and (2) costs that do not vary with the MSP of electric motors (invariant costs).

3. Overall, OEM and distributor sales prices vary in proportion to OEM and distributor costs that are included in the balance sheets.

In support of the first assumption, the income statements itemize firm costs into a number of expense categories, including CGS, operating labor and occupancy costs, and other operating costs and profit. Although OEMs and motor distributors tend to handle multiple commodity lines, the data provide the most accurate available indication of the expenses associated with electric motors.

In the following discussion, DOE assumes a division of costs between those that do not scale with the manufacturer price (labor and occupancy expenses), and those that do (operating expenses and profit). This division of costs led to the estimate of incremental markups addressed below.

In support of the third assumption, the wholesaler industries are relatively competitive, and end-user demand for motors and equipment with motors is relatively inelastic—i.e., the demand is not expected to decrease significantly with a relatively small increase in price. Following standard economic theory, competitive firms facing inelastic demand either set prices in line with costs or quickly go out of business.[2]

6.3 APPROACH FOR ORIGINAL EQUIPMENT MANUFACTURER MARKUPS

Using the above assumptions, DOE developed baseline and incremental markups for OEMs using the firm income statement from several manufacturing industries which design, assemble, and brand equipment that contain electric motors. The *2007 Economic Census Manufacturing Industry Series* reports the payroll (production and total), cost of materials, capital expenditures and total value of shipments, and miscellaneous operating costs for manufacturers of various types of machinery. DOE collected this data for 25 types of OEMs:

- Farm machinery and equipment manufacturing;
- Construction machinery manufacturing;
- Mining machinery and equipment manufacturing;
- Oil and gas field machinery and equipment manufacturing;
- Sawmill and woodworking machinery manufacturing;
- Plastics and rubber industry machinery manufacturing;
- Paper industry machinery manufacturing;
- Textile machinery manufacturing;
- Printing machinery and equipment manufacturing;
- Food product machinery manufacturing;
- Semiconductor machinery manufacturing;
- Other industrial machinery manufacturing;
- Air-purification equipment manufacturing;
- Industrial and commercial fan and blower manufacturing;
- Heating equipment (except warm air furnaces) manufacturing;
- Air conditioning and warm-air heating and commercial/industrial refrigeration equipment manufacturing;
- Machine-tool (metal cutting types) manufacturing;
- Machine-tool (metal forming types) manufacturing;
- Rolling mill machinery and equipment manufacturing;
- Pump and pumping equipment manufacturing;
- Air and gas compressor manufacturing;
- Elevator and moving stairway manufacturing;
- Conveyor and conveying equipment manufacturing;
- Packaging machinery manufacturing; and
- Fluid-power pump and motor manufacturing.

DOE used the baseline markups, which cover all of the OEM's costs (both variant and invariant costs), to determine the sales price of baseline models. Variant costs were defined as costs that vary in proportion to the change in MSP induced by increased efficiency standards; in contrast, invariant costs were defined as costs that do not vary in proportion to the change in MSP due to increased efficiency standards. The baseline markup relates the MSP to the OEM selling price. For each of the 25 OEMs identified above, DOE calculated the OEM baseline markup as follows:

$$\frac{\text{SALES}}{\text{PAY} + \text{MAT} + \text{CAP}} = \text{MU}_{\text{BASE}}$$

Where:

$SALES$ = value of shipments,
PAY = payroll expenses,
MAT = material input expenses,
CAP = capital expenses,
MU_{BASE} = baseline markup.

The baseline markups range between 1.32 (machine-tool manufacturing) and 1.63 (semiconductor machinery manufacturing), with the sales-weighted average of 1.44.

Incremental markups are coefficients that relate the change in the MSP of more energy-efficient models, or that equipment that meets the requirements of new energy conservation standards, to the change in the OEM selling price. Incremental markups cover only those costs that scale with a change in the manufacturer's sales price (VC). It calculated the incremental markup (MU_{INCR}) for each of the 25 OEMs using the following equation:

$$MU_{INCR} = \frac{CGS_{OEM} + VC_{OEM}}{CGS_{OEM}}$$

Where:

MU_{INCR} = incremental OEM markup,
CGS_{OEM} = OEM's cost of goods sold, and
VC_{OEM} = OEM's variant costs.

The incremental markups range between 1.27 (machine-tool manufacturing) and 1.56 (pump and pumping equipment manufacturing), with the sales-weighted average of 1.39.

6.4 APPROACH FOR MOTOR DISTRIBUTOR MARKUPS

The type of financial data used to estimate markups for OEMs is also available for distributors. DOE based its distributor markups on financial data from *the 2007 U.S. Census Business Expenses Survey* (BES). DOE organized the financial data into income statements that break down cost components incurred by firms that sell equipment with electric motors or replacement motors, "Electrical Goods Merchant Wholesalers" (NAICS 4236).[a]

Using the above assumptions, DOE developed baseline and incremental markups and applied them in calculating end-user equipment prices from manufacturer sales prices. The BES

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[a] The distributors to whom these financial data refer handle multiple commodity lines.

provides gross margin (GM) as percent of sales for the electrical goods merchant wholesalers industry; therefore, baseline markups can be derived with the following equation:

$$\mathrm{MU}_{\mathrm{BASE}} = \frac{Sales(\%)}{Sales(\%) - GM(\%)}$$

DOE used financial data from the BES for the categories "Electrical Goods Merchant Wholesalers" to calculate incremental markups used by wholesalers of motors. Incremental markups are coefficients that relate the change in the MSP of higher-efficiency models to the change in the wholesaler selling price. Hence, incremental markups cover only those costs that scale with a change in the manufacturer's sales price (i.e., VC). DOE considers higher-efficiency models to be equipment sold under market conditions with new efficiency standards. It calculated the incremental markup (MU_{INCR}) for distributors using the following equation:

$$MU_{INCR} = \frac{CGS_{DISTRIBUTOR} + VC_{DISTRIBUTOR}}{CGS_{DISTRIBUTOR}}$$

Where:

MU_{INCR} = incremental wholesaler markup,
$CGS_{DISTRIBUTOR}$ = distributor's cost of goods sold, and
$VC_{DISTRIBUTOR}$ = distributor's variant costs.

Table 6.4-1 shows the data from the BES and the markups DOE estimated using the procedures described above.

Table 6.4-1 Business Expenses Survey Data Used to Calculate Distributor Markups

Items	**Amount ($1,000,000)**
Sales	348,960
Cost of goods sold (CGS)	258,579
Gross Margin	90,381
Total Operating Expenses	55,785
Labor & Occupancy Expenses	**Amount ($1,000,000)**
Annual payroll	26,785
Employer costs for fringe benefit	5,008
Contract labor costs including temporary help	894
Purchased utilities, total	628
Cost of purchased repair and maintenance services	691
Cost of purchased management consulting administrative services and other professional services	1,863
Purchased communication services	790
Lease and rental payments	2,164
Taxes and license fees (mostly income taxes)	707

Other Operating Expenses & Profit	Amount ($1,000,000)
Expensed computer related supplies	335
Cost of purchased packaging and containers	335
Other materials and supplies not for resale	644
Lease and rental payments for machinery and equipment	347
Cost of purchased transportation, shipping and warehousing services	2,486
Cost of purchased advertising and promotional services	1,890
Expense purchases of software	353
Cost of data processing and other purchased computer services, except communications	268
Depreciation and amortization charges	2,170
Commissions paid	1,444
Other Operating Expenses	6,004
Net profit before taxes	34,575
Baseline Markup=(CGS+GM)/CGS	1.350
Incremental Markup=(CGS+Total Other Operating Expenses and Profit)/CGS	1.197

Source: 2007 Business Expenses Survey, Electrical Goods Merchant Wholesalers (NAICS 4236)

6.5 CONTRACTOR OR INSTALLER MARKUP

DOE used information from RSMeans *Electrical Cost Data*[3] to estimate markups used by contractors in the installation of equipment with small motors or replacement motors. RSMeans *Electrical Cost Data* estimates material expense markups for electrical contractors as 10 percent, leading to a markup factor of 1.10. DOE recognizes that contractors are not used in all installations, as some firms have in-house technicians who would install equipment or replace a motor. However, DOE has no information on the extent to which this occurs, so it applied a markup of 1.10 in all cases.

6.6 SALES TAXES

The sales tax represents state and local sales taxes that are applied to the end-user equipment price of the equipment. The sales tax is a multiplicative factor that increases the end-user equipment price.

DOE derived state and local taxes from data provided by the Sales Tax Clearinghouse.[4] These data represent weighted averages that include county and city rates. DOE then derived population-weighted average tax values for each Census division and large state, as shown in Table 6.6-1 below. This provides a national average tax rate of 7.12 percent, which DOE used for each of the distribution channels.

Table 6.6-1 Average Sales Tax Rates by Census Division and Large State

Census Division/State	**2011 Population**	**Tax Rate (2011) %**
New England	14,492,360	5.64
Middle Atlantic	21,564,041	6.62
East North Central	46,519,084	6.85
West North Central	20,639,751	7.15
South Atlantic	41,167,090	6.27
East South Central	18,553,961	7.93
West South Central	11,304,323	8.47
Mountain	22,373,411	6.80
Pacific	12,799,425	5.24
New York	19,465,197	8.45
California	37,691,912	8.20
Texas	25,674,681	8.00
Florida	19,057,542	6.65
Population Weighted Average		7.12

6.7 OVERALL MARKUP

The overall markup for each distribution channel is the product of the relevant markups, as well as the sales tax. DOE used the overall baseline markup to estimate the end-user equipment price of baseline models, given the MSP of the baseline models. As stated above, DOE considers baseline models to be equipment sold under existing market conditions (i.e., without new energy efficiency standards).

DOE used the overall incremental markup to estimate changes in the end-user equipment price, given changes in the manufacturer cost above the baseline model cost resulting from a standard to raise equipment efficiency. The total end-user equipment price for higher-efficiency models is composed of two components: the end-user equipment price of the baseline model and the change in end-user equipment price associated with the increase in manufacturer cost to meet the new efficiency standard. The following equation shows how DOE used the overall incremental markup to determine the end-user equipment price for higher-efficiency models (i.e., models meeting new efficiency standards).

$$
\begin{aligned}
EQP_{STD} &= MSP_{MFG} \times MU_{OVERALL\_BASE} + \Delta MSP_{MFG} \times \left(MU_{INCR} \times Tax_{SALES} \right) \\
&= EQP_{BASE} + \Delta COST_{MFG} \times MU_{OVERALL\_INCR}
\end{aligned}
$$

Where:

EQP_{STD} = end-user equipment price for models meeting new efficiency standards,
EQP_{BASE} = end-user equipment price for baseline models,
MSP_{MFG} = manufacturer selling price for baseline models,
ΔMSP_{MFG} = change in manufacturer selling price for higher-efficiency models,
MU_{INCR} = incremental OEM or distributor markup,
Tax_{SALES} = sales tax,
$MU_{OVERALL\_BASE}$ = baseline overall markup (product of manufacturer markup, baseline OEM or distributor markup, and sales tax), and
$MU_{OVERALL\_INCR}$ = incremental overall markup (product of manufacturer markup, incremental OEM or distributor markup, and sales tax).

Table 6.7.1 summarizes the markups and the overall baseline and incremental markups for each of the three main identified channels. Weighting the values by the respective shares of each channel yields an average overall baseline markup of 1.63 and an overall incremental markup of 1.50.

Table 6.7.1 Summary of Markups for Three Primary Distribution Channels for Electric Motors

Markup	OEM to End-User (50%)		Distributor to End-User (24%)		Distributor to OEM to End-User (23 %)	
	Baseline	Incremental	Baseline	Incremental	Baseline	Incremental
Distributor	-	-	1.35	1.20	1.35	1.20
OEM	1.44	1.39	-	-	1.44	1.39
Contractor/Installer	-	-	-	-	-	-
Sales Tax	1.0712	1.0712	1.0712	1.0712	1.0712	1.0712
Overall	1.54	1.49	1.45	1.29	2.08	1.79

6.8 SHIPPING COSTS

DOE examined freight shipping costs to evaluate the impact of increased motor weight on installed cost. DOE collected quoted shipping costs from 16 freight shipment companies for single shipments by “less than truckload” (LTL) ground service weighing between 50 and 2,600 pounds and over shipping distances between 350 and 3,000 miles. Marginal shipment costs per pound varied from 7.1 cents to $1.44, depending on the total weight, distance shipped, and guaranteed delivery times. DOE used a median marginal shipment cost of 65 cents per pound.

REFERENCES

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[1] Arthur D. Little, Inc. (1980), *Classification and Evaluation of Electric Motors and Pumps.* Report DOE/TIC-11339. Prepared for the US. Department of Energy, Office of Industrial Programs. Sprindfield, Va.: National Technical Information Service.

[2] Pindyck, R.S. and D.L. Rubinfeld. (2000), *Microeconomics, 5th ed.*, New Jersey: Prentice Hall.

[3] RSMeans Construction Publishers & Consultants. (2010), *Electrical Cost Data, 33st Annual Edition.* 2010. ed. J.H. Chiang, Kingston, MA.

[4] Sales Tax Clearinghouse, Inc. (last access on April 24, 2011), *State sales tax rates along with combined average city and county rates*, http://thestc.com/STrates.stm

CHAPTER 7. ENERGY USE CHARACTERIZATION

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CHAPTER 7. ENERGY USE CHARACTERIZATION

7.1 INTRODUCTION

A key component of the life-cycle cost (LCC) and payback period (PBP) calculations described in chapter 8 of the Technical Support Document is the savings in operating costs that customers would realize from more energy efficient equipment. Energy costs are the most significant component of customer operating costs. The U.S. Department of Energy (DOE) uses annual energy use, along with energy prices, to establish energy costs at various energy efficiency levels. This chapter describes how DOE determined the annual energy use of electric motors.

The analysis focuses on eight representative units identified in the engineering analysis (chapter 5) and for which engineering analysis outputs were obtained. (Table 7.1.1)

Table 7.1.1 Representative Units for Preliminary Analysis

Representative Unit	Equipment class Group	Specifications	Horsepower
1	NEMA Designs A & B	NEMA Design B, T-frame, enclosed, 4-pole	5
2			30
3			75
4	NEMA Design C	NEMA Design C, T-frame, enclosed, 4-pole	5
5			50
6	Fire Pump	Uses same engineering outputs as units 1, 2, and 3	5
7			30
8			75

7.2 ENERGY USE ANALYSIS FOR ELECTRIC MOTORS

7.2.1 Introduction

The energy use by electric motors is derived from three components: energy converted to useful mechanical shaft power, motor losses, and reactive power. Motor losses consist of I^2R losses (both stator and rotor), core losses, stray-load losses, and friction and windage losses.[1] Core losses and friction and windage losses are relatively constant with variations in motor loading, while I^2R losses increase with the square of the motor loading. Stray-load losses are also dependent upon loading. DOE models the I^2R losses and stray-load losses as load-dependent losses.

7.2.2 Motor Losses

For each representative unit, DOE obtained data on part load motor losses from test data developed in the engineering analysis (chapter 5). Based on the test data, DOE modeled the motor losses as a function of loading using a third degree polynomial equation[2]:

$$Loss(L) = A + B \times L + C \times L^2 + D \times L^3$$

where:

Loss(L) = the losses of the motor at loading L in watts
L = motor loading as a fraction of rated power in percent
A/B/C/D = polynomial equation coefficients

Table 7.2.1 presents the polynomial equation coefficients for modeling losses as a function of loading for the eight representative units at each efficiency level analyzed by DOE. These efficiency levels correspond to the candidate standard levels (CSLs) analyzed in the engineering analysis (chapter 5).

Table 7.2.1 Polynomial Equation Coefficients for Losses vs. Loading Relationship

Representative Unit	CSL	A	B	C	D
1	0	234.2	115.8	273.4	168.0
	1	169.6	51.2	208.8	103.4
	2	158.0	77.8	68.3	133.6
	3	150.3	21.8	182.8	50.4
	4	143.5	63.0	110.5	51.8
	5	135.3	29.2	147.8	25.2
2	0	1059.3	181.4	1052.5	332.3
	1	863.1	-14.8	856.3	136.1
	2	639.7	102.7	586.8	201.1
	3	509.6	17.5	622.2	253.9
	4	444.6	228.4	358.3	271.3
	5	444.6	228.4	358.3	271.3
3	0	1775.2	267.1	1757.2	411.8
	1	1599.4	91.3	1581.4	236.0
	2	870.8	280.9	1037.9	508.1
	3	809.6	219.7	976.7	446.9
	4	653.5	1006.4	-261.5	811.8
	5	608.3	961.2	-306.7	766.6
4	0	220.3	62.5	159.7	90.3
	1	202.0	85.7	67.8	82.1
	2	194.2	74.6	76.2	60.3
	3	179.7	36.1	115.0	38.0

5	0	1177.8	106.3	1240.8	282.6
	1	829.6	970.7	-111.9	650.4
	2	781.6	907.0	-140.1	622.2
	3	609.3	1019.3	-575.5	910.2
6	0	169.6	51.2	208.8	103.4
	1	158.0	77.8	68.3	133.6
	2	150.3	21.8	182.8	50.4
	3	143.5	63.0	110.5	51.8
	4	135.3	29.2	147.8	25.2
7	0	863.1	-14.8	856.3	136.1
	1	639.7	102.7	586.8	201.1
	2	509.6	17.5	622.2	253.9
	3	444.6	228.4	358.3	271.3
	4	444.6	228.4	358.3	271.3
8	0	1599.4	91.3	1581.4	236.0
	1	870.8	280.9	1037.9	508.1
	2	809.6	219.7	976.7	446.9
	3	653.5	1006.4	-261.5	811.8
	4	608.3	961.2	-306.7	766.6

To determine the annual energy losses E_{loss} in kilowatt-hours (kWh), DOE converts the full-load losses into part-load losses using the estimate of the motor's loading, and multiplies by the annual operating hours. Annual energy losses are represented by the following equation:

$$E_{loss} = H_{op} \times Loss(L)$$

where:

E_{loss} = annual energy consumed by motor losses in watts per hour
H_{op} = the annual operating hours, also known as the duty factor in hours
L = motor loading as a fraction of rated power in percent

7.2.2.1 Impact of Higher Operating Speeds

DOE is aware that the installation of a more efficient motor could lead to less energy savings than anticipated. According to comments from interested parties, a more efficient motor typically has less slip than a less efficient motor, which is an attribute that can result in a higher operating speed and potentially overloading the motor.

DOE acknowledges that the cubic relation between speed and power requirement in many variable torque applications can affect the benefits gained by efficient motors, which have a lower slip. DOE did not obtain sufficient data to incorporate this effect into the LCC analysis. Instead, DOE incorporated this effect as a sensitivity analysis in the LCC spreadsheet, allowing the user to consider this effect following a scenario which described in Appendix 7-A of the technical support document (TSD).

7.2.3 Reactive Power

In an alternating current power system, the reactive power is the root mean square (RMS) voltage times the RMS current, multiplied by the sine of the phase difference between the voltage and the current. Reactive power occurs when the inductance or capacitance of the load shifts the phase of the voltage relative to the phase of the current. While reactive power does not consume energy directly, it can increase losses and costs for the electricity distribution system. Motors tend to create reactive power because the windings in the motor coils have high inductance.

Alternating-current power flow has three components: real power (P), measured in watts (W); apparent power (S), measured in volt-amperes (VA); and reactive power (Q), measured in reactive volt-amperes (VAr). The power factor is defined as P/S. In the case of a perfectly sinusoidal waveform, P, Q, and S can be expressed as vectors that form a vector triangle such that: $S^2 = P^2 + Q^2$. This implies that the formula for reactive power as a function of real power and power factor is as follows:

$$Q = P * (1/PF^2-1)$$

where:

Q = reactive power in reactive volt-amperes,
P = real power in watts, and
PF = the motor's power factor.

DOE used data on motor power factor as a function of motor loading from test data developed in the engineering analysis (TSD chapter 5) to develop a relationship between power factor and motor loading. This relationship is expressed as a third degree polynomial:

$$PF(L) = A + B \times L + C \times L^2 + D \times L^3$$

Table 7.2.2 presents the polynomial equation coefficients developed to estimate power factor for all representative units at each efficiency level analyzed by DOE.

Table 7.2.2 Polynomial Equation Coefficients for Power Factor vs. Loading Relationship

Representative Unit	CSL	A	B	C	D
1	0	0.036	2.055	-1.856	0.595
	1	0.034	2.053	-1.858	0.592
	2	0.066	1.664	-1.314	0.374
	3	0.071	2.140	-2.034	0.663
	4	0.074	2.140	-2.025	0.661
	5	0.071	2.140	-2.034	0.663
2	0	0.076	2.143	-2.023	0.664
	1	0.034	2.053	-1.858	0.592
	2	0.034	2.053	-1.858	0.592
	3	0.075	1.977	-1.817	0.575

	4	0.047	2.332	-2.387	0.794
	5	0.047	2.332	-2.387	0.794
3	0	0.036	2.055	-1.856	0.595
	1	0.034	2.053	-1.858	0.592
	2	0.074	2.140	-2.025	0.661
	3	0.036	2.055	-1.856	0.595
	4	0.043	2.492	-2.625	0.900
	5	0.038	2.487	-2.630	0.895
4	0	0.033	1.612	-1.276	0.381
	1	0.040	0.860	-0.269	-0.012
	2	0.059	1.324	-0.831	0.177
	3	0.077	1.746	-1.453	0.420
5	0	0.074	2.140	-2.025	0.661
	1	0.044	1.925	-1.704	0.515
	2	0.044	1.925	-1.704	0.515
	3	0.050	2.401	-2.506	0.849
6	0	0.034	2.053	-1.858	0.592
	1	0.066	1.664	-1.314	0.374
	2	0.071	2.140	-2.034	0.663
	3	0.074	2.140	-2.025	0.661
	4	0.071	2.140	-2.034	0.663
7	0	0.034	2.053	-1.858	0.592
	1	0.034	2.053	-1.858	0.592
	2	0.075	1.977	-1.817	0.575
	3	0.047	2.332	-2.387	0.794
	4	0.047	2.332	-2.387	0.794
8	0	0.034	2.053	-1.858	0.592
	1	0.074	2.140	-2.025	0.661
	2	0.036	2.055	-1.856	0.595
	3	0.043	2.492	-2.625	0.900
	4	0.038	2.487	-2.630	0.895

7.2.4 Motor Applications

The annual operating hours and loading of motors depend on the sector (i.e., industry, agriculture, and commercial), motor size (in horsepower), and end-use application (e.g., pump). DOE estimated the share of motors in each type of application depending on the National Electrical Manufacturers Association (NEMA) design and size of the motor, and used a distribution of motors across sectors by motor size. DOE drew upon several data sources to develop a model of the applications for which motors covered in this analysis are used.

Six motor applications (air compressors, fans, pumps, material handling and processing, fire pumps, and others) were selected as representative applications based on a previous DOE study (DOE-ITP study)[3] and a database of motor nameplate and field measurement data compiled by the Washington State University (WSU) Extension Energy Program, Applied

Proactive Technologies (APT), and New York State Energy Research and Development Authority (NYSERDA)[4] ("WSU/NYSERDA database")[a]. The tables below summarize the distribution of NEMA Design A and B motors (Table 7.2.3), and NEMA Design C motors (Table 7.2.4) across applications by horsepower range in the industrial sector. No sufficient data were available to develop similar estimates in the commercial or agricultural sector and, instead, the estimates in the industrial sector were used as an approximation.

Table 7.2.3 Distribution of Motors by Application for NEMA Design A and B Motors (in percent)

	Horsepower (hp) range						
Application	**1-5**	**6-20**	**21-50**	**51-100**	**101-200**	**201-500**	**all *hp***
Air Compressor	1.8	1.3	2.2	5.6	5.4	8.3	2.2
Fans	22.5	24.9	26.6	25.7	18.9	21.7	24.0
Pumps	22.3	31.6	33.0	34.2	36.0	25.5	28.5
Material Handling and Processing	12.0	9.4	6.8	10.6	7.8	7.6	10.0
Other	41.4	32.8	31.4	23.9	31.9	36.9	35.3
Fire Pumps	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7.2.4 Distribution of Motors by Application for NEMA Design C Motors (in percent)

	Horsepower (hp) range					
Application	**1-5**	**6-20**	**21-50**	**51-100**	**101-200**	**all *hp***
Air Compressor	0.0	0.0	0.0	0.0	0.0	0.0
Fans	25.0	11.1	0.0	11.1	10.3	10.3
Pumps	0.0	0.0	28.6	0.0	6.9	6.9
Material Handling and Processing	25.0	11.1	14.3	11.1	13.8	13.8
Other	50.0	77.8	57.1	77.8	69.0	69.0
Fire Pumps	0.0	0.0	0.0	0.0	0.0	0.0

The distribution of motors across sectors by motor size was extracted from an Easton Consultants report[5] which provides the distribution of alternating-current integral-horsepower motors by horsepower across various sectors. DOE adjusted the distribution across sectors to only account for three-digit NEMA frame size motors assuming that two-digit NEMA frame size

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[a] The motors database comprised of information gathered by WSU and APT during 123 industrial motor surveys or assessments: 11 motor assessments were conducted between 2005 and 2011 and occurred in industrial plants; 112 industrial motor surveys were conducted between 2005 and 2011 and were funded by NYSERDA and conducted in New York State.

motors account for 30 percent of total integral motors below 5 hp and are primarily used in the commercial sector. (Table 7.2.5)

Table 7.2.5 Motor Distribution across Sector by Motor Size

Horsepower range	Industry %	Agriculture %	Commercial %
1-5	37	0	63
6-20	26	0	74
21-50	26	0	74
51-100	63	7	30
101-200	76	3	21
201-500	69	3	28

7.2.5 Loading

To calculate the annual kWh use at each efficiency level in each equipment class, DOE used the losses versus load curves from the engineering analysis (Table 7.2.1), along with estimates of motor operating hours and average loading.

The average motor loading mainly depends on the motor's end-use application (e.g., fan, pump) and sector (e.g., industrial). In the industrial sector, the DOE-ITP study shows that, for a specific application, loading does not vary significantly across horsepower ranges. DOE estimated application-specific average loading based on approximately 15,000 field measurements provided by the WSU/NYSERDA database. A statistical distribution to characterize variability in the field was also extracted from the WSU/NYSERDA database. Table 7.2.6 presents the average motor loading by applications in the industrial sector. Because sufficient data were not available, the same average loading values and statistical distribution were used in the commercial and agricultural sectors.

Table 7.2.6 Average Motor Loading by Application

Application	Loading %
Air compressors	0.70
Fans	0.60
Pumps	0.68
Material Handling and Processing	0.48
Other	0.71
Fire Pumps	0.62

7.2.6 Motor Hours of Operation/Duty Factor

DOE estimated average annual operating hours by sector, application, and horsepower ranges and developed statistical distributions to use in its Monte Carlo analysis (the Monte Carlo analysis is described in TSD chapter 8).

For the industrial sector, DOE used the WSU/NYSERDA database to determine average annual operating hours by application and horsepower ranges and statistical distributions. For example, Figure 7.2.1 shows the cumulative form of the discrete distributions for motors between 21 and 50 horsepower in various applications.

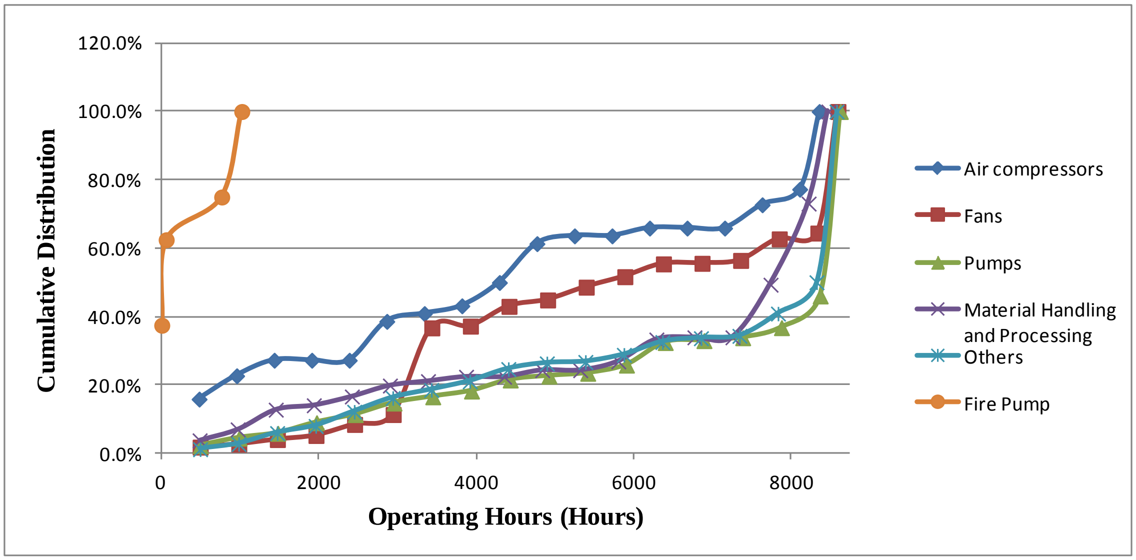

Figure 7.2.1 Cumulative Distribution for 21-50 Horsepower Motors by Applications in Industry Sector.

For the commercial and agricultural sectors, DOE derived estimates of average operating hours by application and horsepower range from various sources: a presentation by Richard A. Peterson[6], an article by Michael Gallaher *et al.*[7], the Regional Technical Forum[8], DOE's own analysis on classification and evaluation of electric motors and pump[9], an Electric Power Research Institute (EPRI) report[10], and a DOE report by Arthur D. Little[11]. For fire pumps, DOE assumed a uniform distribution between 0.5 hours (based on comments from interested parties) to 6 hours.

Table 7.2.7 displays the average hours of motor operation by application and motor sizes for the industrial, commercial, and agricultural sectors.

Table 7.2.7 Average Motor Operating Hours by Application and Horsepower Range

	Horsepower (hp) range					
	1-5	**6-20**	**21-50**	**51-100**	**101-200**	**201-500**
Industry						
Air Compressors	4,647	5,033	4,578	5,337	6,226	6,349
Fans	6,193	6,490	5,849	6,975	7,163	8,015
Pumps	6,028	6,773	6,972	6,869	6,985	6,934
Material Handling	6,486	6,284	6,518	6,315	7,172	6,116
Other	6,571	6,274	6,814	7,128	7,337	7,528
Fire Pump	13	366	366	3,848	4,411	4,411
Commercial						
Air Compressors	1,000	1,200	1,500	1,500	1,500	1,500
Fans	3,000	3,300	3,600	3,900	4,200	4,500
Pumps	1,500	1,650	1,800	1,950	2,100	2,250
Material Handling	1,959	2,165	2,380	2,567	2,753	2,939
Other	1,959	2,165	2,380	2,567	2,753	2,939
Fire Pump	0.5-6	0.5-6	0.5-6	0.5-6	0.5-6	0.5-6
Agriculture						
Air Compressors	1,901	1,901	1,901	1,901	1,901	1,901
Fans	4,800	4,800	4,800	4,800	4,800	4,800
Pumps	1,800	1,800	1,800	1,900	2,000	2,000
Material Handling	1,500	1,500	1,500	1,500	1,500	1,500
Other	1,901	1,901	1,901	1,901	1,901	1,901
Fire Pump	0.5-6	0.5-6	0.5-6	0.5-6	0.5-6	0.5-6

7.3 ANNUAL ENERGY USE

Depending on the hours of operation, the loading, and the efficiency of the motor (which varies with the standard level), the annual energy use varies both by efficiency level and from motor to motor. The annual energy use is calculated using the following expression:

$$E = \frac{HP \times L}{\eta} \times H_{op}$$

where:

E = energy use,
HP = horsepower of the motor, or motor capacity,
L = motor loading as a fraction of rated power in percent
η = operating efficiency, and
H_{op} = motor operating hours.

Table 7.3.1 shows the results of the energy use analysis for the eight representative units at each considered energy efficiency level. Results are given for baseline units (CSL 0) and the three candidate standard levels (CSLs) being considered for motors.

Table 7.3.1 Average Annual Energy Consumption by Efficiency Level for Representative Units

Rep. Unit	**Description**	***kilowatt-hours per year***					
		CSL 0	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
1	Design B, T-frame, 5 hp*, 4 poles, enclosed	10,448	9,869	9,691	9,616	9,567	9,487
2	Design B, T-frame, 30 hp, 4 poles, enclosed	57,642	55,912	55,021	54,492	54,326	54,326
3	Design B, T-frame, 75 hp, 4 poles, enclosed	204,834	202,540	198,496	197,697	197,194	196,604
4	Design C, T-frame, 5 hp, 4 poles, enclosed	9,987	9,808	9,738	9,630	-	-
5	Design C, T-frame, 50 hp, 4 poles, enclosed	89,523	88,507	88,119	87,444	-	-
6	Fire pump, 5 hp, 4 poles, enclosed	19.6	19.2	19.1	19.0	18.8	-
7	Fire pump, 30 hp, 4 poles, enclosed	1,601	1,577	1,562	1,558	1,558	-
8	Fire pump, 75 hp, 4 poles, enclosed	97,791	95,934	95,554	95,313	95,033	-

* hp = horsepower.

REFERENCES

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[1] National Electrical Manufacturers Association (2002), *NEMA Standards Publication: Information Guide for General Purpose Industrial AC Small and Medium Squirrel-Cage Induction Motor Standards*, NEMA, 1300 North 17th Street, Suite 1847, Rosslyn, VA 22209.

[2] Fernando J. T. E. Ferreira, Aníbal T. De Almeida (September 2011), *Technical and Economical Considerations of Line-Start PM Motors Including the Applicability of the IEC600-34-2-1 Standard*, Energy Efficiency in Motor Driven Systems, Alexandria, VA.

[3] U.S Department of Energy (December 2002), *United States Industrial Electric Motor System Market Opportunities Assessment*. Retrieved February 9, 2011, from http://www1.eere.energy.gov/industry/bestpractices/pdfs/mtrmkt.pdf

[4] Database of motor nameplate and field measurement data compiled by the Washington State University Extension Energy Program (WSU) and Applied Proactive Technologies (APT) under contract with the New York State Energy Research and Development Authority (NYSERDA). 2011.

[5] Easton Consultants, I. (2000), *Variable Frequency Drive*. Retrieved February 9, 2011, from http://neea.org/research/reports/E00-054.pdf

[6] Peterson, R. A. (n.d.). *General Energy Management for Agricultural Facilities*. Retrieved March 31, 2011, from http://www.mainerural.org/energy/fieldguide/generalfacilities.pdf

[7] Gallaher, M., Delhotal, K., & Petrusa, J. (2009), *Estimating the potential* CO_2 *mitigation from agricultural energy efficiency in the United States*, *Energy Efficiency* (2), 207-220.

[8] Regional Technical Forum. Retrieved March 31, 2011, from Regional Technical Forum: http://www.nwcouncil.org/energy/rtf/measures/ag/IrrgAg_PremiumMotorsFY10v1_2.xls

[9] U.S. Department of Energy (1980), *Classification and Evaluation of Electric Motors and Pumps*, Washington, D.C.

[10] EPRI (1992), *Electric Motors Markets, Trends, and Applications*, EPRI.

[11] Arthur D. Little, I. (1999), *Opportunities for Energy Savings in the Residential and Commerical Sectors with High-Efficiency Electric Motors*. Washington, DC: Department of Energy.

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 of the technical support document (TSD) presents the U.S. Department of Energy's (DOE)'s life-cycle cost (LCC) and payback period (PBP) analyses. It describes the method DOE used for analyzing the economic impacts of possible standards on consumers. The effect of standards on consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). The LCC and PBP analyses produce two basic outputs to describe the effect of standards on consumers:

- **LCC** is the total (discounted) cost that a consumer pays over the lifetime of the equipment, including purchase price, installation cost, and operating expenses.

- **PBP** measures the amount of time it takes consumers to recover the estimated higher purchase expense of more energy efficient equipment through lower operating costs.

This chapter presents inputs and results for the LCC and PBP analyses, as well as key variables, current assumptions, and computational equations. DOE performed the calculations discussed here using Microsoft Excel spreadsheets, which are accessible on DOE's website (*http://www.eere.energy.gov/buildings/appliance_standards/*). Inputs to the LCC and PBP are discussed in sections 8.2 and 8.3, respectively, of this chapter. Results for the LCC and PBP are presented in section 8.4, with sensitivity results in section 8.5. Details regarding and instructions for using the spreadsheets are discussed in Technical Support Document (TSD) Appendix 8-A.

8.1.1 General Approach for Life-Cycle Cost and Payback Period Analysis

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 a Microsoft Excel spreadsheet combined with Crystal Ball (a commercially available add-on program).

In addition to characterizing several of the inputs to the analysis with probability distributions, DOE also developed a sample of end-use applications for each of the eight representative units. These end-use applications determine the use profile of the motor and the economic characteristics of the motor owner (by sector). Table 8.1.1 shows the market shares of each application for all representative units across all sectors (see TSD chapter 7 for details)[1].

Table 8.1.1 Application Shares by Representative Unit

Representative Unit		Application					
		Air compressors	Fans	Pumps	Material Handling and Processing	Other	Fire Pumps
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	1.8%	22.5%	22.3%	12.0%	41.4%	0.00%
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	2.2%	26.6%	33.0%	6.8%	31.4%	0.00%
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	5.6%	25.7%	34.2%	10.6%	23.9%	0.00%
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	0.0%	25.0%	0.0%	25.0%	50.0%	0.0%
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	0.0%	0.0%	28.6%	14.3%	57.1%	0.0%
6	Fire pump, 5 hp, 4 poles, enclosed	0.0%	0.0%	0.0%	0.0%	0.0%	100%
7	Fire pump, 30 hp, 4 poles, enclosed	0.0%	0.0%	0.0%	0.0%	0.0%	100%
8	Fire pump, 75 hp, 4 poles, enclosed	0.0%	0.0%	0.0%	0.0%	0.0%	100%

In each Monte Carlo iteration, for each representative unit, one of the applications is identified by sampling from a distribution of applications for that representative unit. The selected application determines the number of operating hours per year as well as the motor loading. The operating hours and the motor loading for the application are used in the energy use calculation (see TSD chapter 7).

Further, the sector and the Census region are identified by sampling from distributions and they determine the energy price used in the LCC calculation in each simulation. DOE used Energy Information Administration (EIA) data on electricity prices in 2010 for different customer classes and data from the DOE and the U.S. Department of Agriculture to establish the variability in energy pricing by Census region.

Also, the sector to which the motor belongs determines the discount rate used in the LCC calculation in each simulation.

DOE also used data from the literature on motor loading and motor application characteristics to estimate the variability of annual energy use. Due to the large range of applications and motor use characteristics considered in the LCC and PBP analysis, the range of annual energy use and energy prices can be quite large. Thus, although the annual energy use and energy pricing are known for each sampled motor, their variability across all motors contributes to the range of LCCs and PBPs calculated for any particular standard level.

Results presented at the end of this chapter are based on 10,000 samples per Monte Carlo simulation run. DOE displays the LCC and PBP results as distributions of impacts compared to the base case without standards.

8.1.2 Overview of Life-Cycle Cost and Payback Period Inputs

DOE categorizes inputs to the LCC and PBP analysis as follows: (1) inputs for establishing the initial expense, otherwise known as the total installed cost, and (2) inputs for calculating the operating cost.

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer selling price*: The price at which the manufacturer sells the baseline equipment, which includes the costs incurred by the manufacturer to produce equipment meeting existing standards.
- *Manufacturer selling price increases*: The change in manufacturer selling price associated with producing equipment to meet a particular standard level.
- *Markups and sales tax*: The markups and sales tax associated with converting the manufacturer cost to a consumer equipment price. The markups and sales tax are described in detail in chapter 6, Markups Analysis.
- *Installation cost*: The cost to the consumer of installing the equipment. The installation cost represents all costs required to install the equipment other than the marked-up consumer equipment price. The installation cost includes labor, overhead, and any miscellaneous materials and parts. Thus, the total installed cost equals the consumer equipment price plus the installation cost.

The primary inputs for calculating the operating cost are:

- *Equipment energy consumption and reactive power*: The equipment energy consumption is the site energy use associated with operating the equipment. Reactive power is power that is reflected back to the electrical system by a change in the phase of alternating current power. TSD Chapter 7, Energy Use Characterization, details how DOE determined the equipment energy consumption based on various data sources.

- *Equipment efficiency*: The equipment efficiency dictates the energy consumption associated with standard-level equipment (i.e., equipment with efficiencies greater than baseline equipment). TSD Chapter 7, Energy Use Characterization, details how energy and reactive power change with increasing equipment efficiency and how equipment efficiency relates to actual equipment energy use.

- *Energy prices*: Energy prices are the prices paid by end-users for energy (i.e., electricity). DOE determined current energy prices based on data from the EIA.

- *Energy price trends*: DOE used the EIA *Annual Energy Outlook 2011* (*AEO2011*)[2] to forecast energy prices into the future. For the results presented in this chapter, DOE used the reference case of *AEO2011* to forecast future energy prices.

- *Repair and maintenance costs*: Repair costs are associated with repairing or replacing components that have failed. Maintenance costs are associated with maintaining the operation of the equipment.

- *Lifetime*: The age at which the equipment 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 between the installed cost and operating cost inputs for the calculation of the LCC and PBP. In the figure below, the yellow boxes indicate the inputs, the green boxes indicate intermediate outputs, and the blue boxes indicate the final outputs (the LCC and PBP).

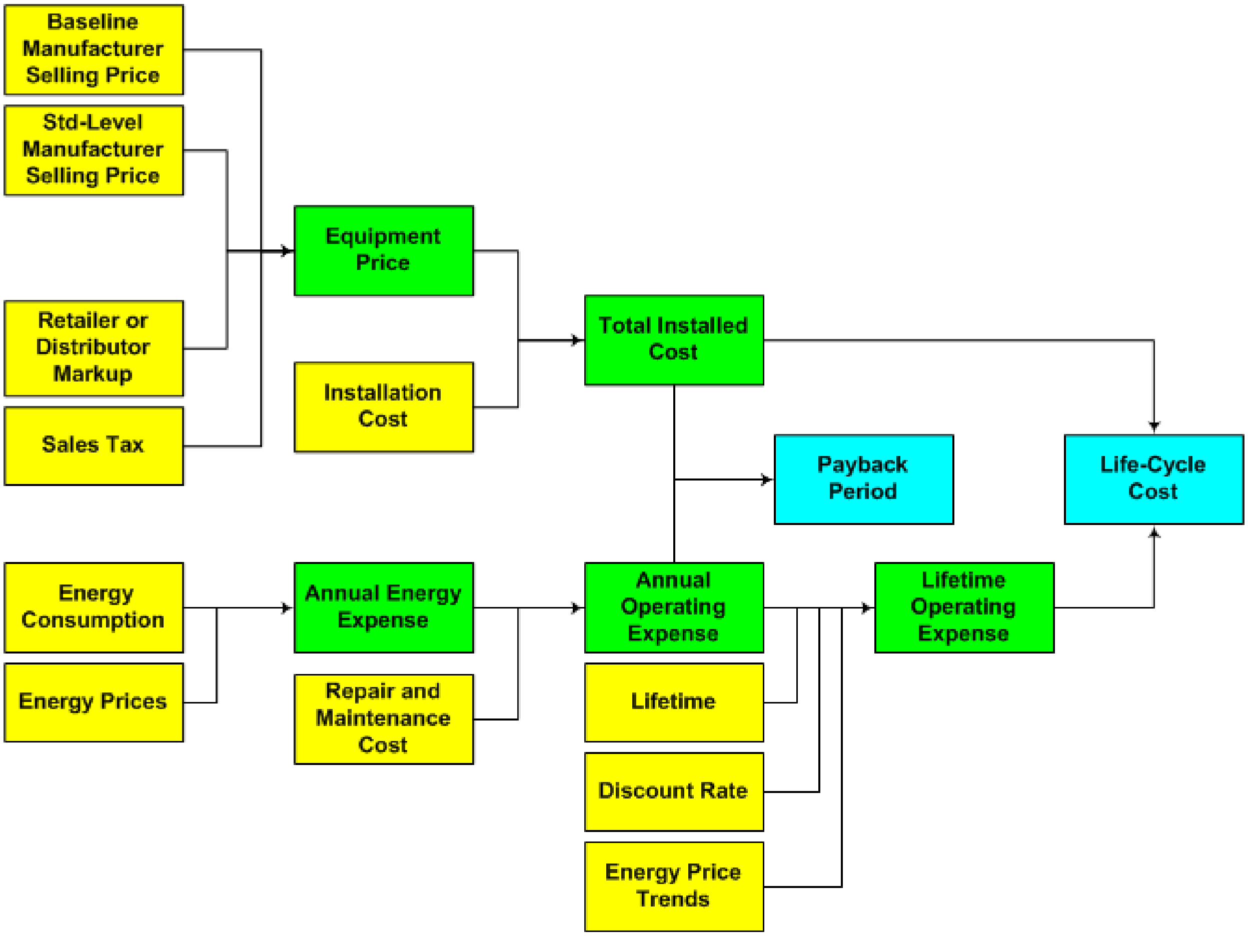

Figure 8.1.1 Flow Diagram of Inputs for the Determination of Life-Cycle Cost and Payback Period

8.2 LIFE-CYCLE COST INPUTS

Life-cycle cost is the total customer expense over the life of a piece of equipment, including purchase expense and operating costs (including energy expenditures). DOE discounts future operating costs to the time of purchase, and sums them over the lifetime of the equipment. DOE defines LCC by the following equation:

$$LCC = IC + \sum_{t=1}^{N} \frac{OC_t}{(1+r)^t}$$

Where:

LCC = life-cycle cost in dollars,
IC = total installed cost in dollars,
$\sum$ = 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 gathered most of its data for the LCC and PBP analysis in 2010 and 2011, and updated its inputs to 2011$ using appropriate measures of inflation where necessary. Throughout this TSD, DOE expresses dollar values in 2011$.

Table 8.2.1 is an example of how DOE calculates the LCC and PBP for representative unit 1 (NEMA Design B, T-Frame, 5 HP, 4 poles, enclosed motor). This table summarizes the total installed cost inputs and the operating cost inputs, including the lifetime, discount rate, and energy price trends. DOE characterized all of the total cost inputs with single-point values, but characterized several of the operating cost inputs with probability distributions that capture the input’s uncertainty or variability, or both. For those inputs characterized with probability distributions, the values provided in the following table are the average or typical values. Also listed in the following table is the chapter of the TSD where more detailed information on the inputs can be found. The sections following the table discuss total installed cost, operating cost, lifetime, and discount rate.

Table 8.2.1 Inputs for Life-Cycle Cost and Payback Period Analysis: Representative Unit 1

Input	Average or Typical Value	Characterization	TSD Chapter Reference
Total Installed Cost Inputs			
Baseline Manufacturer Cost (2011$)	$324	Price for NEMA Design B, T-Frame, 5 hp, 4 poles, Enclosed Motors. Single-Point Value.	5
Candidate Standard-Level (CSL) Manufacturer Cost Increase (2011$)	CSL 1 = $326 CSL 2 = $358 CSL 3 = $370 CSL 4 = $523 CSL 5 = $579	Price for NEMA Design B, T-Frame, 5 hp, 4 poles, Enclosed Motors.	5
Distribution and OEM Markups	Baseline = 1.52 Incremental = 1.40 Shipping Cost = $0.65/pound	Point value for each distribution channel with 20% variance added	6
Sales Tax	1.0712	Point value	6
Installation Cost	No cost increase with efficiency	No cost increase with efficiency	8
Operating Cost Inputs			
Annual Operating Hours	3,623 hours/year	Full distribution ranging from 0.5 to 8,760 hours per year and with distribution varying by application and sector	7
Annual Energy Use	Baseline use* = 10,448 kWh	Variability based on usage	7
Reactive Power	Baseline = 2.64 kilovolt-amperes reactive	Variability based on usage, load, and power factor	7
Average Energy Prices (2011$)	Industrial = 8.35 ¢/kWh Commercial = 11.18 ¢/kWh Agricultural = 8.52 ¢/kWh	Variability based on application owner types	8
Repair and Maintenance Costs (2011$)	Repair: $448 Maintenance: No cost increase with efficiency	Repair: Costs increase with efficiency Maintenance: No cost increase with efficiency	8
Lifetime	10.1 years	Distribution based in part on annual hours of operation	8
Discount Rate	Industry and agricultural = 5.8% Commercial = 5.7%	Variability based on application owner types	8
Energy Price Trend	*AEO 2011* Release	Two sensitivities: High and Low Energy Price Cases	8

* Annual use provided for baseline equipment only. Annual use decreases with increased equipment efficiency.

8.2.1 Total Installed Cost Inputs

DOE defines the total installed cost, IC, using the following equation:

$$IC = EQP + INST$$

Where:

EQP = equipment price (i.e., customer cost for the equipment only), expressed in dollars, and
$INST$ = installation cost or the customer price to install equipment (i.e., the cost for labor and materials), also in dollars.

The equipment price is based on how the customer (end-user) purchases the equipment. As discussed in TSD chapter 6, Markups for Equipment Price Determination, DOE defined markups and sales taxes for converting manufacturing selling prices into customer equipment prices.

Table 8.2.2 summarizes the inputs for the determination of total installed cost.

Table 8.2.2 Inputs for Total Installed Cost

Baseline Manufacturer Selling Price
Manufacturer Selling Price Increase
Markups and Sales Tax
Installation Cost

The *baseline manufacturer selling price* is the price charged by the manufacturer to produce equipment for the current market. *Manufacturer selling price increase* is the change in manufacturer price associated with producing equipment at a standard level. *Markups and sales tax* convert the manufacturer selling price to a consumer equipment price. The *installation cost* is the cost to the consumer of installing the equipment and represents all costs required to install the equipment other than the marked-up consumer equipment price. The installation cost includes labor, overhead, and any miscellaneous materials and parts. Thus, the total installed cost equals the consumer equipment price plus the installation cost. DOE calculated the total installed cost for baseline products based on the following equation:

$$\begin{aligned} IC_{BASE} &= EQP_{BASE} + INST_{BASE} \\ &= MSP_{MFG} \times MU_{OVERALL\_BASE} + INST_{BASE} \end{aligned}$$

Where:

IC_{BASE} = baseline total installed cost,
EQP_{BASE} = consumer equipment price for baseline models,
$INST_{BASE}$ = baseline installation and shipping cost,

MSP_{MFG} = manufacturer selling price for baseline models, and
$MU_{OVERALL\_BASE}$ = baseline overall markup (product of manufacturer markup, baseline retailer or distributor markup, and sales tax).

DOE calculated the total installed cost for standard-level products based on the following equation:

$$\begin{aligned} IC_{STD} &= EQP_{STD} + INST_{STD} \\ &= \left(EQP_{BASE} + \Delta EQP_{STD}\right) + \left(INST_{BASE} + \Delta INST_{STD}\right) \\ &= \left(EQP_{BASE} + INST_{BASE}\right) + \left(\Delta EQP_{STD} + \Delta INST_{STD}\right) \\ &= IC_{BASE} + \left(\Delta MSP_{MFG} \times MU_{OVERALL\_INCR} + \Delta INST_{STD}\right) \end{aligned}$$

Where:

IC_{STD} = standard-level total installed cost,
EQP_{STD} = consumer equipment price for standard-level models,
$INST_{STD}$ = standard-level installation cost,
EQP_{BASE} = consumer equipment price for baseline models,
ΔEQP_{STD} = change in equipment price for standard-level models,
$INST_{BASE}$ = baseline installation and shipping cost,
$\Delta INST_{STD}$ = change in installation and shipping cost for standard-level models,
IC_{BASE} = baseline total installed cost,
ΔMSP_{MFG} = change in manufacturer selling price for standard-level models, and
$MU_{OVERALL\_INCR}$ = incremental overall markup (product of manufacturer markup, incremental retailer or distributor markup, and sales tax).

DOE found no evidence that installation costs would increase with higher motor energy efficiency. Thus, DOE did not incorporate changes in installation costs for motors that are more efficient than baseline products. In addition, motor installation cost data from *RS Means Electrical Cost Data 2010* show a variation in installation costs according to the motor horsepower (for three-phase electric motors), but not according to efficiency[3]. Therefore, in the preliminary analysis, DOE assumed there is no variation in installation costs between a baseline efficiency motor and a higher efficiency motor.

The remainder of this section provides information about each of the above input variables that DOE used to calculate the total installed cost for electric motors.

8.2.1.1 Projection of Future Product Prices

To derive a price trend for electric motors, DOE obtained historical Producer Price Index (PPI) data for integral horsepower motors and generators manufacturing spanning the time period 1969-2011from the Bureau of Labor Statistics' (BLS).[a] The PPI data reflect nominal

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[a] Series ID PCU3353123353123; http://www.bls.gov/ppi/

prices, adjusted for product quality changes. An inflation-adjusted (deflated) price index for integral horsepower motors and generators manufacturing was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index (see Figure 8.2.1).

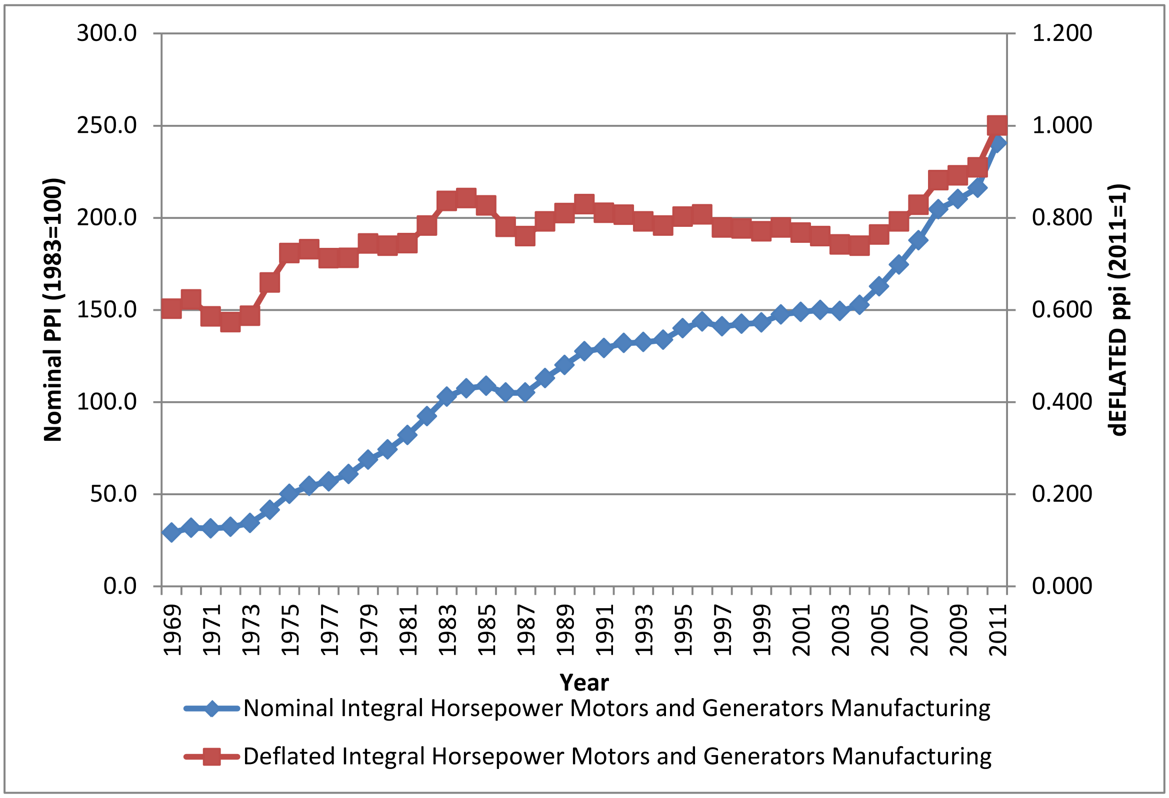

Figure 8.2.1 Historical Nominal and Deflated Producer Price Indexes for Integral Horsepower Motors and Generators Manufacturing

From the mid-1970s to 2005, the deflated price index for electric motors was roughly flat. Since then, the index has risen sharply, primarily due to rising prices of copper and steel products that go into motors (see Figure 8.2.2). The rising prices for copper and steel products were primarily a result of strong demand from China and other emerging economies. Given the slowdown in global economic activity in 2011, DOE believes that the extent to which the trends of the past five years will continue is very uncertain. DOE performed an exponential fit on the deflated price index for electric motors, but the coefficient of determination was relatively low (R^2=0.5). DOE also considered the experience curve approach, in which an experience rate parameter is derived using two historical data series on price and cumulative production, but the time series for historical shipments was not long enough for a robust analysis.

Given the above considerations, DOE decided to use a constant price assumption as the default price factor index to project future motor prices in 2015. Thus, prices forecast for the LCC and PBP analysis are equal to the 2011 values for each efficiency level in each equipment class.

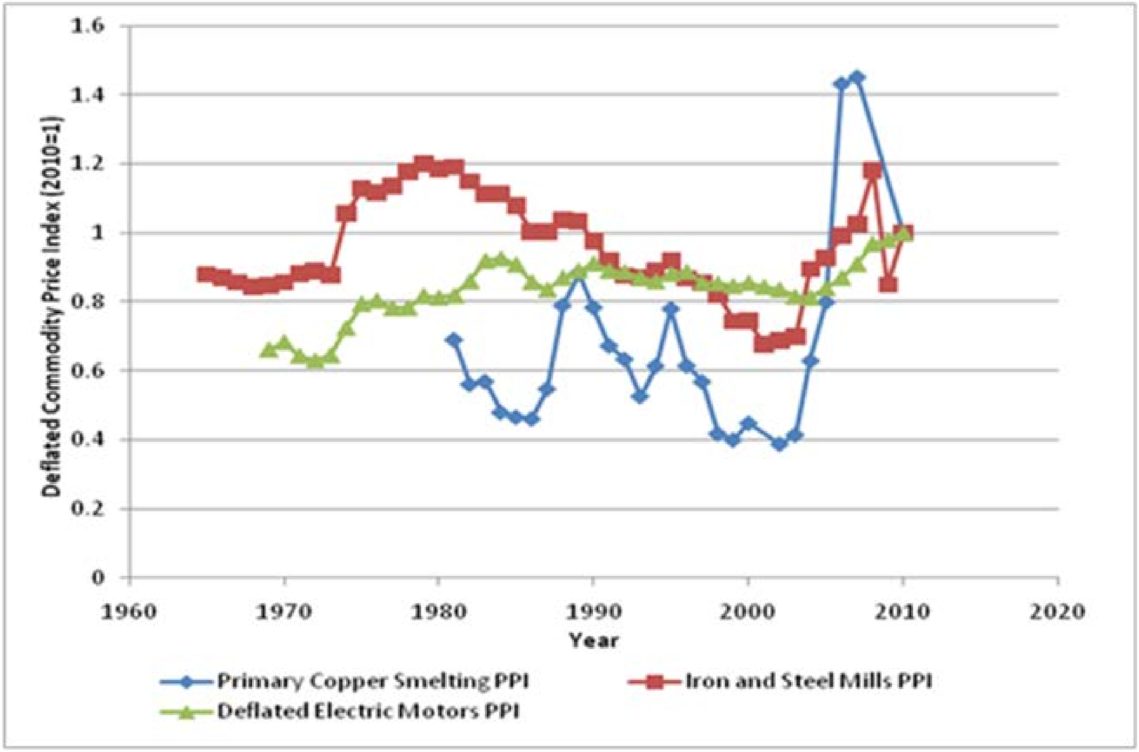

Figure 8.2.2 Historical Deflated Producer Price Indexes for Copper Smelting, Steel Mills Manufacturing and Integral Horsepower Motors and Generators

8.2.1.2 Baseline Manufacturer Selling Price

The engineering analysis provides a baseline manufacturer selling price (MSP) that includes all manufacturer markups (see TSD chapter 5). Table 8.2.3 presents the baseline MSP and the associated energy efficiency for each representative unit analyzed in the engineering analysis.

Table 8.2.3 Engineering Baseline Manufacturer Selling Price

Representative Unit		Baseline Efficiency %	Baseline MSP *2011$*
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	82.5	324
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	89.5	827
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	93.0	1,833
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	87.5	324
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	93.0	1,452
6	Fire pump, 5 hp , 4 poles, enclosed	87.5	326
7	Fire pump, 30 hp, 4 poles, enclosed	92.4	1,044
8	Fire pump, 75 hp, 4 poles, enclosed	94.1	1,994

DOE determined the MSP associated with motors produced at increasing energy efficiency levels for electric motors in the engineering analysis (see TSD chapter 5). Table 8.2.4 through Table 8.2.8 present the MSP, along with the associated energy efficiency for representative units 1 through 5. Representative units 6 through 8 (fire pump electric motors) are analyzed based on the same data for representative units 1 through 3: the efficiency levels and the associated MSPs for candidate standard level (CSL) 1 through 5 for representative units 1 through 3 are the same as baseline through CSL 4 for representative units 6 through 8. (see Table 8.2.4 through Table 8.2.6).

Table 8.2.4 Efficiency and Manufacturer Selling Price Data for Representative Unit 1: NEMA Design B, T-Frame, 5 hp, 4 Poles, Enclosed Motor

Energy Efficiency Level	**Efficiency** *%*	**MSP** ***2011$***
Baseline	82.5	324
1	87.5	326
2	89.5	358
3	90.2	370
4	91.0	523
5	91.7	579

Table 8.2.5 Efficiency and Manufacturer Selling Price Data for Representative Unit 2: NEMA Design B, T-Frame, 30 hp, 4 Poles, Enclosed Motor

Energy Efficiency Level	**Efficiency** *%*	**MSP** ***2011$***
Baseline	89.5	827
1	92.4	1,044
2	93.6	1,193
3	94.1	1,204
4	94.5	1,936

Table 8.2.6 Efficiency and Manufacturer Selling Price Data for Representative Unit 3: NEMA Design B, 75 hp, 4 Poles, Enclosed Motor

Energy Efficiency Level	**Efficiency** *%*	**MSP** ***2011$***
Baseline	93.0	1,833
1	94.1	1,994
2	95.4	2,270
3	95.8	2,581
4	96.2	3,353

5	96.5	3,712

Table 8.2.7 Efficiency and Manufacturer Selling Price Data for Representative Unit 4: NEMA Design C, 5 hp, 4 Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	MSP *2011$*
Baseline	87.5	324
1	89.5	348
2	90.2	522
3	91.0	559

Table 8.2.8 Efficiency and Manufacturer Selling Price Data for Representative Unit 5: NEMA Design C, 50 hp, 4 Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	MSP *2011$*
Baseline	93.0	1,452
1	94.1	1,664
2	94.5	1,992
3	95.0	2,168

Table 8.2.9 shows the baseline and incremental markups estimated for each point in the electric motor supply chain. The overall baseline and incremental markups shown are weighted averages based on the share of shipments in each distribution channel. Refer to TSD chapter 6 for details.

Table 8.2.9 Markups for Electric Motors Covered in this Analysis

Point in Supply Chain	Baseline*	Incremental*
Wholesale	1.17	1.10
OEM	1.32	1.29
Retail and Post-OEM	1.00	1.00
Contractor/Installer	1.52	1.40
Sales Tax	1.0712	
Overall	1.63	1.50

* Weighted average of the three distribution channels.

Total Installed Cost: The total installed cost is the sum of the end-user equipment price and the installation cost. Refer back to section 8.2.1 to see the equations that DOE used to calculate the total installed cost for various energy efficiency levels. Table 8.2.10 through Table 8.2.14 present the end-user equipment price, shipping cost, and total installed cost for representative unit 1 through 5. Representative units 6 through 8 (fire pump electric motors) are analyzed based on the same data for representative units 1 through 3 (see Table 8.2.10 through Table 8.2.12).

Specifically, CSL 1 through 5 for representative units 1 through 3 have the same total installed cost as baseline through CSL 4 for representative units 6 through 8.

Table 8.2.10 Representative Unit 1: NEMA Design B, T-Frame, 5 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2011$*	Shipping Cost *2011$*	Total Installed Cost *2011$*
Baseline	82.5	527	57	584
1	87.5	531	57	588
2	89.5	579	72	651
3	90.2	596	69	665
4	91.0	825	84	909
5	91.7	910	89	998

Table 8.2.11 Representative Unit 2: NEMA Design B, T-Frame, 30 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2011$*	Shipping Cost *2011$*	Total Installed Cost *2011$*
Baseline	89.5	1,346	224	1,570
1	92.4	1,700	286	1,986
2	93.6	1,923	354	2,277
3	94.1	1,939	349	2,288
4	94.5	3,036	432	3,468
5	94.5	3,036	432	3,468

Table 8.2.12 Representative Unit 3: NEMA Design B, T-Frame, 75 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2011$*	Shipping Cost *2011$*	Total Installed Cost *2011$*
Baseline	93.0	2,983	480	3,463
1	94.1	3,246	585	3,831
2	95.4	3,659	636	4,296
3	95.8	4,125	651	4,776
4	96.2	5,282	762	6,044
5	96.5	5,820	820	6,640

Table 8.2.13 Representative Unit 4: NEMA Design C, T-Frame, 5 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2011$*	Shipping Cost *2011$*	Total Installed Cost *2011$*
Baseline	87.5	528	55	583
1	89.5	564	64	627
2	90.2	824	79	903
3	91.0	880	82	961

Table 8.2.14 Representative Unit 5: NEMA Design C, T-Frame, 50 hp, 4 Poles, Enclosed: Consumer Equipment Prices, Shipping Costs, and Total Installed Costs

Energy Efficiency Level	Efficiency *%*	Equipment Price *2011$*	Shipping Cost *2011$*	Total Installed Cost *2011$*
Baseline	93.0	2,364	423	2,786
1	94.1	2,682	492	3,173
2	94.5	3,173	499	3,673
3	95.0	3,436	514	3,950

8.2.2 Operating Cost Inputs

DOE defines the operating cost, OC, by the following equation:

$$OC = EC + RC + MC$$

Where:

EC = energy expenditure associated with operating the equipment,
RC = repair cost associated with component failure, and
MC = cost for maintaining equipment operation.

Table 8.2.15 shows the inputs for determining the operating costs. The inputs listed in Table 8.2.15 are also necessary for determining the present value of lifetime operating expenses, which include the energy price trends, equipment lifetime, discount rate, and effective date of the standard.

Table 8.2.15 Inputs for Operating Cost

Annual Energy Consumption
Energy Prices
Repair and Maintenance Costs
Energy Price Trends

Product Lifetime
Discount Rate
Effective Date of Standard

The *annual energy consumption* is the site energy use associated with operating the equipment. *Energy prices* are the prices paid by end-users for energy supply, including both energy and demand charges. Multiplying the annual energy and demand by the appropriate prices yields the annual energy cost. *Repair costs* are associated with repairing or replacing components that have failed, and *maintenance costs* are associated with maintaining the operation of the equipment. DOE used *energy price trends* to forecast energy supply prices into the future and, along with the equipment lifetime and discount rate, to establish the lifetime energy supply costs. The *equipment lifetime* is the age at which the equipment is retired from service. The *discount rate* is the rate at which DOE discounted future expenditures to establish their present value. DOE calculated the operating cost for the baseline equipment based on the following equation:

$$\begin{aligned} OC_{BASE} &= EC_{BASE} + RC_{BASE} + MC_{BASE} \\ &= AEC_{BASE} \times PRICE_{ENERGY} + RC_{BASE} + MC_{BASE} \end{aligned}$$

Where:

OC_{BASE} = baseline operating cost,
EC_{BASE} = energy expenditures associated with operating the baseline equipment, which may include reactive power costs,
RC_{BASE} = repair cost associated with component failure for the baseline equipment,
MC_{BASE} = cost for maintaining baseline equipment operation,
AEC_{BASE} = annual energy consumption for baseline equipment, and
$PRICE_{ENERGY}$ = energy price.

DOE calculated the operating cost for standard-level equipment based on the following equation:

$$\begin{aligned} OC_{STD} &= EC_{STD} + RC_{STD} + MC_{STD} \\ &= AEC_{STD} \times PRICE_{ENERGY} + RC_{STD} + MC_{STD} \\ &= \left(AEC_{BASE} - \Delta AEC_{STD}\right) \times PRICE_{ENERGY} + \left(RC_{BASE} + \Delta RC_{STD}\right) + \left(MC_{BASE} + \Delta MC_{STD}\right) \end{aligned}$$

Where:

OC_{STD} = standard-level operating cost,
EC_{STD} = energy expenditures associated with operating standard-level equipment,
RC_{STD} = repair cost associated with component failure for standard-level equipment,
MC_{STD} = cost for maintaining standard-level equipment operation,

AEC_{STD} = annual energy consumption for standard-level equipment,
$PRICE_{ENERGY}$ = energy price,
ΔAEC_{STD} = decrease in annual energy consumption caused by standard-level equipment,
ΔRC_{STD} = change in repair cost caused by standard-level equipment, and
ΔMC_{STD} = change in maintenance cost caused by standard-level equipment.

The remainder of this section provides information about each of the above input variables that DOE used to calculate the operating costs for electric motors.

8.2.2.1 Annual Energy Consumption

TSD Chapter 7, Energy Use Characterization, details how DOE determined the annual energy consumption for baseline and standard-level equipment.

Table 8.16 through Table 8.18 provide the average annual energy consumption by efficiency level for each representative unit. DOE captured the variability in energy consumption by estimating energy consumption for a variety of motor-using applications.

DOE used several assumptions to account for a possible decrease in efficiency each time the motor is repaired, which would therefore increase the annual energy consumption. First, DOE assumed that NEMA Designs A, B and C medium electric motors are repaired on average after 32,000 hours of operation, which corresponds to a repair frequency of 5, 16, and 15 years in the industrial, commercial, and agricultural sectors, respectively. DOE also assumed that fire pump electric motors are not repaired often because of their low annual operating hours. Second, DOE assumed that one-third of repairs are performed following good practices and therefore do not affect the efficiency of the motor (*i.e.*, there is no degradation of efficiency after repair)[4,5,6]. In addition, DOE assumed that two-thirds of repairs do not follow good practices and that the repair results in a slight decrease in efficiency. Lastly, DOE assumed the efficiency drops by 1 percent in the case of motors of less than 40 hp, and by 0.5 percent in the case of larger motors[7].

Table 8.2.16 Average Annual Electricity Use by Efficiency Level for Representative Units 1, 2, and 3

Representative Unit 1		**Representative Unit 2**		**Representative Unit 3**	
NEMA Design B, T-frame, 5 hp, 4 poles, enclosed		**NEMA Design B, T-frame, 30 hp, 4 poles, enclosed**		**NEMA Design B, T-frame, 75 hp, 4 poles, enclosed**	
Efficiency ***%***	**Energy Use** ***kWh/yr***	**Efficiency** ***%***	**Energy Use** ***kWh/yr***	**Efficiency** ***%***	**Energy Use** ***kWh/yr***
82.5	10,448	89.5	57,642	93.0	204,834
87.5	9,869	92.4	55,912	94.1	202,540
89.5	9,691	93.6	55,021	95.4	198,496
90.2	9,616	94.1	54,492	95.8	197,697

91.0	9,567	94.5	54,326	96.2	197,194
91.7	9,487	94.5	54,326	96.5	196,604

Table 8.2.17 Average Annual Electricity Use by Efficiency Level for Representative Units 4 and 5

Representative Unit 4		**Representative Unit 5**	
NEMA Design C, T-frame, 5 hp, 4 poles, enclosed		**NEMA Design C, T-frame, 50 hp, 4 poles, enclosed**	
Efficiency ***%***	**Energy Use** ***kWh/yr***	**Efficiency** ***%***	**Energy Use** ***kWh/yr***
87.5	9,987	93.0	89,523
89.5	9,808	94.1	88,507
90.2	9,738	94.5	88,119
91.0	9,630	95.0	87,444

Table 8.2.18 Average Annual Electricity Use by Efficiency Level for Representative Units 6, 7, and 8

Representative Unit 6		**Representative Unit 7**		**Representative Unit 8**	
Fire pump, 5 hp, 4 poles, enclosed		**Fire pump, 30 hp, 4 poles, enclosed**		**Fire pump, 75 hp, 4 poles, enclosed**	
Efficiency ***%***	**Energy Use** ***kWh/yr***	**Efficiency** ***%***	**Energy Use** ***kWh/yr***	**Efficiency** ***%***	**Energy Use** ***kWh/yr***
87.5	19.6	92.4	1,601	94.1	97,791
89.5	19.2	93.6	1,577	95.4	95,934
90.2	19.1	94.1	1,562	95.8	95,554
91.0	19.0	94.5	1,558	96.2	95,313
91.7	18.8	94.5	1,558	96.5	95,033

8.2.2.2 Energy Prices

To estimate the energy prices faced by motor end-users throughout the United States, DOE uses sector-specific regional electricity prices as well as a statistical distribution of motors across sectors and regions to assign an appropriate electricity price to each motor end-user.

First, DOE distributed the motors across the three sectors using data from an Easton Consultants report[8] (see Table 8.2.19).

Table 8.2.19 Distribution Across Sector by Motor Size

Horsepower Range *hp*	Industry %	Agriculture %	Commercial %
1-5	37	0	63
6-20	26	0	74
21-50	26	0	74
51-100	63	7	30
101-200	76	3	21
201-500	69	3	28

Then, for each sector, DOE distributed the motors in four Census regions based on the following indicators:

- value of shipments of manufactured goods from the Manufacturing Energy Consumption Survey for the industrial sector[9];
- value of shipments of agricultural products from the U.S. Census of Agriculture for the agricultural sector [10]; and
- commercial floor space from the Commercial Building Energy Consumption Survey for the commercial sector[11].

Table 8.2.20 shows the resulting distribution.

Table 8.2.20 Sector Specific Share of Electric Motors by Census Region

Census Region	Agricultural %	Industrial %	Commercial %
Northeast	4.6	8.7	19.5
Midwest	42.8	26.4	25.3
South	29.5	52.5	37.3
West	23.1	12.4	17.9

For each sector, DOE then estimated weighted regional average prices using EIA Form 861 data.[12] These data are published annually and include annual electricity usage in kilowatt-hours (kWh), revenues from electricity sales, and number of consumers for the residential, commercial, and industrial sectors for every utility serving final consumers. The calculation used the most recent EIA data available at the time the analysis was conducted. Table 8.2.21 shows the average agricultural, industrial, and commercial electricity prices in 2010 for each Census region.

Table 8.2.21 Average Electricity Prices in 2010

Census Region	Average Agricultural Price *2011$/kWh*	Average Industrial Price *2011$/kWh*	Average Commercial Price *2011$/kWh*
Northeast	0.103	0.103	0.149
Midwest	0.084	0.084	0.095
South	0.078	0.078	0.100
West	0.094	0.094	0.120
Average (weighted)	0.087	0.087	0.111

8.2.2.3 Energy Price Trends

DOE used price forecasts by the EIA to estimate the trends in electricity prices for all sectors. To arrive at prices in future years, DOE multiplied the average prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO 2011*. To estimate the trend after 2035, DOE followed past guidelines provided to the Federal Energy Management Program by EIA and used the projected average rate of change during 2025–2035 for electricity prices.

As an example, Figure 8.2.3 shows the projected trends in industrial electricity prices based on the *AEO 2011* reference case. For the LCC results presented in this chapter, DOE used only the energy price forecast from the *AEO 2011* reference case.

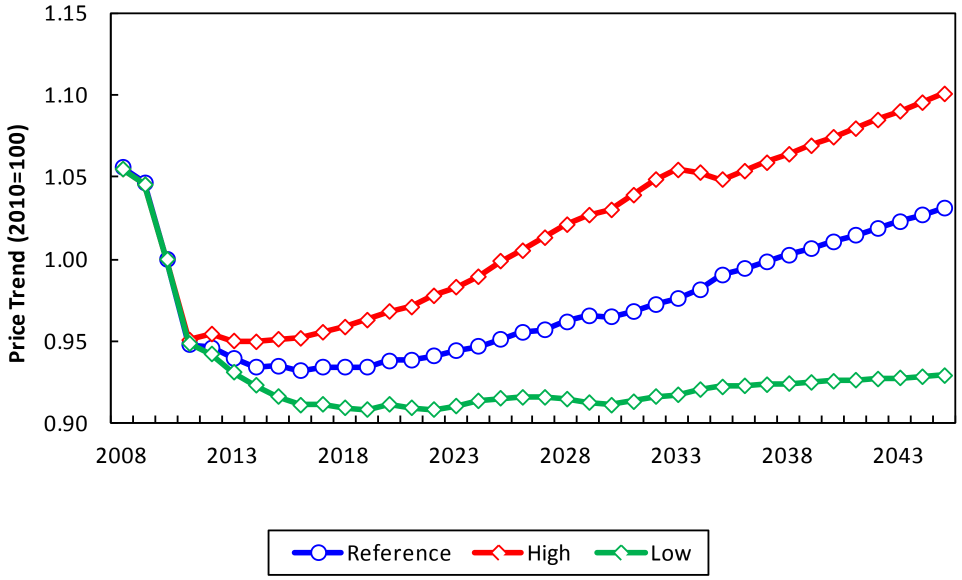

Figure 8.2.3 Industrial Electricity Price Trends

8.2.2.4 Repair and Maintenance Costs

DOE accounted for the differences in repair costs of a higher efficiency motor compared to a baseline-efficiency motor. Based on data from Vaughen's[13], DOE derived a model to estimate repair costs by horsepower, enclosure, and pole, for each CSL level:

$$RepairCost = R(hp, poles, encl, CSL),$$

$$R(hp, poles, encl, CSL) = R'(hp, poles) \cdot R''(encl) \cdot A(CSL),$$

where:

$$R'(hp, poles) = r_2(hp, poles) + r_1(hp, poles) + r_0(poles),$$

with:

$$r_2(hp, poles) = (-0.000005 \cdot poles) \cdot hp^2,$$

$$r_1(hp, poles) = (-0.00027 \cdot poles^2 + 0.00752 \cdot poles + 0.02563) \cdot hp,$$

$$r_0(poles) = (0.00956 \cdot poles^2 + 0.03599 \cdot poles + 0.64067),$$

and,

$$R''(encl) = \begin{cases} 1.0, & Open, \\ 1.2, & Enclosed, \end{cases}$$

and "A" (CSL) is given by Table 8.2.22:

Table 8.2.22 Repair Cost Calculation Parameters

Efficiency level	A
Baseline	0%
CSL 1	15%
CSL 2	25%
CSL 3	30%
CSL 4	35%
CSL 5	40%

Table 8.2.23 shows the resulting repair costs estimates for all horsepower, enclosure, and pole combination for motors with an efficiency level corresponding to CSL 0.

Table 8.2.23 Repair Cost Estimates by Equipment Class (all equipment class groups)

CSL 0	Open				Enclosed			
hp	**2 poles**	**4 poles**	**6 poles**	**8 poles**	**2 poles**	**4 poles**	**6 poles**	**8 poles**
1	324	295	376	513	389	354	451	616
1.5	333	302	385	524	399	363	462	629
2	341	310	394	535	409	372	473	642
3	358	325	412	557	430	390	495	668
5	392	356	449	600	470	427	538	720
7.5	434	394	494	655	520	473	592	786
10	475	432	539	709	571	518	647	850
15	559	508	629	816	671	609	754	980
20	642	583	718	923	770	700	862	1,108
25	725	659	807	1,030	870	790	968	1,236
30	807	733	895	1,136	969	880	1,074	1,363
40	971	882	1,071	1,345	1,166	1,059	1,285	1,614
50	1,134	1,030	1,245	1,552	1,361	1,236	1,494	1,863
60	1,295	1,177	1,417	1,757	1,554	1,412	1,700	2,108
75	1,535	1,394	1,672	2,059	1,842	1,673	2,006	2,470
100	1,928	1,751	2,087	2,549	2,313	2,101	2,505	3,059
125	2,312	2,101	2,492	3,024	2,774	2,521	2,990	3,629
150	2,688	2,442	2,885	3,483	3,226	2,931	3,462	4,179
200	3,416	3,104	3,638	4,352	4,100	3,725	4,365	5,222
250	4,112	3,735	4,346	5,158	4,934	4,483	5,215	6,189
300	4,774	4,337	5,009	5,899	5,729	5,205	6,011	7,079
350	5,404	4,909	5,628	6,577	6,484	5,891	6,754	7,893
400	6,000	5,451	6,202	7,192	7,200	6,542	7,443	8,630
450	6,564	5,964	6,732	7,742	7,877	7,157	8,078	9,291
500	7,095	6,447	7,216	8,229	8,515	7,736	8,660	9,874

Table 8.2.24 summarizes the repair cost for representative units by efficiency level.

Table 8.2.24 Summary of Repair Cost for Each Representative Unit by Energy Efficiency Level

Representative Unit		CSL	Repair Cost *2011$*
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	Baseline	448
		1	515
		2	560
		3	582
		4	604
		5	627
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	Baseline	923
		1	1,061
		2	1,153

		3	1,199
		4	1,246
		5	1,246
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	Baseline	1,754
		1	2,017
		2	2,193
		3	2,280
		4	2,368
		5	2,456
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	Baseline	515
		1	537
		2	560
		3	582
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	Baseline	1,490
		1	1,555
		2	1,620
		3	1,685
6	Fire pump, 5 hp, 4 poles, enclosed	Baseline	515
		1	560
		2	582
		3	604
		4	627
7	Fire pump, 30 hp, 4 poles, enclosed	Baseline	1,061
		1	1,153
		2	1,199
		3	1,246
		4	1,246
8	Fire pump, 75 hp, 4 poles, enclosed	Baseline	2,017
		1	2,193
		2	2,280
		3	2,368
		4	2,456

For the maintenance costs, DOE did not find data indicating a variation in maintenance costs between a baseline efficiency and a higher efficiency motor. According to Vaughen's, the price of replacing bearings, which is the most common maintenance practice, is the same at all efficiency levels.

8.2.3 Motor Lifetime

For NEMA Designs A, B, and C equipment-class groups, DOE relied on several sources to inform its model of their lifetimes: expert estimates of a motor's average lifetime in years (including repairs) in the industrial sector and average operating hours in all sectors and applications (see chapter 6, Energy Use Characterization).

DOE used the weighted average lifetime estimates across all applications and the application-specific average operating hours in the industry sector to develop average mechanical lifetimes by horsepower range across all sectors (Table 8.2.25).

Table 8.2.25 Motor Mechanical Lifetime by Horsepower Range

Horsepower Range ***hp***	**Weighted Average Lifetime Across Applications (Industry Sector)** ***Years***	**Mechanical Lifetime Across all Sectors** ***Hours***
1 – 5	5.0	31,505
6 – 20	5.0	32,850
21 – 50	10.0	64,881
51 – 100	10.0	67,819
101 – 200	15.0	106,424
201 – 500	15.0	108,398

In the LCC, DOE uses a more sophisticated motor lifetime model. This model combines annual operating hours by application and sector with motor mechanical lifetime in hours to estimate the distribution of motor lifetimes in years. This model results in a negative correlation between annual hours of operation and motor lifetime; motors operated many hours per year are likely to be retired sooner than motors that are used for only a few hundred hours per year.

Further, motors with a size less than 50–100 horsepower are typically embedded in other equipment (i.e., “application”) such as pumps or compressors. For each of these motors (less than 75 hp), DOE first determined the lifetime in years by dividing its mechanical lifetime in hours by its annual hours of operation. DOE then compared this lifetime (in years) with the sampled application lifetime (also in years), and assumed that the motor would be retired at the younger of these two ages. For example, a pump motor with a duty factor of 2,500 hours per year may have a mechanical lifetime of 30,000 hours (12 years) and an application lifetime of 10 years. DOE assumed the motor would retire in 10 years, when its application reached the end of its lifetime, even if the motor itself could run for two more years. If the pump motor were to run for 6,000 hours per year, with the same mechanical and application lifetimes, DOE would assume it would retire after 5 years due to motor failure upon reaching its mechanical lifetime of 30,000 hours.

Table 8.2.26 presents the average application lifetimes used in the LCC [14,15,16,17].

Table 8.2.26 Average Application Lifetime

Application	**Average Lifetime** ***Yr***
Air Compressor	15
Fans	15
Pumps	11
Material Handling and Processing	20
Other	15

The DOE's motor lifetime model relies on four distributions: (1) the annual operating hours distribution derived for use in the energy use analysis (see chapter 6); (2) the distribution of motor shipments into six application areas, each with its own distribution of annual hours of operation; (3) a Weibull distribution of mechanical motor lifetimes, expressed in total hours of operation before failure; and (4) a Weibull distribution of application lifetimes, expressed in years. DOE used its estimate of motor mechanical lifetime in hours and application lifetime in years to develop the parameters for the Weibull distributions for all represented units. DOE's Monte Carlo analysis of a motor's LCC selected an application, an appropriate number of hours of operation, a motor mechanical lifetime, and an application lifetime from these distributions in order to calculate the sampled motor's lifetime in years.

The National Impact Analysis (NIA) calculation uses average lifetimes in years by equipment class group, horsepower range, and sector. DOE used the operating hours in order to convert the motor mechanical lifetimes into average lifetimes in years. Results are presented in Table 8.2.27 and Table 8.2.28 by equipment class grouping, horsepower range, and sector. Further, based on literature review,[18,19,20] DOE assumed that the maximum motor lifetime in years is 29 years.[20]

Table 8.2.27 Weighted Average Lifetime for NEMA Design A and B Motors

Horsepower Range ***hp***	**Weighted Average Lifetime** ***Yr***		
	Industrial	**Commercial**	**Agricultural**
1-5	5	15	13
6-20	5	14	13
21-50	10	26	25
51-100	10	26	26
101-200	15	29	29
201-500	15	29	29

Table 8.2.28 Weighted Average Lifetime for NEMA Design C Motors

Horsepower Range ***hp***	**Weighted Average Lifetime** ***Yr***		
	Industrial	**Commercial**	**Agricultural**
1-5	5	14	12
6-20	5	14	15
21-50	10	29	36
51-100	10	25	31
101-200	15	29	29
201-500	15	29	29

DOE further developed Weibull distributions for each of these average lifetimes in years.

For fire pump electric motors, DOE assumed an average lifetime of 29 years and developed a Weibull distribution around this value (both in the LCC and in the NIA).

8.2.3.1 The Weibull Distribution

The Weibull distribution is a probability distribution commonly used to measure failure rates.[b] 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:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta \text{, and}$$

$$P(x) = 1 \text{ for } x \le \theta$$

Where:

$P(x)$ = probability that the equipment is still in use at age x,
x = equipment 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, or location, 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 mechanical equipment, β commonly is greater than 1, reflecting an increasing failure rate as equipment ages.

8.2.3.2 Mechanical Motor Lifetime and Application Lifetime

DOE's derived Weibull parameters for each representative unit's mechanical lifetime is listed in Table 8.2.29. The Weibull parameters account for a three-year manufacturer warranty period. During this period DOE assumes that no motors fail.

Table 8.2.29 Weibull Parameters for Mechanical Motor Lifetimes

	Representative Unit	**Parameters**		
		A	β	θ
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	14,179	2.65	18,903
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	51,100	2.65	19,464
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	53,413	2.65	20,346
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	14,179	2.65	18,903
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	51,100	2.65	19,464

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[b] 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/>.

DOE's derived Weibull parameters for motor applications are listed in Table 8.2.30.

Table 8.2.30 Weibull Parameters for Application Lifetime

	Application	**Parameters**		
		α	B	θ
1	Fan	8.44	2.65	7.50
2	Air Compressor	8.44	2.65	7.50
3	Pump	6.19	2.65	5.50
4	Material Handling and Process	11.25	2.65	10.00
5	Others	8.63	2.65	7.67
6	Fire Pump	16.31	2.65	14.50

In the scope of this life-cycle analysis, DOE combines these two distributions with the appropriately weighted duty factor distribution to select a lifetime for each motor.

Table 8.2.31 summarizes calculated motor lifetimes of sampled motors.

Table 8.2.31 Summary of Sampled Motor Lifetimes

Representative Unit		**Median** *yr*	**Min** *yr*	**Max** *yr*	**Average** *yr*
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	10.5	2.3	31.3	10.1
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	12.2	2.9	35.4	12.5
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	10.3	2.7	30.6	10.9
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	10.9	2.3	31.8	10.5
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	12.8	2.8	33.1	13.1
6	Fire pump, 5 hp, 4 poles, enclosed	28.8	14.8	51.4	29.1
7	Fire pump, 30 hp, 4 poles, enclosed	28.8	14.8	51.4	29.1
8	Fire pump, 75 hp, 4 poles, enclosed	28.8	14.8	51.4	29.1

8.2.4 Discount Rates

DOE derived the discount rates for the LCC and PBP analysis from estimates of the finance cost of purchasing the considered products. Following financial theory, the finance cost of raising funds to purchase equipment can be interpreted as: (1) the financial cost of any debt incurred to purchase equipment, or (2) the opportunity cost of any equity used to purchase equipment.

Commercial, Industrial, and Agricultural Owners

For motors purchased and used in the industrial, agricultural, and commercial sectors, DOE calculated the discount rate for a distribution of representative equipment owners. This distribution of representative owners is the weighted sum of discount rate distributions for different ownership categories. DOE calculated a distribution of discount rates for owners within each ownership category. The discount rate for an individual owner is the weighted average cost of capital (WACC) where, given the mix of debt and equity for that individual owner, a weighted average of the discount rates for each loan and investment calculated in which the weights are equal to the size of the loan or investment.

DOE estimated the cost of equity using the capital asset pricing model (CAPM).[21] The CAPM assumes that the cost of equity (k_e) for a particular company is proportional to the systematic risk faced by that company, where 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 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 the firm indicates the risk associated with that firm relative to the price variability in the stock market. 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. The cost of equity financing is estimated using the following equation, where the variables are defined as above:

$$k_e = R_f + \left(\beta \times ERP\right)$$

Where:

k_e = cost of equity,
R_f = expected return on risk-free assets,
β = risk coefficient of the firm, and
ERP = equity risk premium.

Several parameters of the cost of capital equations can vary substantially over time, and therefore the estimates can vary with the time period over which data is selected and the technical details of the data averaging method. For guidance on the time period for selecting and averaging data for key parameters and the averaging method, DOE used Federal Reserve methodologies for calculating these parameters. In its use of the CAPM, the Federal Reserve uses a forty-year period for calculating discount rate averages, utilizes the gross domestic product price deflator for estimating inflation, and considers the best method for determining the risk free rate as one where "the time horizon of the investor is matched with the term of the risk-free security." [22]

Damodaran Online is a widely used source of information about company debt and equity financing for most types of firms.[23] By taking a forty-year geometric average of Damodaran Online data, DOE found for this analysis the following risk free rates for 2009-2011 (Table 8.2.32). DOE also estimated the ERP by calculating the difference between risk free rate and stock market return for the same time period.

Table 8.2.32 Risk-free fate and equity risk premium, 2009-2011

Year	Risk-Free Rate (%)	ERP (%)
2009	6.88	3.07
2010	6.74	3.23
2011	6.61	2.94

The cost of debt financing (k_d) is the interest rate paid on money borrowed by a company. 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 stock prices. So for firm *i*, the cost of debt financing is:

$$\boldsymbol{k_{di} = R_f + R_{ai}}$$

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 WACC using the following equation:

$$WACC = k_e \times w_e + k_d \times w_d$$

Where:

$WACC$ = weighted average cost of capital,
w_e = proportion of equity financing, and
w_d = proportion of debt financing.

By adjusting for the influence of inflation, DOE estimates the real weighted average cost of capital, or discount rate, for each sector. DOE then aggregates the sectoral real weighted-average costs of capital to estimate the discount rate for each of the three non-residential ownership types in the medium electric motors analysis, weighting each sector's discount rate by the number of companies in the sector.[c]

Table 8.2.33 shows the average WACC values for the three non-residential ownership types in the medium electric motors analysis. While WACC values for any sector may trend higher or lower over substantial periods of time, these values represent a private sector cost of capital that is averaged over major business cycles. Due to limited data availability, DOE applies the discount rate estimated for the industrial sector to the agricultural sector.

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[c] Giving equal weight to each industry, rather than weighting by number of companies leads to similar estimate of discount rates; the mean industrial / agricultural discount rate is estimated to be 6.00% and the mean commercial discount rate is estimated to be 5.86%.

Table 8.2.33 Weighted Average Cost of Capital for Sectors that Purchase Medium Electric Motors

Sector	Real Weighted Average Cost of Capital %
Industrial	5.82
Agricultural	5.82
Commercial	5.66

8.2.5 Effective Date and Compliance Date of Standard

The effective date of an energy conservation standard is essentially the official date that the text of the final rule becomes a regulation in the Code of Federal Regulations. The compliance date is when compliance with a standard is required. Any amended standard for electric motors "shall apply to electric motors manufactured on or after a date which is five years after the effective date of the standards date such rule is published." (42 U.S.C. 6313(b)(3)) In this case, the statutory effective date was December 19, 2010, and the compliance date of any new energy conservation standard for electric motors would be December 19, 2015. DOE calculated the LCC and PBP for all end-users as if each would purchase a new piece of equipment in the year that compliance is required.

8.2.6 Equipment Energy Efficiency in the Base Case

For purposes of conducting the LCC analysis, DOE analyzed efficiency levels relative to a base case (*i.e.*, the case without new energy efficiency standards). This requires an estimate of the distribution of equipment efficiencies in the base case (*i.e.*, what consumers would have purchased in the year 2015 in the absence of new standards). DOE refers to this distribution of equipment energy efficiencies as the base-case efficiency distribution.

DOE used six major manufacturer and one distributor’s catalog data to develop the base-case efficiency distributions using the number of models (in all representative units) meeting the requirements of each efficiency level. The distribution is estimated separately for each representative unit.

Table 8.2.34 shows the energy efficiency distribution for base cases for all representative units. Using the base case efficiency distribution, DOE assigned a baseline efficiency to each motor unit. If a unit is assigned a baseline efficiency that is greater than or equal to the efficiency of the standard level under consideration, the LCC calculation shows that this unit would not be affected by that standard level.

Table 8.2.34 Base Case Energy Efficiency Distribution for All Representative Units

Unit #1: NEMA Design B, T-Frame, 5 hp, 4 poles, Enclosed

Level		FL[*] Nominal Efficiency	Share
0	Minimum Commercially Available	82.5%	0.06
1	EPACT 1992	87.5%	0.38
2	NEMA Premium	89.5%	0.44
3	Maximum Commercially Available	90.2%	0.08
4	Incremental	91.0%	0.03
5	Maximum Technology	91.7%	0.01

Unit #2: NEMA Design B, T-Frame, 30 hp, 4 poles, Enclosed

Level		FL Nominal Efficiency	Share
0	Minimum Commercially Available	89.5%	0.05
1	EPACT 1992	92.4%	0.30
2	NEMA Premium	93.6%	0.48
3	Maximum Commercially Available	94.1%	0.09
4	Incremental	94.5%	0.08
5	Maximum Technology	94.5%	0.00

Unit #3: NEMA Design B, T-Frame, 75 hp, 4 poles, Enclosed

Level		FL Nominal Efficiency	Share
0	Minimum Commercially Available	93.0%	0.05
1	EPACT 1992	94.1%	0.29
2	NEMA Premium	95.4%	0.48
3	Maximum Commercially Available	95.8%	0.10
4	Incremental	96.2%	0.05
5	Maximum Technology	96.5%	0.02

Unit #4: NEMA Design C, T-Frame, 5 hp, 4 poles, Enclosed

Level		FL Nominal Efficiency	Share
0	EPACT 1992	87.5%	0.92
1	NEMA Premium	89.5%	0.08
2	Incremental	90.2%	0.00
3	Maximum Technology	91.0%	0.00

Unit #5: NEMA Design C, T-Frame, 50 hp, 4 poles, Enclosed

Level		FL Nominal Efficiency	Share
0	EPACT 1992	93.0%	0.73
1	Incremental	94.1%	0.27
2	NEMA Premium	94.5%	0.00
3	Maximum Technology	95.0%	0.00

Unit #6: Fire Pump, 5 h, 4 poles, Enclosed

Level		FL Nominal Efficiency	Share
0	EPACT 1992	87.5%	0.95
1	NEMA Premium	89.5%	0.05
2	Maximum Commercially Available	90.2%	0.00
3	Incremental	91.0%	0.00
4	Maximum Technology	91.7%	0.00

Unit #7: Fire Pump, 30 hp, 4 poles, Enclosed

Level		FL Nominal Efficiency	Share
0	EPACT 1992	92.4%	0.82
1	NEMA Premium	93.6%	0.06
2	Maximum Commercially Available	94.1%	0.13
3	Incremental	94.5%	0.00
4	Maximum Technology	94.5%	0.00

Unit #8: Fire Pump, 75 hp, 4 poles, Enclosed			
Level		FL Nominal Efficiency	Share
0	EPACT 1992	94.1%	0.81
1	NEMA Premium	95.4%	0.02
2	Maximum Commercially Available	95.8%	0.17
3	Incremental	96.2%	0.00
4	Maximum Technology	96.5%	0.00

*FL = Full Load

8.3 PAYBACK PERIOD INPUTS

The PBP is the amount of time it takes the consumer to recover the assumed higher purchase expense of more energy-efficient equipment as a result of lower operating costs. Numerically, the PBP is the ratio of the increase in purchase expense (*i.e.*, from a less efficient design to a more efficient design) to the decrease in annual operating expenditures. This type of calculation is known as a “simple” PBP, because it does not take into account changes in operating expense over time or the time value of money; the calculation is done at an effective discount rate of zero percent.

The equation for PBP is:

$$PBP = \frac{\Delta IC}{\Delta OC}$$

Where:

ΔIC = change, generally an increase in the total installed cost between the more efficient standard level and the baseline design, and
ΔOC = change, generally a decrease in annual operating expenses.

A PBP is expressed in years. A PBP that is greater than the life of the product indicates that the increased total installed cost is not recovered in reduced operating expenses.

The data inputs to PBP are the total installed cost of the equipment to the purchaser for each efficiency level and the annual (first-year) operating expenditures for each standard level. The inputs to the total installed cost are the equipment price and the installation cost. The inputs to the operating costs are the annual energy cost, the annual repair cost, and the annual maintenance cost. The PBP uses the same inputs as the LCC analysis as described in section 8.2, except that lifetime, energy price trends, and discount rates are not required. Because the PBP is a “simple” payback, the required energy price is only for the year in which compliance with a new standard is required—in this case, the year 2015. The energy price DOE used in the PBP calculation was the price projected for that year.

8.4 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS FOR REPRESENTATIVE UNITS

This section presents the LCC and PBP results for the representative units analyzed. As discussed in section 8.1.1, DOE's approach for conducting the LCC analysis relied on developing samples of customers for each representative unit. DOE also characterized the uncertainty of many of the inputs to the analysis with probability distributions. DOE used a Monte Carlo simulation technique to perform the LCC calculations on the customers in the sample. For each set of sample customers using motors in each representative unit, DOE calculated the average LCC and LCC savings and the median and average PBP for each of the standard levels.

In the subsections below, DOE presents figures showing the distribution of LCCs in the base case for each representative unit. Also presented below for a specific standard level are figures showing the distribution of LCC impacts and the distribution of PBPs. The figures are presented as frequency charts that show the distribution of LCCs, LCC impacts, and PBPs with their corresponding probabilities of occurrence. DOE generated the figures for the distributions from a Monte Carlo simulation run based on 10,000 samples. The LCC and PBP calculations were performed 10,000 times by sampling from the probability distributions that DOE developed to characterize many of the inputs.

Based on the Monte Carlo simulations that DOE performed, for each efficiency level, DOE calculated the share of motor users with a net LCC benefit and with a net LCC cost. To illustrate the range of LCC and PBP impacts among the motor end-users, the sections below present figures that provide such information for each representative unit.

8.4.1 Representative Unit 1, NEMA Design B, 5 Horsepower, 4 poles, Enclosed Motor

Figure 8.4.1 is an example of a frequency chart showing the distribution of LCC savings for representative unit 1, at candidate standard level (CSL) 3. The efficiency level of CSL 3 is the maximum commercially available level for representative unit 1 motors. In the figure, a text box next to a vertical line at that value on the x-axis shows the mean change in LCC (a net benefit of approximately $45 in this example Monte Carlo run).

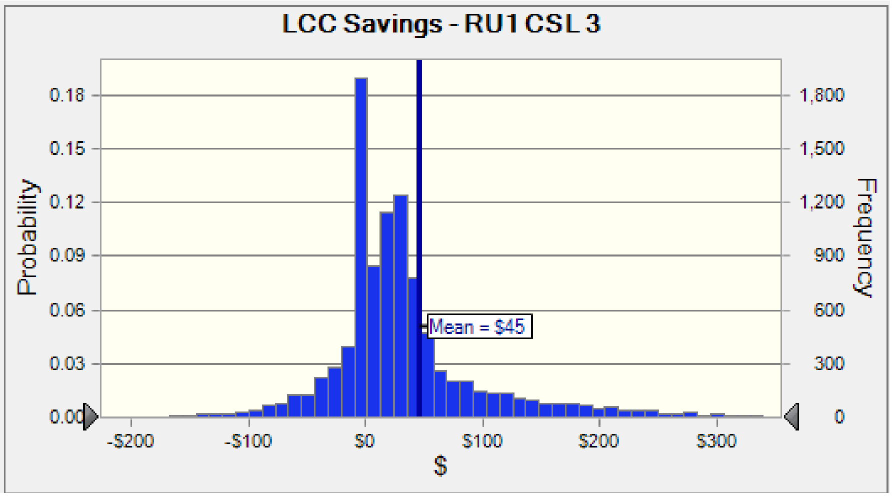

Figure 8.4.1 Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 2

Figure 8.4.2 is an example of a frequency chart showing the distribution of PBPs for the efficiency level corresponding to CSL 3 for the representative unit 1. Because many motors operate for very few hours per year and because the operating cost savings is very small compared to the increase in first cost, there are a significant number of motors that may have extremely long PBPs. The distribution in the figure illustrates that most motors have a payback of less than 30 years, but the mean value of the distribution payback is large (59.0 years) because of the small, but significant number of motors with PBPs longer than 60 years. Because of the skewed distribution in PBPs, DOE also considers the PBP of the typical customer, or the median of the distribution, which is 4.7 years for Figure 8.4.2.

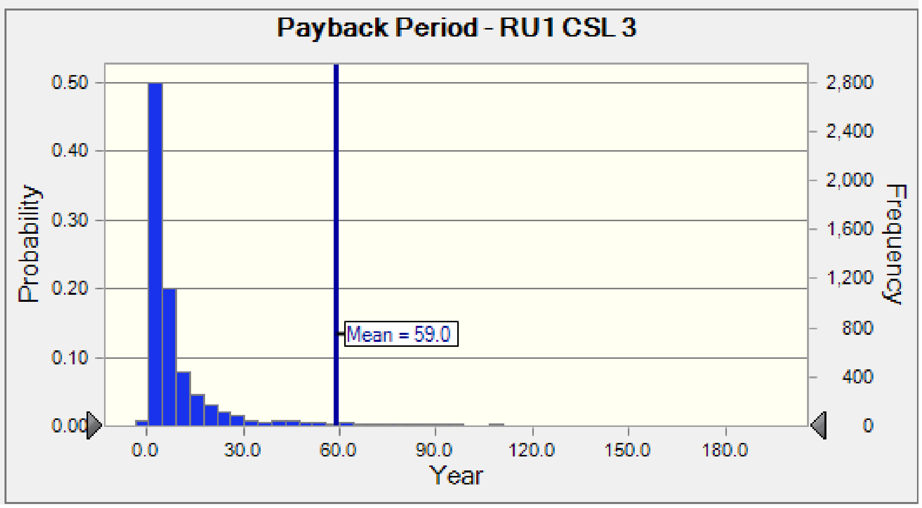

Figure 8.4.2 Representative Unit 1: Distribution of Payback Periods for CSL 2.

The distribution of PBP for other representative units associated with other efficiency levels are illustrated in Appendix 8-B.

Table 8.4.1 summarizes the LCC and PBP results for the representative unit 1 based on a run of 10,000 Monte Carlo samples. The most rigorous CSL that provides positive average LCC savings is CSL 3. DOE estimates that 67.8 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL. At this CSL the increase in average total installed cost (relative to the base case) is $81, or 13.9 percent, while operating costs decrease by $46, or 4.6 percent.

Table 8.4.1 Life-Cycle Cost and Payback Period Results for Representative Unit 1: NEMA Design B, T-Frame, 5 horsepower, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	82.5	584	10,448	1,006	5,926					
1	87.5	588	9,869	969	5,649	16	0.1	5.8	0.4	0.1
2	89.5	651	9,691	963	5,631	25	18.9	26.4	33.7	5.1
3	90.2	665	9,616	960	5,608	45	20.5	67.8	59.0	4.7
4	91.0	909	9,567	960	5,831	-169	89.3	6.5	361.4	28.2
5	91.7	998	9,487	958	5,883	-220	93.3	5.4	162.7	26.9

8.4.2 Representative Unit 2, NEMA Design B, 30 Horsepower, 4 poles, Enclosed Motor

Figure 8.4.3 is an example of a frequency chart showing the distribution of LCC impacts for the case of CSL 3 for the representative unit 2, that is, an energy efficiency of 94.1 percent for a NEMA Design B, T-frame, 30 horsepower, 4-pole, enclosed electric motor. The net benefit of LCC is $511 in this Monte Carlo run.

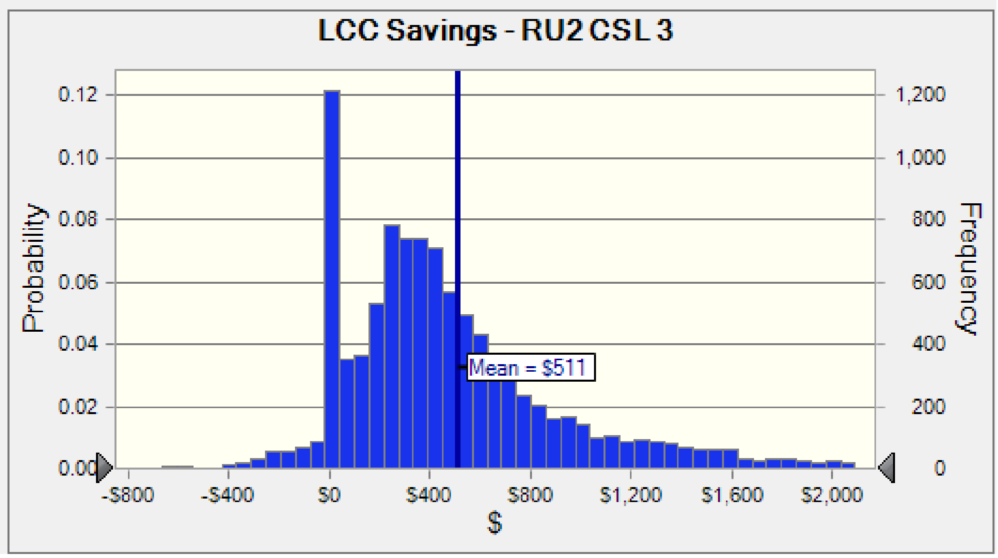

Figure 8.4.3 Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 2

Table 8.4.2 summarizes the LCC and PBP results for representative unit 2 based on a run of 10,000 Monte Carlo samples. The most rigorous CSL that provides positive average LCC savings is CSL 3. DOE estimates that 86.6 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL. At this CSL the increase in average total installed cost (relative to the base case) is $718, or 45.7 percent, while operating costs decrease by $234, or 4.3 percent.

Table 8.4.2 Life-Cycle Cost and Payback Period Results for Representative Unit 2: NEMA Design B, T-Frame, 30 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	89.5	1,570	57,642	5,489	44,182					
1	92.4	1,986	55,912	5,358	43,376	45	0.6	4.9	11.6	3.5
2	93.6	2,277	55,021	5,295	43,035	177	5.7	32.9	14.6	5.3
3	94.1	2,288	54,492	5,255	42,666	511	4.0	86.6	6.0	0.7
4	94.5	3,468	54,326	5,249	43,735	-558	87.1	12.9	107.6	23.8

8.4.3 Representative Unit 3, NEMA Design B, 75 Horsepower, 4 poles, Enclosed Motor

Figure 8.4.4 is an example of a frequency chart showing the distribution of LCC savings for the case of CSL 3 for the representative unit 3. The LCC net benefit is $597 in this Monte Carlo run. DOE has published a frequency chart like the one shown in Figure 8.4.4 for every efficiency level in Appendix 8-B to this chapter.

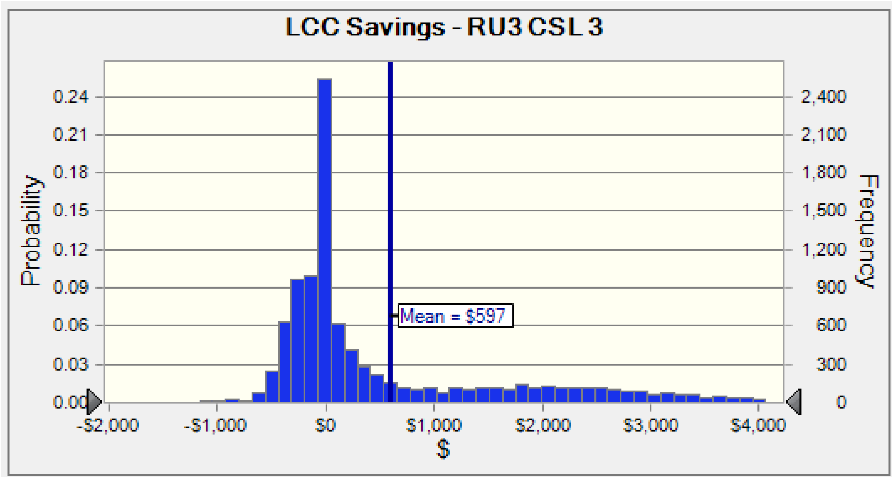

Figure 8.4.4 Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 2

Table 8.4.3 summarizes the LCC and PBP results for representative unit 3 based on a run of 10,000 Monte Carlo samples. The most rigorous CSL that provides positive average LCC savings is CSL 3. DOE estimates that 47.5 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL. At this CSL the increase in average total installed cost (relative to the base case) is $1,313, or 37.9 percent, while operating costs decrease by $481, or 2.8 percent.

Table 8.4.3 Life-Cycle Cost and Payback Period Results for Representative Unit 3: NEMA Design B, T-Frame, 75 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	93.0	3,463	204,834	17,168	124,170					
1	94.1	3,831	202,540	17,033	123,348	40	0.8	4.5	24.3	2.9
2	95.4	4,296	198,496	16,733	121,510	663	1.4	32.9	6.6	1.5
3	95.8	4,776	197,697	16,687	121,590	597	35.1	47.5	38.3	6.5
4	96.2	6,044	197,194	16,661	122,598	-340	66.9	25.9	162.7	15.5
5	96.5	6,640	196,604	16,631	122,905	-639	73.6	23.7	136.2	16.0

8.4.4 Representative Unit 4, NEMA Design C, 5 Horsepower, 4 poles, Enclosed Motor

Figure 8.4.5 is an example of a frequency chart showing the distribution of LCC savings for the case of CSL 2 for the representative unit 4. The LCC net benefit is -$203 in this Monte Carlo run.

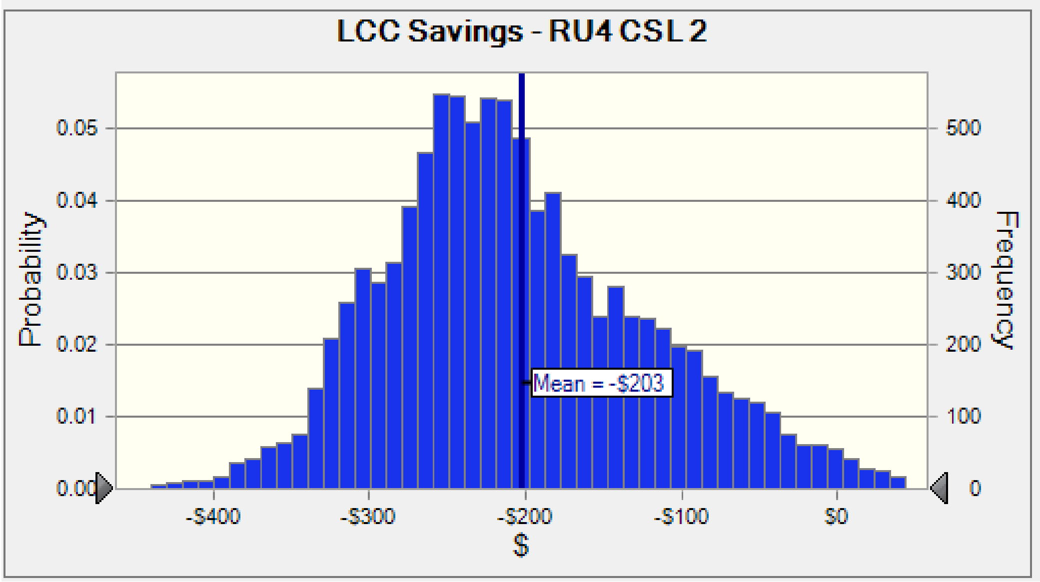

Figure 8.4.5 Representative Unit 4: Distribution of Life-Cycle Cost Savings for CSL 2

Table 8.4.4 summarizes the LCC and PBP results for the representative unit 4 based on a run of 10,000 Monte Carlo samples. The most rigorous CSL that provides positive average LCC savings is CSL 1. DOE estimates that 59.9 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL. At this CSL the increase in average total installed cost (relative to the base case) is $44, or 7.5 percent, while operating costs decrease by $10, or 1.0 percent.

Table 8.4.4 Life-Cycle Cost and Payback Period Results for Representative Unit 4: NEMA Design C, T-Frame, 5 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	87.5	583	9,987	984	5,807					
1	89.5	627	9,808	974	5,771	34	32.3	59.9	29.7	4.6
2	90.2	903	9,738	971	6,007	-203	97.8	2.2	95.6	25.0
3	91.0	961	9,630	966	6,011	-207	95.6	4.4	122.7	20.2

8.4.5 Representative Unit 5, NEMA Design C, 50 Horsepower, 4 poles, Enclosed Motor

Figure 8.4.6 is an example of a frequency chart showing the distribution of LCC savings for the case of CSL 2 for the representative unit 5. The LCC net benefit is $5 in this Monte Carlo run.

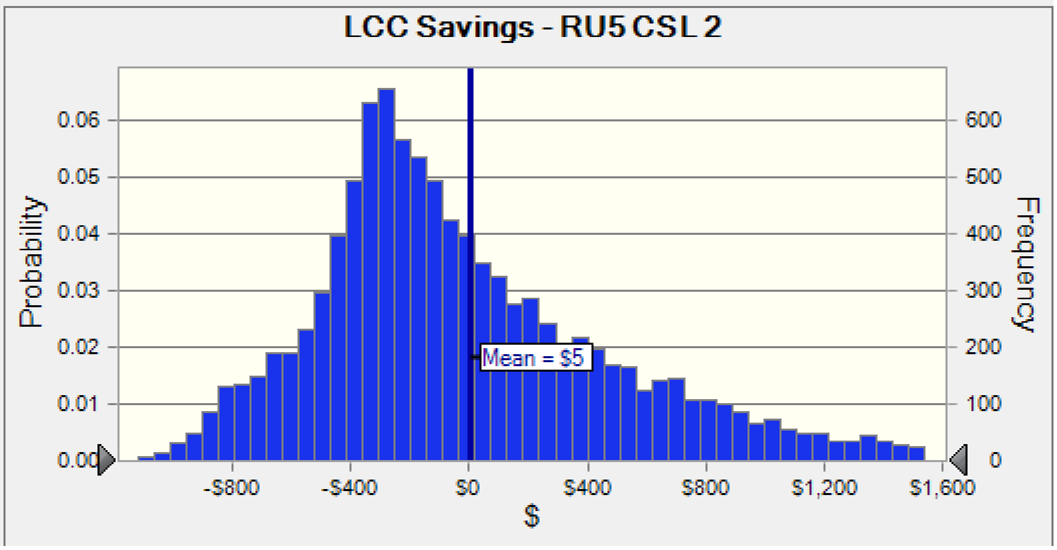

Figure 8.4.6 Representative Unit 5: Distribution of Life-Cycle Cost Savings for CSL 2

Table 8.4.5 summarizes the LCC and PBP results for representative unit 5 based on a run of 10,000 Monte Carlo samples. The most rigorous CSL that provides positive average LCC savings is CSL 3. DOE estimates that 57.8 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL. At this CSL the increase in average total installed cost (relative to the base case) is $1,164, or 41.8 percent, while operating costs decrease by $150, or 1.8 percent.

Table 8.4.5 Life-Cycle Cost and Payback Period results for Representative Unit 5: NEMA Design C, T-Frame, 50 hp, Four Pole, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	2,786	89,523	8,459	69,419					
1	94.1	3,173	88,507	8,383	69,098	236	18.3	55.6	38.8	5.9
2	94.5	3,673	88,119	8,360	69,329	5	59.6	40.4	53.3	12.7
3	95.0	3,950	87,444	8,309	69,104	229	42.3	57.8	25.2	9.8

8.4.6 Representative Unit 6, Fire Pump, 5 Horsepower, 4 poles, Enclosed Motor

Figure 8.4.7 is an example of a frequency chart showing the distribution of LCC savings for the case of CSL 2 for representative unit 6. The LCC net benefit is -$70 in this Monte Carlo run.

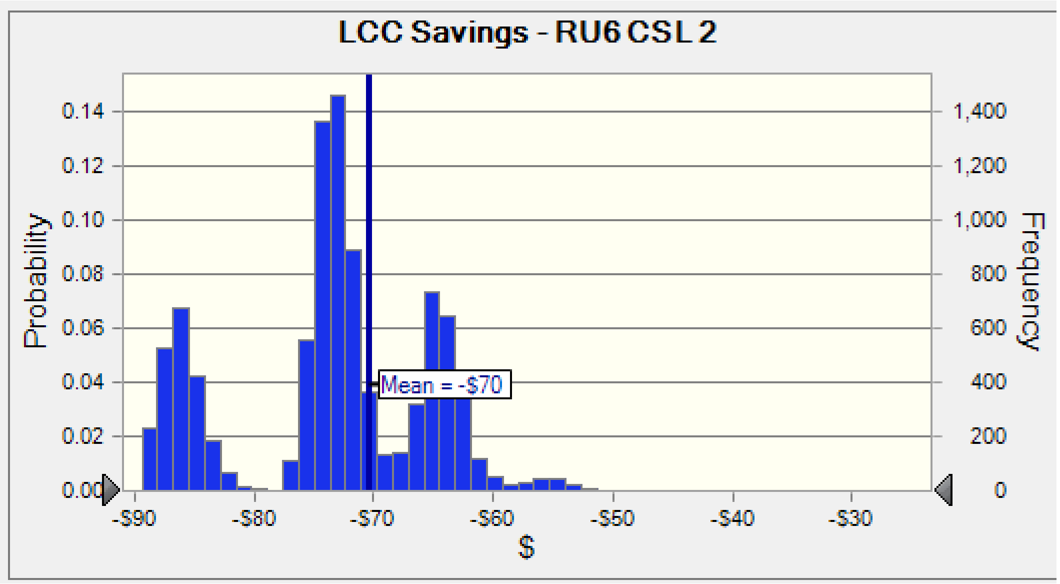

Figure 8.4.7 Representative Unit 6: Distribution of Life-Cycle Cost Savings for CSL 2

Table 8.4.6 summarizes the LCC and PBP results for Unit 6 motors based on a run of 10,000 Monte Carlo samples. All CSLs lead to negative average LCC savings.

Table 8.4.6 Life-Cycle Cost and Payback Period Results for Representative Unit 6: Fire Pump, NEMA Design B, T-Frame, 5 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	588	19.6	106	632					
1	89.5	651	19.2	115	697	-62	95.1	0.0	NA	NA
2	90.2	665	19.1	119	706	-70	99.9	0.1	NA	NA
3	91.0	909	19.0	124	949	-314	100.0	0.0	NA	NA
4	91.7	998	18.8	128	1,038	-403	100.0	0.0	NA	NA

8.4.7 Representative Unit 7, Fire Pump, 30 Horsepower, 4 poles, Enclosed Motor

Figure 8.4.8 is an example of a frequency chart showing the distribution of LCC savings for the case of CSL 2 for the representative unit 7. The LCC net benefit is -$207 in this Monte Carlo run.

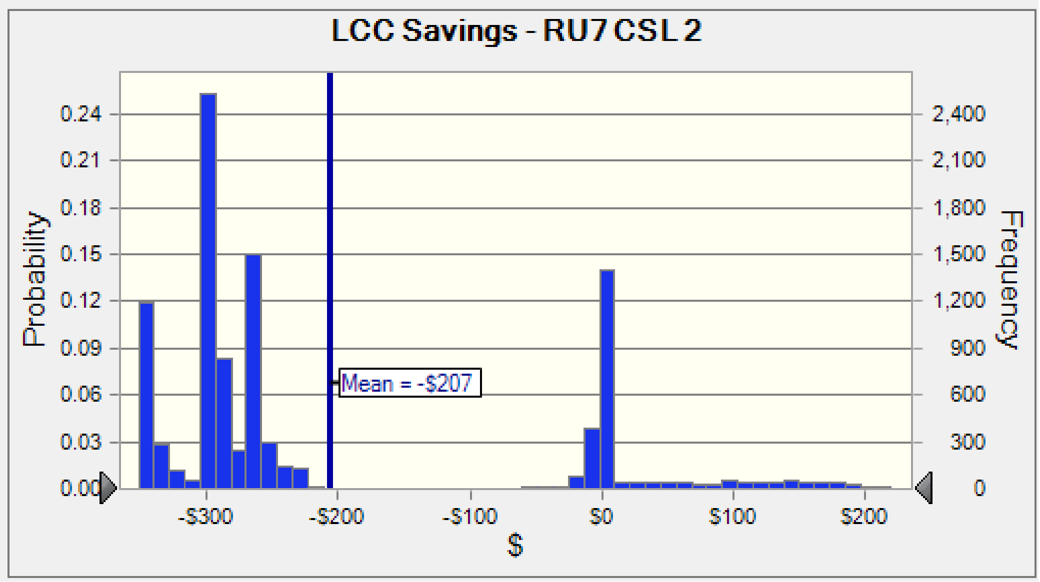

Figure 8.4.8 Representative Unit 7: Distribution of Life-Cycle Cost Savings for CSL 2

Table 8.4.7 summarizes the LCC and PBP results for representative unit 7 based on a run of 10,000 Monte Carlo samples. All CSLs lead to negative average LCC savings.

Table 8.4.7 Life-Cycle Cost and Payback Period Results for Representative Unit 7: Fire Pump, NEMA Design B, T-Frame, 30 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	92.4	1,986	1,601	347	3,869					
1	93.6	2,277	1,577	363	4,131	-213	78.8	2.5	1,579	104.9
2	94.1	2,288	1,562	371	4,124	-207	78.7	8.1	923	79.2
3	94.5	3,468	1,558	380	5,295	-1,378	100.0	0.0	3,157	433.6
4	94.5	3,468	1,558	380	5,295	-1,378	100.0	0.0	3,157	433.6

8.4.8 Representative Unit 8, Fire Pump, 75 Horsepower, 4 poles, Enclosed Motor

Figure 8.4.9 is an example of a frequency chart showing the distribution of LCC savings for the case of CSL 2 for the representative unit 8. The LCC net benefit is $1,193 in this Monte Carlo run.

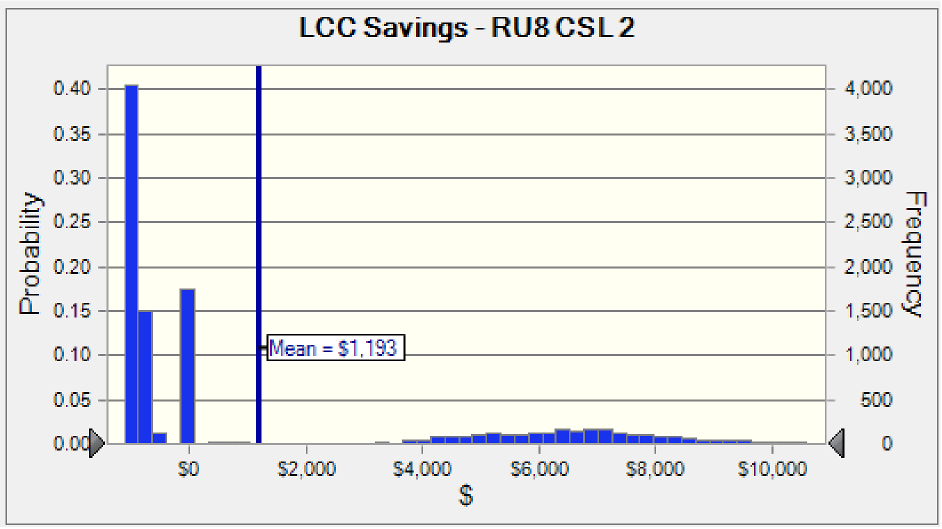

Figure 8.4.9 Representative Unit 8: Distribution of Life-Cycle Cost Savings for CSL 2

Table 8.4.8 summarizes the LCC and PBP results for the representative unit 8 based on a run of 10,000 Monte Carlo samples. The most rigorous CSL that provides positive average LCC savings is CSL 3. DOE estimates that 27.0 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL. At this CSL the increase in average total installed cost (relative to the base case) is $2,213, or 57.8 percent, while operating costs decrease by $126, or 1.6 percent.

Table 8.4.8 Life-Cycle Cost and Payback Period Results for Representative Unit 8: Fire Pump, NEMA Design B, T-Frame, 75 hp, Four Poles, Enclosed Motor

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	94.1	3,831	97,791	8,050	110,032					
1	95.4	4,296	95,934	7,937	108,445	1,274	55.4	25.3	1.1	1.1
2	95.8	4,776	95,554	7,927	108,544	1,193	56.7	26.0	2.1	1.9
3	96.2	6,044	95,313	7,924	109,522	215	73.0	27.0	25.3	4.5
4	96.5	6,640	95,033	7,920	109,826	-89	72.0	28.0	10.5	5.3

8.5 LIFE-CYCLE COST SENSITIVITY CALCULATIONS

DOE developed a number of sensitivity analyses in order to analyze the particular impacts of many inputs to its LCC analysis. These sensitivity analyses include lower and higher retail price discounts, and two alternative energy price trend scenarios. Table 8.5.1 displays the user choices and associated values for each sensitivity parameter analyzed.

Table 8.5.1 Life-Cycle Cost Sensitivity Case Parameters and Values

Parameter	**Choices**	**Typical Value**
Energy Price Trend	Default High Value Low Value	AEO 2011 Reference Case AEO 2011 High Case AEO 2011 Low Case
Retail Price Discount	Default High Discount Medium Discount Low Discount	1 0.7 0.5 0.3

Table 8.5.2 compares the average LCC savings using the default value for energy price trends with the LCC savings using high and low sensitivity values for representative units 2, 5, and 7. As expected, DOE observed larger savings with higher energy prices and smaller savings with lower energy prices.

Table 8.5.2 Life –Cycle Cost Results for Energy Price Trend Sensitivity Cases

Representative Unit 2				
Energy Efficiency Level	Efficiency %	Average LCC Savings $		
		Default Value	High Value	Low Value
0	89.5			
1	92.4	45	47	43
2	93.6	177	187	168
3	94.1	511	532	492
4	94.5	-558	-533	-580
5	94.5	-558	-533	-580
Representative Unit 5				
Energy Efficiency Level	Efficiency %	Average LCC Savings $		
		Default Value	High Value	Low Value
0	93.0			
1	94.1	236	253	221
2	94.5	5	31	-18
3	95.0	229	272	192
Representative Unit 7				

Energy Efficiency Level	Efficiency %	Average LCC Savings $		
		Default Value	High Value	Low Value
0	92.4			
1	93.6	-213	-212	-214
2	94.1	-207	-205	-209
3	94.5	-1,378	-1,376	-1,380
4	94.5	-1,378	-1,376	-1,380

Table 8.5.3 shows an example of retail price discount sensitivity analyses for representative units 2, 5, and 7. The default case does not include any discounts, whereas the other cases incorporate different discounts. The sensitivity results reflect that the higher the discount used, the greater the savings that are achieved.

Table 8.5.3 Life –Cycle Cost Results for Retail Price Discount Sensitivity Cases

Representative Unit 2					
Energy Efficiency Level	Efficiency %	Average LCC Savings $			
		Default Value	Low	Medium	High
0	89.5				
1	92.4	45	51	55	59
2	93.6	177	209	230	251
3	94.1	511	547	571	595
4	94.5	-558	-193	51	294
5	94.5	-558	-193	51	294
Representative Unit 5					
Energy Efficiency Level	Efficiency %	Average LCC Savings $			
		Default Value	Low	Medium	High
0	93.0				
1	94.1	236	307	354	401
2	94.5	5	223	368	513
3	95.0	229	526	724	922
Representative Unit 7					

Energy Efficiency Level	Efficiency %	Average LCC Savings $			
		Default Value	Low	Medium	High
0	92.4				
1	93.6	-213	-159	-122	-86
2	94.1	-207	-149	-109	-70
3	94.5	-1,378	-990	-732	-473
4	94.5	-1,378	-990	-732	-473

DOE collected the results of each sensitivity analysis, applied individually, in Appendix 8-C. The DOE's LCC analysis and PBP spreadsheet tool is available for download via the Internet[d] and allows the user to examine the results for the sensitivity scenario of their choice.

8.6 REBUTTABLE PAYBACK PERIOD

A more energy efficient motor will usually cost more to buy than a motor of standard energy efficiency. However, the more efficient motor will usually cost less to operate due to reductions in operating costs (*i.e.*, lower energy bills). The PBP is the time (usually expressed in years) it takes to recover the additional installed cost of the more efficient motor through energy cost savings. The Energy Policy and Conservation Act (EPCA) provides a rebuttable presumption that, in essence, an energy conservation standard is economically justified if the increased purchase cost for a product that meets the standard is less than three times the value of the first-year energy savings resulting from the standard. However, DOE routinely conducts a full economic analysis that considers the full range of impacts, including those to the customer, manufacturer, nation, and environment, as required under 42 U.S.C. 6295(o)(2)(B)(i) and 42 U.S.C. 6316(e)(1). The results of this analysis serve as the basis for DOE to evaluate definitively the economic justification for a potential standard level (thereby supporting or rebutting the results of any preliminary determination of economic justification).

The results of DOE's rebuttable PBP calculations are shown in Table 8.6.1 below.

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[d] See links from this web site: http://www1.eere.energy.gov/buildings/appliance_standards/commercial/small_electric_motors.html

Table 8.6.1 Rebuttable Presumption Payback for All Representative Units

Representative Unit		Payback Period *years*				
		CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
1	NEMA Design B, T-frame, 5 hp, 4 poles, enclosed	0.0	0.5	0.6	2.2	2.7
2	NEMA Design B, T-frame, 30 hp, 4 poles, enclosed	0.8	1.1	1.0	2.7	2.7
3	NEMA Design B, T-frame, 75 hp, 4 poles, enclosed	1.1	1.2	1.6	2.8	3.2
4	NEMA Design C, T-frame, 5 hp, 4 poles, enclosed	1.3	7.0	6.5	-	-
5	NEMA Design C, T-frame, 50 hp, 4 poles, enclosed	2.8	4.8	4.7	-	-
6	Fire pump, 5 hp, 4 poles, enclosed	1,013	926	3,013	3,231	-
7	Fire pump, 30 hp, 4 poles, enclosed	99	73	290	290	-
8	Fire pump, 75 hp, 4 poles, enclosed	2.8	4.3	8.2	9.1	-

REFERENCES

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[1] Database of motor nameplate and field measurement data compiled by the Washington State University Extension Energy Program (WSU) and Applied Proactive Technologies (APT) under contract with the New York State Energy Research and Development Authority (NYSERDA). 2011.

[2] U.S. Department of Energy-Energy Information Administration (December 2010), *Annual Energy Outlook 2011*, Washington, DC. http://www.eia.doe.gov/oiaf/aeo

[3] RS Means (2010), *Electrical Cost Data, 33RD Annual Edition*, Kingston, MA.

[4] Bonneville Power Administration (1994), *Industrial Motor Repair in the United States*, 1994. p. iv.

[5] Electrical Apparatus Service Association, Inc. (2010), *EASA Standard AR100-2010, Recommended Practice for the Repair of Rotating Electrical Apparatus*, Missouri. http://www.easa.com/sites/default/files/AR100-2010_1010-2.pdf

[6] EASA/Association of Electrical and Mechanical Trades (AEMT) (2003), *The Effect of Repair/Rewinding on Motor Efficiency*.

[7] Sahnil, Sahil, Avid Boustani1, Timothy Gutowski, and Steven Graves (January 2010), *Electric Motor Remanufacturing and Energy Savings*, p. 12.

[8] Easton Consultants, I. (2000), *Variable Frequency Drive*. Retrieved February 9, 2011. http://neea.org/research/reports/E00-054.pdf

[9] U.S. Department of Energy Information Administration (2006), *Energy Consumption by Manufacturers*. http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html

[10] U.S. Department of Agriculture (2007), *The Census of Agriculture*. http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_US_State_Level/index.asp

[11] U.S. Department of Energy Information Administration (2003), *Commercial Buildings Energy Consumption Survey*. http://www.eia.gov/emeu/cbecs/contents.html

[12] U.S. Department of Energy-Energy Information Administration (2009), *Form EIA-861 for 2009*, Washington, DC. http://www.eia.doe.gov/cneaf/electricity/page/eia861.html

[13] Vaughen's (2011), *Vaughen's Motor & Pump Repair Price Guide, 2011 Edition*. http://www.vaughens.com/

[14] Fraunhofer (2008), *Eup Lot 11: Fans for Ventilation in Non Residential Building*.

---

[15] Falkner, Hugh and Geoff Dollard (2008), *Lot 11 - Water Pumps (in commercial buildings, drinking water pumping, food industry, agriculture)*.

[16] Innovation Center for US Dairy, *Case Study - Compressed Air Systems*. http://www.usdairy.com/Sustainability/BestPractices/Documents/CaseStudy-CompresedAirSystems.pdf

[17] Conveyor Dynamics, Inc., *A New Era In Overland Conveyor Belt Design*. http://www.ckit.co.za/secure/conveyor/papers/troughed/overland/overland.htm

[18] John C. Andreas (1982), *Energy-Efficient Electric Motors: Selection and Application*.

[19] Northwest Power & Conservation Council (2009), Regional Technical Forum. http://www.nwcouncil.org/energy/rtf/measures/Default.asp

[20] ACEEE (2007), *Impact of Proposed Increases to Motor Efficiency Performance Standards, Proposed Federal Motor Tax Incentives and Suggested New Directions Forward*. http://www.aceee.org/sites/default/files/publications/researchreports/ie073.pdf

[21] Ibbotsons Associates (2001), *SBBI Valuation Edition 2001 Yearbook*, Chicago, IL. pp. 38, 44.

[22] The Federal Reserve Board. *Federal Reserve Bank Services Private Sector Adjustment Factor*, 2005, Docket No.OP-1229. Washington, DC. http://www.federalreserve.gov/boarddocs/Press/other/2005/20051012/attachment.pdf

[23] Damodaran Online. *The Data Page: Cost of Capital by Industry Sector*, 2009, 2010, 2011. http://pages.stern.nyu.edu/~adamodar/

CHAPTER 9. SHIPMENTS ANALYSIS

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9.1 INTRODUCTION

The U.S. Department of Energy (DOE) analyzes shipments of affected equipment as a part of its rulemakings about new or amended energy efficiency standards for equipment that impact national energy use. Estimates of shipments are a necessary input to calculating national energy savings (NES) and net present value (NPV) of the investment in more efficient equipment; both of these calculations are required to analyze the impact of proposed new or amended energy efficiency standards. Shipments also are a necessary input to the manufacturer impact analysis (MIA), which DOE conducts to prepare its notice of proposed rulemaking (NOPR). The MIA estimates the impact of potential efficiency standards on manufacturers of the affected equipment, in this case electric motors, and assesses the direct impact of such standards on employment and manufacturing capacity. This chapter describes the method DOE used to project annual shipments for electric motors under base- and standards-case efficiency levels and the results obtained.

DOE developed a shipments model to predict shipments of electric motors covered in this analysis. The core of the shipments analysis is a model that DOE developed to simulate how future purchases are incorporated into an in-service stock of aging motors that are gradually replaced. DOE's motors shipments projections are based on forecasts of economic growth and do not incorporate a distinction within shipments between replacements and purchases for new applications.

To formulate its total shipments estimates, DOE began with shipments data from a market research report[1], input from interested parties, and responses to the Request for Information (RFI) published in the Federal Register (76 FR 17577 (March 30, 2011)). Based on a database of motor field data[2], U.S. Census Bureau's Current Industrial Reports[3,4], and stakeholder input, DOE then developed a distribution of shipments across each of the three equipment class group (NEMA Design A and B, NEMA Design C, and fire pump motors). Within each category, motor shipments were split into several horsepower ratings, rotation speeds (corresponding to 2-pole, 4-pole, 6-pole, and 8-pole motors), and two enclosure types (open or enclosed) to arrive at shipments at the equipment class level.

The shipments model is prepared as a Microsoft Excel spreadsheet that is accessible on the Internet (http://www.eere.energy.gov/buildings/appliance_standards/). Appendix 10-A discusses how to access the shipments model and other related spreadsheets and provides basic instructions for using them. The rest of this chapter explains the shipments model in more detail. Section 9.2 provides a summary of the data DOE used to develop estimates of the shipments of covered electric motors by equipment class and for each sector and applications. Section 9.3 describes the methodology that underlies development of the model and presents the shipments projection.

9.2 TOTAL SHIPMENTS

Based on a market research report[1] and stakeholder input and responses to the RFI, annual shipments of covered motors were estimated to total 4.56 million units in 2011.

DOE drew upon two data sources to develop a distribution of the total shipments across the 510 equipment classes: input from interested parties, and data from extensive field measurements collected by the Washington State University Extension Energy Program (WSU), Applied Proactive Technologies and the New York State Energy Research and Development Authority (NYSERDA) 2 ("WSU/NYSERDA database").

9.2.1 Distribution across Equipment Class Groups

DOE derived the distribution by equipment class group from the WSU/NYSERDA database (Table 9.2.1).

Table 9.2.1 Share of Motors by Equipment Class Group in Percent

NEMA Design A and B	NEMA Design C	Fire Pump
99.68	0.20	0.12

9.2.2 Distribution across Horsepower

Shipments were first distributed by horsepower range, based on U.S. Census Bureau's Current Industrial Reports3,[4] and input from interested parties (Table 9.2.2).

Table 9.2.2 Share of Motors by Horsepower Range

Range *hp*	**2011 Shipments (*1,000*)**	**Percentage of Total (*%*)**
1 – 5	2,668	58.5%
6 – 20	1,368	30.0%
21 – 50	342	7.5%
51 – 100	114	2.5%
101 – 200	46	1.0%
201 – 500	23	0.5%
Total	4,560	100.0%

DOE then split shipments by individual horsepower rating, based on the distribution observed in the WSU/NYSERDA database (Table 9.2.3).

Table 9.2.3 Share of Motors by Horsepower Rating

Horsepower rating *hp*	Percentage of Total (%)
1	6.2%
1.5	5.6%
2	10.2%
3	14.5%
5	22.1%
7.5	9.1%
10	8.2%
15	8.1%
20	4.5%
25	2.1%
30	2.0%
40	2.1%
50	1.3%
60	0.8%
75	0.9%
100	0.8%
125	0.4%
150	0.4%
200	0.3%
250	0.3%
300	0.1%
350	0.04%
400	0.1%
450	0.02%
500	0.03%

9.2.3 Distribution across Pole Configurations and Enclosures

DOE derived the distribution by pole configuration and enclosure from the WSU/NYSERDA database (Table 9.2.4).

Table 9.2.4 Share of Motors by Pole Configuration and Enclosure (All Equipment Class Groups)

Enclosure	**Open**				**Enclosed**			
Range *hp*	**2 poles**	**4 poles**	**6 poles**	**8 poles**	**2 poles**	**4 poles**	**6 poles**	**8 poles**
1 – 5	0.7%	8.1%	1.1%	0.1%	5.0%	19.6%	2.6%	1.4%
6 – 20	1.0%	6.2%	0.6%	0.1%	6.6%	17.0%	1.5%	0.2%
21 – 50	0.3%	2.3%	0.2%	0.1%	2.7%	8.1%	1.6%	0.1%
51 – 100	0.1%	0.9%	0.4%	0.1%	0.7%	4.1%	1.0%	0.1%
101 – 200	0.0%	0.4%	0.1%	0.1%	0.2%	2.3%	1.0%	0.2%
201 – 500	0.1%	0.1%	0.1%	0.1%	0.1%	0.4%	0.1%	0.1%

DOE then combined the distribution by horsepower and the share of motors by pole and enclosure configuration to estimate the shipment distribution per equipment class.

9.2.4 Distribution across Equipment Classes, Sectors and Applications

DOE used the data presented in Table 9.2.1, Table 9.2.2, Table 9.2.3, and Table 9.2.4 to produce market shares for each of the 510 equipment classes. Further, DOE developed a model of the applications and sectors for which motors covered in this analysis are used. These distributions are presented in chapter 7, Energy Use Characterization.

9.3 SHIPMENTS PROJECTION

9.3.1 Shipments Model

DOE projected shipments of covered motors throughout the 30-year analysis period, which stretches from 2015 (the effective date of the standard) to 2044. DOE projects total shipments using a model driven by forecasted economic growth. DOE assumed that motors sales are driven by economic growth and machinery production growth for equipment including motors.

Based on historical data for the period 1993-2011 on U.S. shipments provided by the U.S. Census Bureau[3,5]and NEMA[6,7] and private fixed investment data from the Bureau of Economic Analysis's (BEA)[8,9], DOE assumes that annual shipments growth rate correlate to the annual growth rate of private fixed investment in selected equipment and structures[10,a] including motors (Figure 9.3.1).

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[a] Heating, ventilation, and air conditioning (HVAC) equipment which incorporates motors is typically included in "structures" and not in equipment. Based on RSMeans, DOE estimates that 9 percent of investments in structures are related to HVAC equipment.

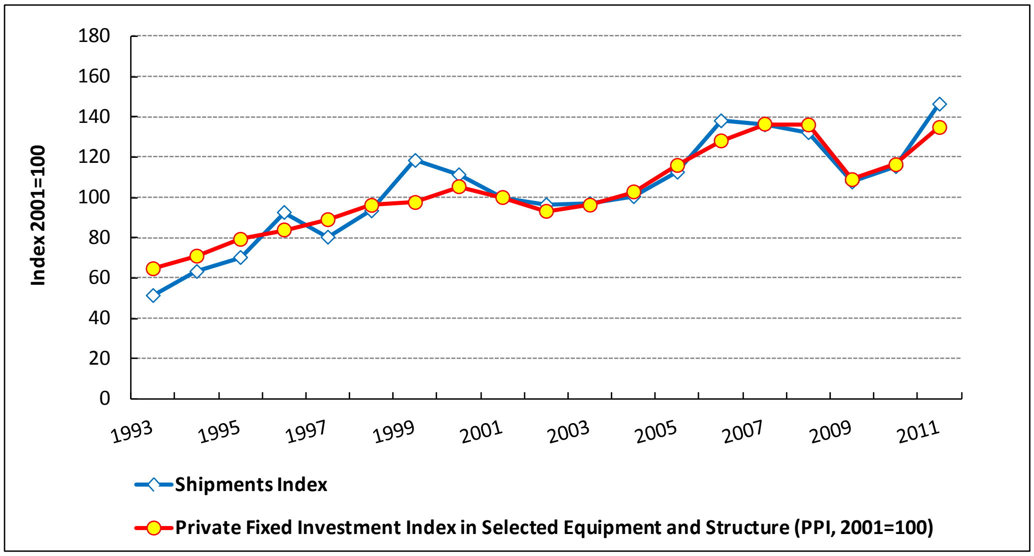

Figure 9.3.1 Shipments Index vs. Private Fixed Investment Index in Selected Equipment and Structure

DOE developed a relationship between shipments and private fixed investment in equipment and structures including motors (indexed to 2001). The relation, derived from a linear regression (R^2=0.91), is expressed by the following equation:

$$Shipments_{index}(y) = 1.15126 \cdot FixInvest_{index}(y) - 15.17265\mathrm{Shipments}_{\mathrm{index}}(\mathrm{y}) = 1.15126 \cdot \mathrm{FixInvest}_{\mathrm{index}}(\mathrm{y})\text{-}15.17265 \quad \text{[Equation 1, Step 0]}$$

Where:

$Shipments_{index}$ (y) is the shipments index based in 2001 in year *y*, and
$FixInvest_{index}$ (y) is the private fixed investment index based in 2001 for selected equipment and structure including motors in year *y*.

DOE projects private fixed investment in selected equipment and structure from 2015 through 2035 based on the real "gross domestic product" (GDP) growth from the Energy Information Administration Annual Energy Outlook for 2011 (*AEO2011*) for the period 2015–2035. DOE then extrapolated the GDP growth trend from 2035 to 2044. The steps for the calculation are:

1) Based on historical data from the BEA, DOE projected private fixed investment in equipment and structure including motors as a share of total private fixed investment in equipment and structure for 2015 to 2044.
2) For 2015 to 2035, DOE used total private fixed investment in equipment and structures data (private domestic investment data) from *AEO2011* to project private fixed investment in equipment and structure including motors.

3) From 2035 to 2044, DOE used *AEO 2011* data to estimate a trend for private domestic investment as a share of GDP using a linear regression ($R^2>0.99$). DOE then projected the GDP for 2035 to 2044 using a quadratic regression based on *AEO 2011* data ($R^2>0.99$). Using the GDP projection, DOE projected *private domestic investment* and estimated private fixed investment in equipment and structure including motors.
4) DOE used the data on projected private fixed investment in equipment and structure including motors and Equation 1 to estimate shipments growth over the analysis period (2015–2044).

Following the same methodology, DOE estimated shipments projections for the Reference Economic Growth Case, the High Economic Growth Case, and Low Economic Growth Case available in *AEO 2011*.

9.3.2 Shipments in Standards Cases

Sales of electric motors may be sensitive to increases in the installed cost that may result from efficiency standards. Increased motor prices could affect the repair versus replace decision that the user makes and could lead to increasing the longevity of less efficient motors and decreased shipments. However, DOE did not find sufficient data to quantitatively estimate the impact of increased efficiency levels on shipments and therefore used a price elasticity equal to zero as a default.

9.3.3 Shipments Data

Figure 9.3.2 shows the annual shipments for each scenario case between 2015 and 2044.

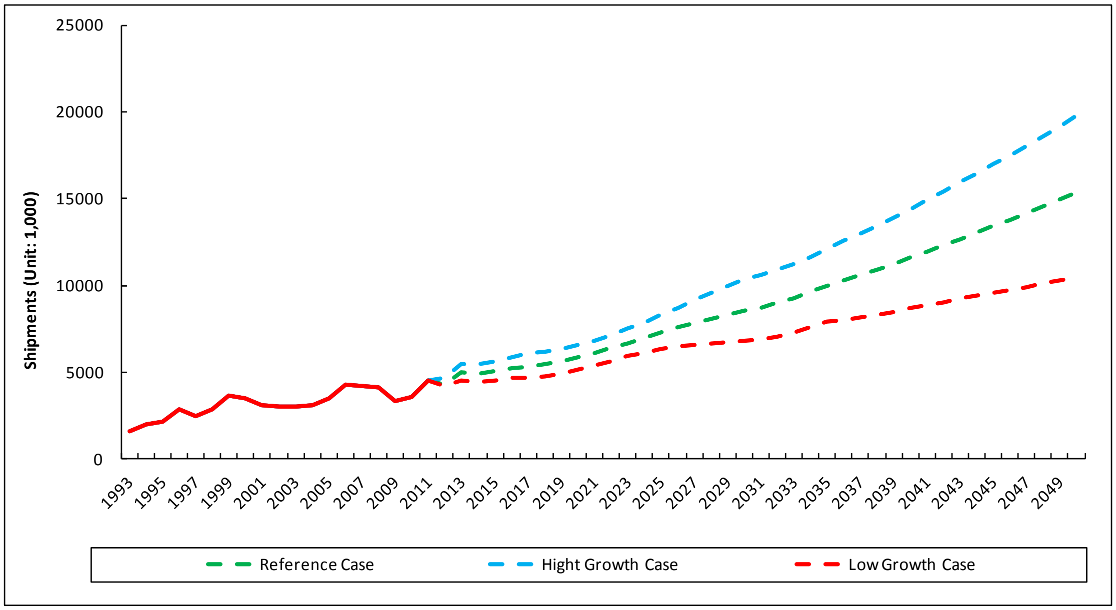

Figure 9.3.2 Shipments Projection by Scenario Case

Table 9.3.1 shows the annual and cumulative shipments for each equipment class grouping for Reference Case

Table 9.3.1 Annual and Cumulative Shipments Projection

Equipment Class Grouping	**Annual Shipments** ***thousand units***				
	2015	**2025**	**2035**	**2044**	**Cumulative 2015–2044**
NEMA Designs A & B	5,072	7,254	9,958	13,005	256,846
NEMA Design C	10	15	20	26	515
Fire Pump	6	9	12	16	309
Total*	5,089	7,278	9,990	13,047	257,671

*Total may not sum up because of rounding.

There are two major assumptions inherent in the shipments model:

1) The relative market shares of the different equipment classes are constant over time.
2) U.S. production, imports, exports, and therefore shipments (i.e. apparent consumption) have the same growth rate as described by the shipments index provided by NEMA[6,7] (see section 9.3.1).

REFERENCES

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[1] IMS Research (February 2012), The *World Market for Low Voltage Motors, 2012 Edition*, Austin.

[2] Database of motor nameplate and field measurements compiled by the Washington State University Extension Energy Program (WSU) and Applied Proactive Technologies (APT) under contract with the New York State Energy Research and Development Authority (NYSERDA). 2011.

[3] U.S. Census Bureau (November 2004), *Motors and Generators – 2003.MA335H(03)-1*. http://www.census.gov/manufacturing/cir/historical_data/discontinued/ma335h/index.html

[4] U.S. Census Bureau (August 2003), *Motors and Generators – 2002.MA335H(02)-1*. at http://www.census.gov/manufacturing/cir/historical_data/discontinued/ma335h/ma335h02.xls

[5] U.S. Census Bureau, Current Industrial Report: Manufacturing Profiles, 1994-1998.

[6] NEMA (2007), *Motor Shipments Slip in Third Quarter of 2007*, NEMA News, on 05 Dec 2007.

[7] NEMA (2011*), Motors Shipments on the Upswing in First Half of 2011*, NEMA News, on 18 Aug 2011.

[8] Bureau of Economic Analysis (March 01, 2012), Private *Fixed Investment in Equipment and Software by Type*. http://www.bea.gov/iTable/iTable.cfm?ReqID=12&step=1

[9] Bureau of Economic Analysis (March 01, 2012), Private *Fixed Investment in Structures by Type*. http://www.bea.gov/iTable/iTable.cfm?ReqID=12&step=1

[10] RSMeans (2011), *RSMeans Facilities Construction Cost Data 201*, Norwell.

CHAPTER 10. NATIONAL IMPACT ANALYSIS

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10.1 INTRODUCTION

The Energy Policy and Conservation Act (EPCA) provides that any new or amended standard must be chosen so as to achieve the maximum improvement in energy efficiency that is technologically feasible, economically justified, and would save a significant amount of energy. In determining whether economic justification exists, the U.S. Department of Energy (DOE) must determine whether the benefits of an energy efficiency standard exceed its burdens. Key factors in this decision are: the total projected amount of energy savings likely to result directly from the imposition of the standard, and the savings in operating costs throughout the life of the covered equipment compared to any increase in the price of, or in the initial charges for or maintenance expenses of, the covered equipment that are likely to result from the promulgation of the standard.

To satisfy this EPCA requirement and to more fully understand the national impact of potential efficiency regulations for electric motors, DOE conducted a national impact analysis (NIA). This analysis assessed future national energy savings (NES) from electric motor energy conservation standards and the national economic impact using the net present value (NPV) metric.

This chapter describes the method used to estimate the national impacts of candidate standard levels (CSLs) for electric motors covered in this analysis. These electric motors have been categorized into three distinct equipment class groups: National Electrical Manufacturers Association (NEMA) Design A and B motors, NEMA Design C motors, and fire pump electric motors. For each of these equipment class groups, and for each equipment class, DOE evaluated the following impacts: (1) NES attributable to each potential standard level, (2) monetary value of the lifetime energy savings to consumers of the considered equipment, (3) increased total lifetime cost of the equipment because of standards, and (4) NPV resulting from energy savings (the difference between the energy cost savings and the increased total lifetime cost of the equipment).

To conduct its NIA, DOE determined both the NES and NPV for each of the efficiency levels being considered as the new standard for electric motors. DOE performed all calculations for each considered equipment class group and equipment class using Microsoft Excel spreadsheet models, which are accessible on the Internet.[a] Details and instructions for using the NIA model are provided in Appendix 10-A of the Technical Support Document (TSD). The spreadsheets combine the calculations for determining the NES and NPV for each considered equipment class group and equipment class with input from the appropriate shipments model that DOE used to project future purchases of the considered equipment. Chapter 9 provides a detailed description of the shipments models.

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[a] See www.eere.energy.gov/buildings/appliance_standards/

To calculate the national impacts of new standards for all equipment class groups considered in this rulemaking DOE used scaling factors (described in Chapter 5 and section 10.3.2 below) to estimate equipment related costs and annual energy consumption for all equipment classes. DOE derived these factors from the engineering outputs for the eight representative units.

Figure 10.2.1 presents a graphical flow diagram of the electric motor NIA spreadsheet model. In the diagram, the arrows show the direction of information flow for the calculation. The information begins with inputs (shown as parallelograms). As information flows from these inputs, it is integrated into intermediate results (shown as rectangles) into major outputs (shown as boxes with curved bottom edges).

The NIA calculation started with the shipments model. This model produces a projection of annual shipments of motors. DOE used the annual projection of such shipments to produce an accounting of annual national energy savings, annual national energy cost savings, and annual national incremental non-energy costs resulting from purchasing, installing and operating the units projected to be shipped in each year of the analysis period during their estimated lifetime. The annual values, therefore, refer to the lifetime, cumulative energy related savings and non-energy related additional costs associated to the units marketed in each year of the analysis period.

To calculate the annual national energy savings, DOE first estimated the lifetime primary and fuel-fuel-cycle[b] (FFC) energy consumption at the unit level for each equipment class, and for each year in the analysis period. The unit's lifetime primary and FFC energy consumptions were then scaled up to the national level based on the annual shipments projection. The primary and FFC national energy consumptions were then evaluated, each one, for two scenarios: the *base case* scenario, with no changes in the existing energy efficiency standards; and (b) the *standards case* scenario, where energy efficiency standards are set at the energy efficiency level corresponding to one of the CSLs. This produced, for each equipment class, two sets of two streams of annual national energy consumption, from which DOE derived two streams of annual national energy savings: one that accounts for primary energy savings, and one that accounts for the FFC energy savings. The annual national primary and FFC energy savings of all equipment classes within an equipment class group were, each one, aggregated over the full analysis period into national energy primary and FFC savings by equipment class group. DOE then summed the aggregated national primary and FFC energy savings to produce the primary and FFC NESs of all equipment class groups.[c]

DOE followed a similar procedure to calculate the annual national energy cost savings and the annual national incremental non-energy costs. DOE first estimated the lifetime energy cost and the lifetime non-energy costs at unit level for each equipment class within each

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[b] The full-fuel-cycle energy consumption adds to the primary energy consumption the energy consumed by the energy supply chain upstream to power plants.

[c] Because not all equipment class groups are classified into the same number of CSLs: (a) results for CSL 4 aggregates the results from Design A and B and from fire pump electric motors at CSL 4 with those estimated for Design C at CSL 3; and (b) results for CSL 5 aggregates the results from Design A and B at CSL 5 with those from fire pump electric motors at CSL 4 and Design C at CSL 3.

equipment class group, and for each year in the analysis period. The units lifetime energy and non-energy costs, for each year in the analysis period, were then scaled up to the national level based on the annual shipments projection and for the same—*base case* and *standards case*—scenarios. This produced, for each equipment class: (a) two streams of annual national energy costs, from which DOE derived a stream of annual national energy cost savings and its corresponding present-value, and (b) two streams of annual national non-energy costs, from which DOE derived a stream of annual national incremental equipment non-energy costs and its corresponding present-value. The present-values of the annual national energy cost savings and the annual national incremental non-energy costs of all equipment classes within an equipment class group were aggregated over the full analysis period, respectively, into national energy cost savings and national incremental non-energy costs by equipment class group. DOE then calculated the difference between the aggregated national energy cost savings and national incremental non-energy costs, and aggregated these values across equipment class groups to produce the NPV.[c]

Two models included in the NIA are provided below—the NES model in section 10.2, and the NPV model in section 10.3. Each technical description begins with a summary of the model. It then provides a descriptive overview of how DOE performed each model's calculations and follows with a summary of the inputs. The final subsections of each technical description describe each of the major inputs and computation steps in detail and with equations, when appropriate. After the technical model descriptions, this chapter presents the results of the NIA calculations.

10.2 NATIONAL ENERGY SAVINGS

DOE developed the NES model to estimate the total national primary and FFC energy savings using information from the life-cycle cost (LCC) relative to energy consumption, combined with the results from the shipments model. The savings shown in the NES reflect decreased energy losses resulting from the installation of more efficient electric motors nationwide, in comparison to a base case with no changes in the current national standards. Positive values of NES correspond to net energy savings, that is, a decrease in energy consumption after implementation of a standard in comparison to the energy consumption in the base case scenario.

10.2.1 National Energy Savings Overview

DOE calculated the cumulative primary and FFC energy savings from an electric motor efficiency standard, relative to a base case scenario of no standard, over the analysis period. It calculated NES for each candidate standard level, in units of quadrillion British thermal units (Btus) (quads), for standards that will be effective in the year 2015. The NES calculation started with estimates of shipments, which are outputs of the shipments model (Chapter 9). DOE then obtained estimates of electric motor parameters from the LCC analysis (Chapter 8), projections of site-to-primary conversion factors[d] from the *Annual Energy Outlook*[6] (AEO) and projections

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[d] The site-to-primary factors account for electricity generation, transmission and distribution losses.

of primary-to-FFC conversion factors[e] from a NEMS-based methodology (Appendix 10-C), and calculated the market average of the total primary and FFC energy used by the units shipped in each year over their lifetime, for both a base case and a standards case. Since in the standards case part of the units shipped is more efficient than its corresponding in the base case, the average energy consumed per unit decreases in the standards case relative to the base case. For each year analyzed, the lifetime primary and FFC energy savings from all motors of a given capacity and configuration (combination of enclosure and number of poles), shipped in that year, are the differences in their primary and FFC energy use between the corresponding base case and the standards case scenarios.

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[e] The primary-to-FFC factors account for the energy consumption in the supply chain of the fuels used for electricity generation.

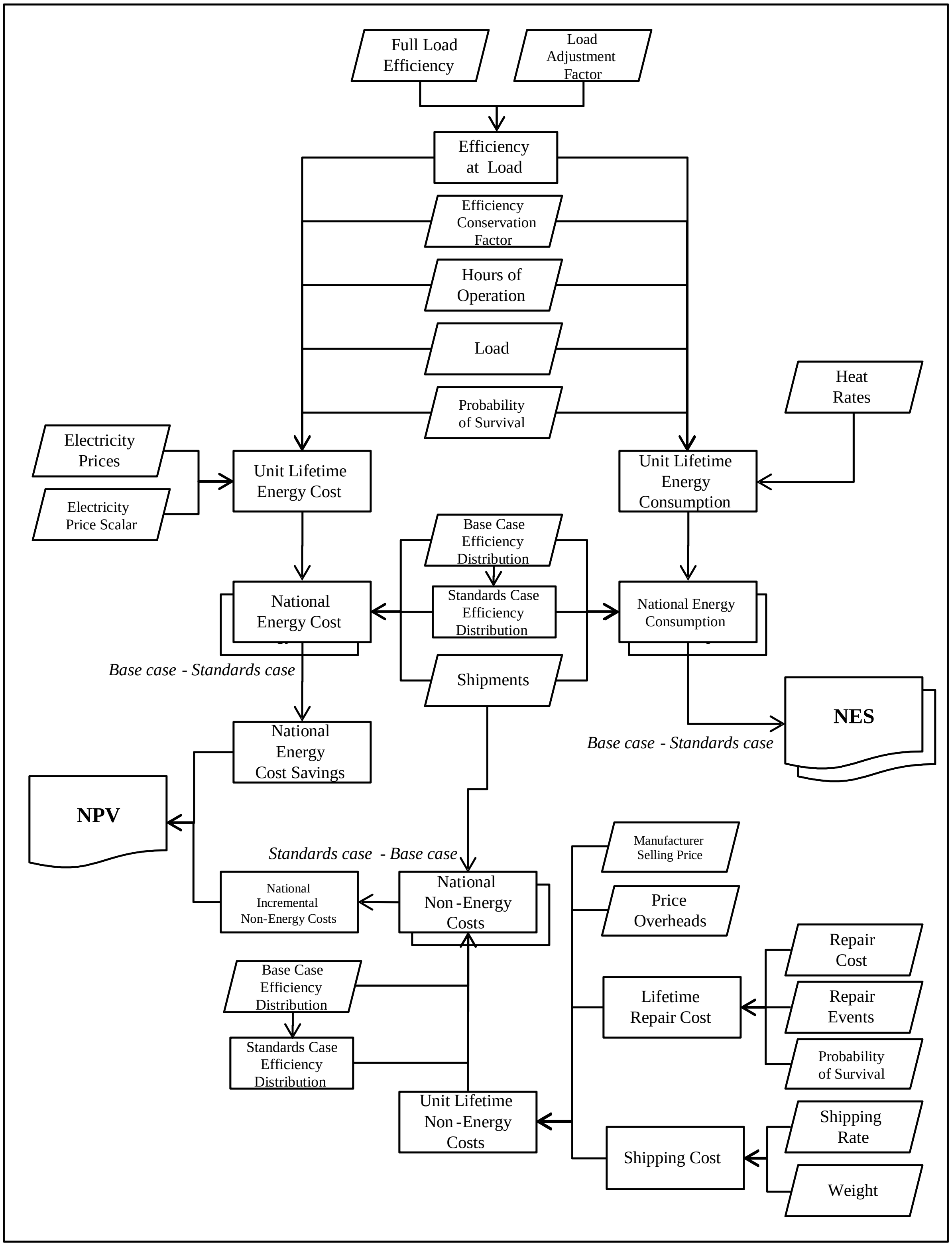

Figure 10.2.1 National Impact Analysis Model Flowchart

This calculation is expressed by the following formulas:

Lifetime Primary Energy Savings

$$nSES_{hp,g}(y) = \sum_s \sum_a \left(nSrcECbc_{hp,g}(s,a,y) - nSECst_{hp,g}(s,a,y)\right) \qquad \text{Eq. 10.1}$$

$$nSECbc_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uSEC_{hp,g,c}(s,a,y) \cdot Mbc_{hp,c}(y)\right) \qquad \text{Eq. 10.2}$$

$$nSECstd_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uSEC_{hp,g,c}(s,a,y) \cdot Mstd_{hp,c}(y)\right) \qquad \text{Eq. 10.3}$$

$$uSEC_{hp,g,c}(s,a,y) = \sum_{i=1..LT} aSEC_{hp,g,c}(s,a,y,i) \qquad \text{Eq. 10.4}$$

where:

$nSES_{hp,g}(y)$ = the lifetime primary energy savings of all motors with capacity *hp* and configuration *g* shipped in year *y*,

$nSECbc_{hp,g}(s,a,y)$ = the base case, lifetime primary energy consumption of motors with capacity *hp* and configuration *g* shipped in year *y* to be used in application *a* in sector *s*,

$nSECstd_{hp,g}(s,a,y)$ = the standards case, lifetime primary energy consumption of motors with capacity *hp* and configuration *g* shipped in year *y* to be used in application *a* in sector *s*,

$Shp_{hp,g}(s,y)$ = the number of motors with capacity *hp* and configuration *g* shipped in year *y* to sector *s*,

$A(a)$ = the probability of a motor to be used in application *a*,

$uSEC_{hp,g,c}(s,a,y)$ = the lifetime primary energy consumption of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y* to be used in application *a* in sector *s*,

$aSEC_{hp,g,c}(s,a,\mathrm{y},\mathrm{i})$ = the annual primary energy consumption in the i-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*, shipped in year *y* to be used in application *a* in sector *s*,

$Mbc_{hp,c}(y)$ = the base case market share of units with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y*, and

$Mstd_{hp,c}(y)$ = the standards case market share of units with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y*.

Lifetime Full-Fuel-Cycle Energy Savings

$$nFES_{hp,g}(y) = \sum_s \sum_a \left(nFECbc_{hp,g}(s,a,y) - nFECst_{hp,g}(s,a,y)\right) \qquad \text{Eq. 10.5}$$

$$nFECbc_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uFEC_{hp,g,c}(s,a,y) \cdot Mbc_{hp,c}(y)\right) \qquad \text{Eq. 10.6}$$

$$nFECstd_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_{c} \left(uFEC_{hp,g,c}(s,a,y) \cdot Mstd_{hp,c}(y) \right) \quad \text{Eq. 10.7}$$

$$uFEC_{hp,g,c}(s,a,y) = \sum_{i=1..LT} \left(aSEC_{hp,g,c}(s,a,y,i) \cdot ffc(y+i-1) \right) \quad \text{Eq. 10.8}$$

where:

$nFES_{hp,g}(y)$ = the lifetime FFC energy savings of all motors with capacity *hp* and configuration *g* shipped in year *y*,

$nFECbc_{hp,g}(s,a,y)$ = the base case, lifetime FFC energy consumption of motors with capacity *hp* and configuration *g* shipped in year *y* to be used in application *a* in sector *s*,

$nFECstd_{hp,g}(s,a,y)$ = the standards case, lifetime FFC energy consumption of motors with capacity *hp* and configuration *g* shipped in year *y* to be used in application *a* in sector *s*,

$Shp_{hp,g}(s,y)$ = the number of motors with capacity *hp* and configuration *g* shipped in year *y* to sector *s*,

$A(a)$ = the probability of a motor to be used in application *a*,

$uFEC_{hp,g,c}(s,a,y)$ = the lifetime FFC energy consumption of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y* to be used in application *a* in sector *s*,

$aSEC_{hp,g,c}(s,a,\mathrm{y},\mathrm{i})$ = the annual primary energy consumption in the i-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*, shipped in year *y* to be used in application *a* in sector *s*,

$ffc(y)$ = the primary-to-FFC conversion factor in year *y*,

$Mbc_{hp,c}(y)$ = the base case market share of units with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y*, and

$Mstd_{hp,c}(y)$ = the standards case market share of units with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y*.

DOE used the lifetime primary and FFC energy savings estimated for all motors shipped from 2015 through 2044 to calculate the total primary NES (NES_{src}) and the total FFC NES (NES_{FFC}) for the analysis period. The calculation used the following formulas:

$$NES_{src} = \sum_{hp} \sum_{g} \sum_{y=2015}^{2044} nSES_{hp,g}(y) \quad \text{Eq. 10.9}$$

$$NES_{FFC} = \sum_{hp} \sum_{g} \sum_{y=2015}^{2044} nFES_{hp,g}(y) \quad \text{Eq. 10.10}$$

where:

$nSES_{hp,g}(y)$ = the lifetime primary energy savings of all motors with capacity *hp* and configuration *g* shipped in year *y*, and

$nFES_{hp,g}(y)$ = the lifetime FFC energy savings of all motors with capacity hp and configuration g shipped in year y.

Once the shipments model provides the estimate of shipments and the primary-to-FFC factors convert primary energy consumption into FFC energy consumption, the key to the NES calculation is in calculating the unit annual primary energy consumption and market share distributions using inputs from the LCC analysis. The next section summarizes the inputs necessary for the NES calculation and then presents them individually; the following sections detail, respectively, how the unit lifetime primary energy consumption and the standards case efficiency distribution were calculated.

10.2.2 National Energy Savings Inputs

The NES model inputs include: (a) the parameters necessary to the unit energy consumption calculation, (b) the site-to-primary conversion factors, which enable the calculation of primary energy consumption from site energy use, and (c) shipment efficiency distributions in the base case. The list of NES model inputs is as follows:

1. motor capacity;
2. annual hours of operation;
3. operating load;
4. energy efficiency (at the operating load, and including efficiency adjustment due to repairs);
5. lifetime (probability) distribution;
6. electricity site-to-primary conversion factors;
7. electricity primary-to-FFC conversion factors, and
8. base case shipments efficiency distribution.

10.2.2.1 Motor Capacity

The motor capacity refers to the unit horsepower (hp) rating converted to kilowatts (kW) using the following conversion factor: 1 hp = 0.7457 kW.

10.2.2.2 Annual Hours of Operation

For the NIA, DOE considered the average annual hours of operation by sector, application and horsepower ranges described in Chapter 7, Section 7.2.6.

10.2.2.3 Operating Load

For the NIA, DOE considered the average operating load by application described in Chapter 7, Section 7.2.5.

10.2.2.4 Energy Efficiency

For the NIA, DOE considered the energy efficiencies by CSL presented in chapter 5. Those efficiencies, however, refer to motors performance when operating at full load. Since motors usually do not operate at full load, DOE adjusted the full load efficiencies to the part-load levels corresponding to the motors' weighted average operating load across applications, based on part load efficiency data from the engineering analysis (Chapter 5). Additionally, DOE assumed that: (a) motors are repaired on average after 32,000 hours of operation[f]; (b) repair costs vary depending on motor size, configuration, and efficiency; and (c) some motors have a slight decrease in their energy efficiency after undergoing a repair. (See Chapter 8, Section 8.2.2.1 for more details.) To account for the effects of repair on the energy efficiency of motors, DOE used a time-varying adjusting factor that reduces the initial motor efficiency over its lifetime (see Table 10.2.1).[g]

Table 10.2.1 Factors to Adjust Motor Initial Efficiency to its Efficiency after Repair

Year of Operation	< 40 hp	≥ 40 hp
1-5	1.00000	1.00000
6-10	0.99333	0.99667
11-15	0.98671	0.99334
16-20	0.98013	0.99003
21-25	0.97360	0.98673
26-30	0.96711	0.98344

10.2.2.5 Lifetime Distribution

For the NIA, DOE uses motor average lifetime in years derived from motor mechanical lifetime in hours (see Chapter 8, Section 8.2.3) and from annual operating hours (see Section 10.2.2.2).

10.2.2.6 Electricity Site-to-primary Conversion Factors

The site-to-primary conversion factor for electricity is the factor by which site energy (in kilowatt-hours (kWh)) is multiplied to obtain primary (source) energy (in Btu). Since the NES estimates the change in energy use of the resource (e.g., the power plant), this conversion factor is necessary to account for losses in generation, transmission, and distribution. After calculating energy consumption at the site of its use for the base case and the standards case, DOE multiplied these values by the conversion factor to obtain the primary energy consumption in each scenario and then calculated the corresponding savings, expressed in quads. This

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[f] Based on the annual operating hours by sector and application, this corresponds, on average, to a repair frequency of 5, 16, and 15 years in the industrial, commercial and agricultural sectors, respectively.

[g] Notwithstanding, DOE understands that the Electrical Apparatus Service Association (EASA) commented that a comprehensive study has been done by EASA and the Association of Electrical and Mechanical Trades to investigate the effect of repair and rewind on electric motor efficiency. EASA commented that the study showed that electric motor efficiency could be maintained by following the good practices identified in the study. (EASA, No.7 at pp. 1-2) Both EASA Standard AR100-2010 and the EASA/AEMT Rewind Study are available at http://www.easa.com/.

conversion permitted comparison across (source) fuels by taking into account the heat content of different fuels and the efficiency of different energy conversion processes. The annual conversion factor values are the U.S. averages for electricity generation for base load. DOE obtained these conversion factors using a variant of the *National Energy Modeling System* (NEMS)[7], called NEMS-BT.[h] Table 10.2.2 presents the average annual conversion factors DOE used.

10.2.2.7 Electricity Primary-to-Full-Fuel-Cycle Conversion Factors

DOE has historically presented NES in terms of primary energy savings. On August 18, 2011, DOE announced its intention to use full-fuel-cycle (FFC) measures of energy use and greenhouse gas and other emissions in the national impact analyses and emissions analyses included in future energy conservation standards rulemakings. (76 FR 51282) While DOE stated in that notice that it intended to use the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to conduct the analysis, it also said it would review alternative methods, including the use of NEMS. After evaluating both models and the approaches discussed in the August 18, 2011 notice, DOE has determined NEMS is a more appropriate tool for this specific use. Therefore, DOE intends to use the NEMS model, rather than the GREET model, to conduct future FFC analyses.For this preliminary analysis DOE used the methodology described in Appendix 10-C to calculate the primary-to-FFC conversion factors presented in Table 10.2.2.

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[h] For more information on NEMS, refer to Energy Information Administration (EIA) at http://www.eia.gov/ . A useful summary is the "National Energy Modeling System: An Overview 2003.5" EIA approved use of the name NEMS to describe only an official version of the model without any modification to code or data. However, the analysis for electric motors entailed some minor code modifications and the model run under policy scenarios that are variations on EIA assumptions. Consequently, the abbreviation "NEMS-BT" refers to the model as used by DOE's Building Technologies (BT) Program.

Table 10.2.2 Site-to-Primary and Primary-to-Full-Fuel-Cycle Conversion Factors

Year	Conversion Factors	
	Site-to-Primary (Btu/kWh)	**Primary-to-FFC** (quad/quad)
2015	6448.1	1.05853
2016	6443.3	1.05781
2017	6432.7	1.05776
2018	6426.7	1.05747
2019	6424.7	1.05705
2020	6435.6	1.05630
2021	6467.8	1.05516
2022	6482.8	1.05493
2023	6506.5	1.05456
2024	6533.7	1.05387
2025	6533.9	1.05363
2026	6537.5	1.05344
2027	6552.1	1.05349
2028	6555.0	1.05378
2029	6551.4	1.05408
2030	6548.0	1.05452
2031	6551.8	1.05474
2032	6551.1	1.05482
2033	6548.5	1.05498
2034	6550.0	1.05528
2035	6561.1	1.05535
2036-2044	6561.1	1.05535

10.2.2.8 Base Case Shipment Efficiency Distribution

To estimate market averages for unit energy consumption, DOE used statistical distributions of shipments across CSLs. For the base case, DOE developed such distributions from a database which DOE built upon data collected from internet catalogs from six major manufacturers and one large distributor (see Table 10.2.4), and considered those distributions to remain constant over the analysis period.

Table 10.2.3 Base Case Energy Efficiency Distributions

	Market Share in 2015					
	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B Electric Motors						
1-5 hp	5.5%	38.4%	44.4%	7.6%	3.0%	1.1%
6-20 hp	4.7%	35.3%	44.3%	8.7%	6.1%	0.8%
21-50 hp	5.3%	30.3%	47.8%	8.8%	7.9%	0.0%
51-100 hp	5.4%	28.6%	48.4%	10.1%	5.0%	2.5%
101-200 hp	5.4%	23.3%	53.9%	12.0%	4.8%	0.6%
201-500 hp	11.2%	49.9%	32.0%	5.9%	0.9%	0.0%
NEMA Design C Electric Motors						
1-5 hp	92.3%	7.7%	0.0%	0.0%	-	-
6-20 hp	100.0%	0.0%	0.0%	0.0%	-	-
21-50 hp	73.3%	26.7%	0.0%	0.0%	-	-
51-100 hp	50.0%	50.0%	0.0%	0.0%	-	-
101-200 hp	47.8%	30.4%	21.7%	0.0%	-	-
Fire Pump Electric Motors						
1-5 hp	94.9%	5.1%	0.0%	0.0%	0.0%	-
6-20 hp	100.0%	0.0%	0.0%	0.0%	0.0%	-
21-50 hp	81.7%	5.5%	12.8%	0.0%	0.0%	-
51-100 hp	80.6%	2.0%	17.3%	0.0%	0.0%	-
101-200 hp	73.5%	17.6%	8.8%	0.0%	0.0%	-
201-500 hp	75.0%	25.0%	0.0%	0.0%	0.0%	-

10.2.3 Unit Annual Primary Energy Consumption

The unit annual primary energy consumption expresses an estimate of the amount of primary energy that a motor of a given equipment class, meeting the efficiency level of a given CSL, and shipped in a given year to a given sector to be used in a given application will consume in each year of its lifetime. It refers to the variable $aSEC_{hp,g,c}$ in Eq. 10.4 and Eq. 10.8, and is evaluated from the following formulas:

$$aSEC_{hp,g,c}(s,a,y,i) = UEC_{hp,g,c}(s,a,i) \cdot O_{hp}(s,i) \cdot StoS(y+i-1) \qquad \text{Eq. 10.11}$$

$$UEC_{hp,g,c}(s,a,i) = \frac{(hp \times 0.757) \cdot Load(a) \cdot Hours_{hp}(s,a)}{fEff_c \cdot aEff_{hp,c}(a) \cdot Conserv(i)} \qquad \text{Eq. 10.12}$$

where:

$aSEC_{hp,g,c}(s,a,y,i)$ = the annual primary energy consumption in the i-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y* to be used in application *a* in sector *s*,

$UEC_{hp,g,c}(s,a,i)$ = the annual site energy consumption in the *i*-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c* used for application *a* in sector *s*,

$StoS(t)$ = the site-to-primary conversion factor projected to year *t*,
$O_{hp}(s,i)$ = the probability that a unit with capacity *hp*, used in sector *s* will be in operation in the *i*-th year of its lifetime,
hp = the unit capacity (in horse-power),
$Load(a)$ = the typical load of a motor used in application a,
$Hours_{hp}(s,a)$ = annual hours of operation of a unit with capacity *hp*, used for application *a* in sector *s*,
$fEff_c$ = the full-load efficiency of a unit with efficiency level at CSL *c*,
$aEff_{hp,c}(a)$ = the factor used to adjust the full-load efficiency of a unit with capacity *hp* and efficiency level at CSL *c* used in application *a* to the efficiency corresponding to its typical load, and
$Conserv(i)$ = the energy efficiency conservation factor used to reduce the unit initial efficiency to the efficiency it is estimated to present in its *i*-th year of operation due to repairs.

10.2.4 Standards Case Shipment Efficiency Distribution

Section 10.2.2.8 described the market efficiency distribution across CSLs that DOE used for the base case scenario. For the standards case, DOE relied on the base case distribution and calculated the efficiency distributions from the following expression (roll-up scenario approach):

$$Mstd_{hp,c} = \begin{cases} 0, \ c < c^* \\ \sum_{j=1}^{c^*} Mbc_{hp,j}\,, \ c = c^* \\ Mbc_{hp,c}, \ c > c^* \end{cases} \qquad \text{Eq. 10.13}$$

where:

$Mstd_{hp,c}(y)$ = the standards case market share of units with capacity *hp* and efficiency level at CSL *c* shipped in year *y*,
$Mbc_{hp,c}(y)$ = the base case market share of units with capacity *hp* and efficiency level at CSL *c* shipped in year *y*, and
c^* = the selected CSL.

10.3 NET PRESENT VALUE

DOE estimated the national financial impact on consumers from the imposition of new energy efficiency standards using a national NPV accounting component in the national impact spreadsheet. DOE combined the output of the shipments model with energy and financial data from the LCC analysis to calculate an annual stream of costs and benefits resulting from candidate electric motors energy efficiency standards. It discounted this time series to the year 2012 and summed the result, yielding the national NPV.

10.3.1 Net Present Value Overview

The NPV is the present value of the incremental economic impact of a candidate standard level. Like the NES, the NPV calculation started with motor shipments, estimates of which are outputs from the shipments model. DOE then obtained motor input data and average electricity costs from the LCC analysis, and estimated motor non-energy and energy lifetime costs. For both a base case and a standards case, DOE first calculated the amount spent on motor purchases and lifetime repairs,[i] and then calculated the lifetime energy cost by applying the average electricity prices to the electricity used by motors shipped at each year of the analysis period over their lifetime. In the standards case, more expensive yet more efficient units replace the less efficient ones. Thus, in the standards case, the market average lifetime energy cost per unit is lower relative to the base case, while the lifetime equipment non-energy costs are greater. When the energy cost decrease outweighs the non-energy costs increase, the standards have a positive impact on consumers; otherwise, the standards impact is negative.

DOE discounted the non-energy and energy expenses with motors using a national average discount factor. The discount factor converts a future expense to a present value. The difference in present value of the non-energy and energy expenses between the base case and the standards case scenarios leads to the national NPV impact. DOE calculated the NPV impact in 2012 from motors that were purchased between the effective date of the standard and 2044, inclusive, to calculate the total NPV impact from purchases during the analysis period. Mathematically, the NPV is the value in the present time of a time series of costs and savings, described by the equation:

$$NPV = PVS - PVC \qquad \text{Eq. 10.14}$$

where:

PVS = the present value of electricity cost savings, and
PVC = the present value of incremental non-energy costs.

PVS and PVC are determined according to the following expressions:

$$PVS = \sum_{hp} \sum_{g} \sum_{y=2015}^{2044} nECS_{hp,g}(y) \cdot (1+r)^{2012-y} \qquad \text{Eq. 10.15}$$

$$nECS_{hp,g}(y) = \sum_s \sum_a \left(nNCbc_{hp,g}(s,a,y) - nNCst_{hp,g}(s,a,y) \right) \qquad \text{Eq. 10.16}$$

$$nNCbc_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum_c \left(uNC_{hp,g,c}(s,a,y) \cdot Mbc_{hp,c}(y) \right) \qquad \text{Eq. 10.17}$$

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[i] DOE did not account for installation costs and maintenance costs. Although these costs might have significant impacts on a user's budget, they do not vary with the efficiency level of the motor and therefore would have no impact in the difference of non-energy costs between the base case and the standards case scenarios.

$$nNCst_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum\nolimits_c \left(uNC_{hp,g,c}(s,a,y) \cdot Mst_{hp,c}(y) \right) \qquad \text{Eq. 10.18}$$

and:

$$PVS = \sum_{hp} \sum_{g} \sum_{y=2015}^{2044} nIEC_{hp,g}(y) \times (1+r)^{2012-y} \qquad \text{Eq. 10.19}$$

$$nIEC_{hp,g}(y) = \sum\nolimits_s \sum\nolimits_a \left(nQCbc_{hp,g}(s,a,y) - nQCst_{hp,g}(s,a,y) \right) \qquad \text{Eq. 10.20}$$

$$nQCbc_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum\nolimits_c \left(uQC_{hp,g,c}(s,a,y) \cdot Mbc_{hp,c}(y) \right) \qquad \text{Eq. 10.21}$$

$$nQCst_{hp,g}(s,a,y) = Shp_{hp,g}(s,y) \cdot A(a) \cdot \sum\nolimits_c \left(uQC_{hp,g,c}(s,a,y) \cdot Mst_{hp,c}(y) \right) \qquad \text{Eq. 10.22}$$

where:

$nECS_{hp,g}(y)$ = the lifetime energy cost savings of all motors shipped in year *y*,
$nNCbc_{hp,g}(s,a,y)$ = the base case, lifetime energy cost of all motors shipped in year *y*,
$nNCst_{hp,g}(s,a,y)$ = the standards case, lifetime energy cost of all motors shipped in year *y*,
$uNC_{hp,g,c}(s,a,y)$ = the lifetime energy cost of a unit with efficiency level at CSL *c* shipped in year *y*,
$nIECS_{hp,g}(y)$ = the lifetime incremental equipment non-energy costs of all motors shipped in year *y*,
$nQCbc_{hp,g}(s,a,y)$ = the base case, lifetime equipment non-energy costs of all motors shipped in year *y*,
$nQCst_{hp,g}(s,a,y)$ = the standards case, lifetime equipment non-energy costs of all motors shipped in year *y*,
$uQC_{hp,g,c}(s,a,y)$ = the lifetime equipment non-energy costs of a unit with efficiency level at CSL *c* shipped in year *y*,
$Shp_{hp,g}(s,y)$ = the number of motors with capacity *hp* and configuration *g* shipped in year *y* to sector *s*,
$Mbc_{hp,c}(y)$ = the base case market share of units with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y*, and
$Mst_{hp,c}(y)$ = the standards case market share of units with capacity *hp*, configuration *g* and efficiency level at CSL *c* shipped in year *y*, and
r = the discount rate.

Once the shipments model provides the estimate of shipments, the following sections describe the inputs necessary for the NPV calculation and detail how unit lifetime energy and non-energy costs are calculated.

10.3.2 Net Present Value Inputs

The NPV model inputs include: (a) the parameters that help calculate the unit energy consumption, (b) the electricity prices that enable the calculation of energy costs, (c) equipment first- and non-energy operating costs, and (d) shipment efficiency distributions for the base case. The list of NPV model inputs is as follows:

1. motor capacity;
2. annual hours of operation;
3. operating load;
4. energy efficiency (at the operating load, and including efficiency degradation due to repairs);
5. manufacturer selling price (MSP) and price overheads;
6. motor weight and shipment costs;
7. repair costs;
8. lifetime (probability) distribution;
9. electricity price;
10. discount rate;
11. base case shipments efficiency distribution.

Inputs 1-4, 8 and 11 have already been introduced in Section 10.2.2 and therefore are not described in this section.

10.3.2.1 Manufacturer Selling Price and Price Overheads

The Engineering Analysis, chapter 5 provides MSP data for eight representative units. DOE developed scaling relationships to estimate MSP for all covered equipment classes.

For each CSL, DOE first established an index to describe how MSP varies by pole and enclosure across horsepower ratings. DOE established these indices using statistical estimates derived from a database of motor prices which DOE built upon data collected from internet catalogs from six major manufacturers and one large distributor (see Table 10.3.1 for an example of these indices estimated for Designs A and B motors, CSL 1.).

Table 10.3.1 Example of Manufacturer Selling Price Scaling Index Across Poles and Enclosures (Designs A and B motors, CSL 1)

	Enclosed				Open			
hp	**2 poles**	**4 poles**	**6 poles**	**8 poles**	**2 poles**	**4 poles**	**6 poles**	**8 poles**
1	0.9729	1.0000	1.0271	1.0543	0.9215	0.9487	0.9758	1.0030
1.5	0.9623	1.0000	1.0377	1.0753	0.8911	0.9288	0.9665	1.0041
2	0.9533	1.0000	1.0467	1.0934	0.8650	0.9117	0.9584	1.0051
3	0.9385	1.0000	1.0615	1.1230	0.8222	0.8837	0.9452	1.0067
5	0.9177	1.0000	1.0823	1.1647	0.7620	0.8443	0.9266	1.0090
7.5	0.9009	1.0000	1.0991	1.1983	0.7134	0.8125	0.9117	1.0108
10	0.8896	1.0000	1.1104	1.2208	0.6809	0.7912	0.9016	1.0120
15	0.8755	1.0000	1.1245	1.2491	0.6399	0.7645	0.8890	1.0136
20	0.8669	1.0000	1.1331	1.2662	0.6153	0.7484	0.8814	1.0145
25	0.8612	1.0000	1.1388	1.2776	0.5988	0.7376	0.8764	1.0151
30	0.8571	1.0000	1.1429	1.2857	0.5870	0.7299	0.8727	1.0156
40	0.8517	1.0000	1.1483	1.2966	0.5712	0.7196	0.8679	1.0162
50	0.8482	1.0000	1.1518	1.3036	0.5612	0.7130	0.8648	1.0166
60	0.8458	1.0000	1.1542	1.3084	0.5542	0.7084	0.8626	1.0168
75	0.8433	1.0000	1.1567	1.3134	0.5470	0.7037	0.8604	1.0171
100	0.8407	1.0000	1.1593	1.3185	0.5396	0.6989	0.8581	1.0174
125	0.8392	1.0000	1.1608	1.3217	0.5350	0.6959	0.8567	1.0175
150	0.8381	1.0000	1.1619	1.3238	0.5319	0.6939	0.8558	1.0177
200	0.8367	1.0000	1.1633	1.3265	0.5280	0.6913	0.8545	1.0178
250	0.8359	1.0000	1.1641	1.3282	0.5256	0.6897	0.8538	1.0179
300	0.8354	1.0000	1.1646	1.3293	0.5240	0.6887	0.8533	1.0180
350	0.8350	1.0000	1.1650	1.3301	0.5229	0.6879	0.8530	1.0180
400	0.8347	1.0000	1.1653	1.3307	0.5220	0.6873	0.8527	1.0180
450	0.8344	1.0000	1.1656	1.3312	0.5213	0.6869	0.8525	1.0181
500	0.8342	1.0000	1.1658	1.3315	0.5208	0.6865	0.8523	1.0181

For each equipment class group and CSL level, using the MSP from the engineering analysis, DOE developed an equation to scale the MSP of a 4-pole enclosed motor across motor horsepower. The relations derived from power law regressions, with $0.981 < R^2 < 0.999$, are expressed by the following equation:

$$MSP_{4,e}(hp) = a.(hp)^b \qquad \text{Eq. 10.23}$$

where:

$MSP_{4,e}(hp)$ = the MSP of a 4-pole enclosed unit with capacity hp, and
a and b = parameters calibrated by equipment class group and CSL.

Table 10.3.2 provides *a* and *b* values for all CSLs by equipment class group. As mentioned in Chapter 5, the MSPs of fire pump electric motors are the same as the ones used for NEMA Designs A and B motors.

Table 10.3.2 Manufacturer Selling Price Scaling Equation Parameters across Horsepower

NEMA Design A and B motors, and fire pump electric motors						
	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
a	1.133E+02	1.110E+02	1.237E+02	1.256E+02	1.806E+02	2.001E+02
b	6.241E-01	6.657E-01	6.702E-01	6.853E-01	6.826E-01	6.825E-01
NEMA Design C motors						
	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
a	1.133E+02	1.20E+02	1.98E+02	2.11E+02	-	-
b	6.52E-01	6.70E-01	5.93E-01	5.97E-01	-	-

Figure 10.3.1 shows an example of the scaling relations across horsepower for NEMA Designs A and B motors and fire pump electric motors.

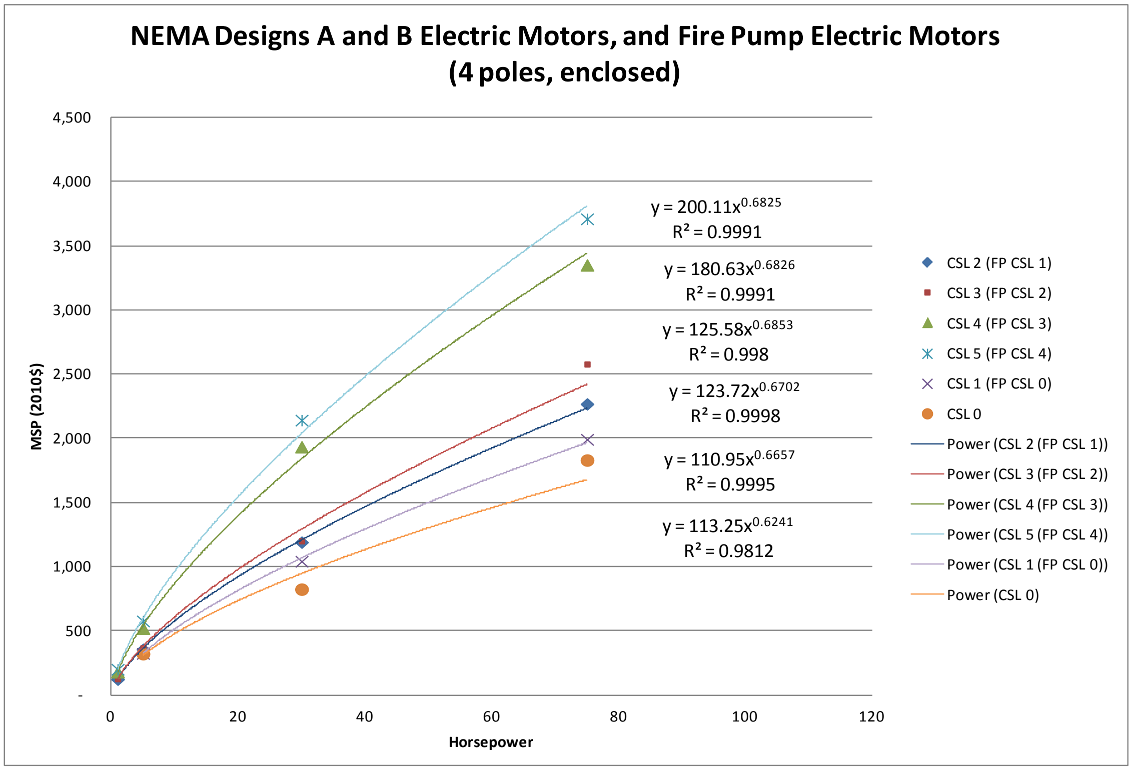

Figure 10.3.1 Example of Manufacturer Selling Price Scaling Equation across Horsepower

Using the scaling relations across horsepower, DOE estimated the MSP for 4 poles enclosed motors at each CSL, for each equipment class group and all horsepower ratings. DOE then used the index presented in Table 10.3.1 to obtain MSP estimates for all equipment classes. The final MSP estimates are available in the NIA spreadsheet.

In the NIA, an average baseline and incremental markup are applied to derive equipment prices from the MSPs. Chapter 6 provides more details on the markups calculation.

10.3.2.2 Projection of Future Equipment Prices

For reasons discussed in chapter 8 of the TSD (section 8.2.1.1), DOE used a constant price assumption for the default projection in the NIA. To investigate the impact of different equipment price projections on the consumer net present value (NPV) for the considered CSLs for electric motors, DOE also considered two alternative price trends. One of these used an exponential fit on the deflated price index for electric motors, and the other is based on *AEO2011*'s projected price index for industrial equipment. Details on how these alternative price trends were developed are in Appendix 10-B, which also presents the results of the sensitivity analysis.

10.3.2.3 Motor Weight and Shipment Costs

DOE used the same methodology described in section 10.3.2.1 to derive weight data for all covered equipment classes based on outputs from the engineering analysis, chapter 5.

For each CSL, DOE established an index to describe how motor weight varies by pole and enclosure across horsepower ratings. DOE established these indices using statistical estimates derived from a database of motor weights which DOE built upon data collected from internet catalogs from six major manufacturers and one large distributor (see Table 10.3.3 for an example of these indices estimated for Designs A and B motors, CSL 1.).

Table 10.3.3 Example of Weight Scaling Index Across Poles and Enclosures (Designs A and B motors, CSL 1)

	Enclosed				Open			
hp	**2 poles**	**4 poles**	**6 poles**	**8 poles**	**2 poles**	**4 poles**	**6 poles**	**8 poles**
1	0.977	1.000	1.023	1.045	0.936	0.958	0.981	1.003
1.5	0.968	1.000	1.032	1.063	0.910	0.941	0.973	1.005
2	0.960	1.000	1.040	1.080	0.887	0.926	0.966	1.006
3	0.947	1.000	1.053	1.107	0.848	0.901	0.955	1.008
5	0.926	1.000	1.074	1.148	0.790	0.864	0.938	1.011
7.5	0.909	1.000	1.091	1.182	0.741	0.832	0.923	1.014
10	0.897	1.000	1.103	1.206	0.707	0.810	0.913	1.016
15	0.881	1.000	1.119	1.238	0.662	0.781	0.899	1.018
20	0.871	1.000	1.129	1.257	0.634	0.762	0.891	1.020
25	0.865	1.000	1.135	1.271	0.615	0.750	0.885	1.021
30	0.860	1.000	1.140	1.280	0.601	0.741	0.881	1.021
40	0.853	1.000	1.147	1.294	0.582	0.729	0.876	1.022
50	0.849	1.000	1.151	1.302	0.570	0.721	0.872	1.023
60	0.846	1.000	1.154	1.308	0.561	0.715	0.869	1.024
75	0.843	1.000	1.157	1.314	0.552	0.710	0.867	1.024
100	0.840	1.000	1.160	1.321	0.543	0.704	0.864	1.025
125	0.838	1.000	1.162	1.325	0.537	0.700	0.862	1.025
150	0.836	1.000	1.164	1.328	0.534	0.697	0.861	1.025
200	0.834	1.000	1.166	1.331	0.529	0.694	0.860	1.025
250	0.833	1.000	1.167	1.333	0.526	0.692	0.859	1.025
300	0.833	1.000	1.167	1.335	0.524	0.691	0.858	1.026
350	0.832	1.000	1.168	1.336	0.522	0.690	0.858	1.026
400	0.832	1.000	1.168	1.337	0.521	0.689	0.857	1.026
450	0.831	1.000	1.169	1.337	0.520	0.689	0.857	1.026
500	0.831	1.000	1.169	1.338	0.519	0.688	0.857	1.026

For each CSL level and equipment class group, using the weight data from the engineering analysis, DOE developed an equation to scale the weight of a 4-pole enclosed motor by horsepower. The relationships, derived from power law regressions ($0.992 < R^2 < 0.999$), are expressed by the following equations:

$$Weight_{4,e}(hp) = a'.(hp)^{b'} \qquad \text{Eq. 10.24}$$

where:

$Weight_{4,e}(hp)$ = the weight of a 4-pole enclosed unit with capacity *hp*, and
a' and b' = parameters calibrated by equipment class group and CSL.

Table 10.3.4 below provides *a'* and *b'* values for all CSLs by equipment class group. As mentioned in Chapter 5, the weights of fire pump electric motors are the same as the ones used for NEMA Designs A and B motors.

Table 10.3.4 Weight Scaling Equation Parameters across Horsepower

NEMA Designs A and B motors, and Fire Pump Electric Motors						
	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
a'	2.285E+01	2.215E+01	2.878E+01	2.720E+01	3.352E+01	3.520E+01
b'	7.837E-01	8.441E-01	8.144E-01	8.298E-01	8.230E-01	8.289E-01
NEMA Design C electric motors						
	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
a'	2.285E+01	2.55E+01	3.26E+01	3.37E+01	-	-
b'	8.241E-01	8.40E-01	7.86E-01	7.86E-01	-	-

Using the scaling relations across horsepower, DOE estimated the weight for 4-pole enclosed motors at each CSL, for each equipment class group and all horsepower ratings. DOE then used the index presented in Table 10.3.3 to obtain weight estimates for all equipment classes. The final weight estimates are available in the NIA spreadsheet.

10.3.2.4 Repair Costs

DOE calculated the repair costs in two steps. First DOE considered the cost of one repair event by motor horsepower, configuration and efficiency level described in chapter 8, section 8.2.2.4. Then DOE calculated the lifetime repair cost of a motor with a given horsepower, configuration and efficiency level, operating in a certain sector, as the present-value of a stream of repair events occurring every 5, 15 or 16 years (depending on the sector) after the motor's warranty period and during 30 years. For the calculation of the present-value DOE used the two discount rates discussed in section 10.3.2.6. However, DOE understands that not all motors will operate for 30 years. Consequently, in the calculation of present value, DOE multiplied the cost of each repair event by the probability that the motor will be in operation by that time, according to its horsepower rating and the sector where the motor is used. (See section 10.2.2.5 above for more about lifetime distributions.)

10.3.2.5 Electricity Prices

For the NIA, DOE considered the electricity prices by sector as national weighted averages of the regional electricity prices described in Chapter 8 of the TSD, section 8.2.2.2.

10.3.2.6 Discount Rate

The discount rate expresses the time value of money. DOE used real discount rates of 3 percent and 7 percent, as established by the U.S. Office of Management and Budget (OMB) guidelines on regulatory analysis.[8] The discount rates DOE used in the LCC are distinct from those it used in the NPV calculations, in that the NPV discount rates represent the societal rate of return on capital investment, whereas LCC discount rates reflect the owner cost of capital and the financial environment of electric utilities and commercial and industrial entities.

10.3.3 Unit Lifetime Energy Cost

The unit lifetime energy cost expresses an estimate of the market average expense with electricity that owners of all motors of a given equipment class, shipped in a given year, will have to operate these motors over their lifetime. It refers to the variable $uLTNC_{hp,g,c}$ in Eq. 10.17 and Eq. 10.18, and is evaluated as the sum of the annual energy cost over the motor lifetime:

$$uLTNC_{hp,g,c}(s,a,y) = \sum_{i=1}^{30}\left(UEC_{hp,g,c}(s,a,i)\cdot nP(y+i-1)\cdot(1+r)^{1-i}\cdot O_{hp}(s,i)\right) \qquad \text{Eq. 10.25}$$

$$UEC_{hp,g,c}(s,a,i) = \frac{(hp \times 0.757)\cdot Load(a)\cdot Hours_{hp}(s,a)}{fEff_{c}\cdot aEff_{hp,c}(a)\cdot Conserv(i)} \qquad \text{Eq. 10.26}$$

where:

$uLTNC_{\mathrm{hp,g},c}(s,a,y)$ = the lifetime energy cost of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*, shipped in year *y* and used for application *a* in sector *s*,
$UEC_{\mathrm{hp,g},c}(s,a,i)$ = the site energy consumption in the *i*-th year of operation of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c* used for application *a* in sector *s*,
$nP(\mathrm{t})$ = the national average electricity price in year *t*,
r = the discount rate,
$O_{hp}(s,i)$ = the probability that a unit with capacity *hp*, used in sector *s* will be in operation in the *i*-th year of its lifetime,
hp = the unit capacity (in horse-power),
$Load(a)$ = the typical load of a motor used in application *a*,
$Hours_{hp}(s,a)$ = annual hours of operation of a unit with capacity *hp*, used for application *a* in sector *s*,
$fEff_{c}$ = the full-load efficiency of a unit with efficiency level at CSL *c*,
$aEff_{hp,c}(a)$ = the factor used to adjust the full-load efficiency of a unit with capacity *hp* and efficiency level at CSL *c* used in application *a* to the efficiency corresponding to its typical load, and
$Conserv(i)$ = the energy efficiency conservation factor used to reduce the unit initial efficiency to the efficiency it is estimated to present in its *i*-th year of operation due to repairs.

10.3.4 Unit Lifetime Non-Energy Costs

The unit lifetime non-energy costs expresses an estimate of the market average expenses that owners of all motors of a given equipment class, shipped in a given year, will have with purchasing and repairing these motors over their lifetime. It refers to the variable $uLTQC_{hp,g,c}$ in Eq. 10.21 and Eq. 10.22, and is evaluated as the sum of the motor initial costs with the sum of all repair costs over the motor lifetime:

$$uLTQC_{hp,g,c}(s,y) = uIC_{hp,g,c}(y) + \sum_{i=1}^{30}\left(uRC_{hp,g,c}(i)\cdot(1+r)^{1-i}\cdot O_{hp}(s,i)\right) \qquad \text{Eq. 10.27}$$

$$uIC_{hp,g,c}(y) = kP(y)\cdot uQC_{hp,g,c} + uSC_{hp,g,c} \qquad \text{Eq. 10.28}$$

$$uQC_{hp,g,c} = MSP_{hp,g,0}\cdot(OVHbase - OVHinc) + MSP_{hp,g,c}\cdot OVHinc \qquad \text{Eq. 10.29}$$

$$uSC_{hp,g,c} = uWeight_{hp,g,c}\cdot sP \qquad \text{Eq. 10.30}$$

$$uRC_{hp,g,c}(i) = \begin{cases} uRCepact_{hp,g}\cdot kR_c, i = 6, 11, 16, 21, 26 \\ 0, i \neq 6, 11, 16, 21, 26 \end{cases} \qquad \text{Eq. 10.31}$$

where:

$uLTQC_{\mathrm{hp,g},c}(s,a,y)$ = the lifetime non-energy costs of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*, shipped in year *y* to sector *s*,
$uIC_{\mathrm{hp,g},c}(y)$ = the total installed cost of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*, shipped in year *y*,
$\mathrm{kP(y)}$ = the price-trend multiplier for a unit shipped in year *y*,
$uQC_{\mathrm{hp,g},c}$ = the retail price of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*,
$uSC_{\mathrm{hp,g},c}$ = the shipment cost of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*,
$MSP_{\mathrm{hp,g},c}$ = the manufacturer price of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*,
$\mathrm{OVHbase}$ = the baseline price overhead,
OVHinc = the incremental price overhead,
$uWeight_{\mathrm{hp,g},c}$ = the weight of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c*,
sP = the per pound shipment cost,
$uRC_{\mathrm{hp,g},c}(i)$ = the repair cost of a unit with capacity *hp*, configuration *g* and efficiency level at CSL *c* in its *i*-th year of operation,
$\mathrm{uRCepact}_{\mathrm{hp,g}}$ = the repair cost of a unit with capacity *hp*, configuration *g* and efficiency level below the applicable under the Energy Policy Act of 1992 (EPACT 1992),
kR_c = the repair cost adder of a unit with efficiency level at CSL *c* relative to the repair cost of a unit with efficiency level below EPACT 1992,
$\mathrm{O}_{\mathrm{hp}}(s,i)$ = the probability that a unit with capacity *hp*, used in sector *s* will be in operation in the *i*-th year of its lifetime, and
r = the discount rate.

10.4 RESULTS

10.4.1 National Energy Savings and Net Present Value for Candidate Standard Levels

DOE evaluated the NES and NPV using the inputs and methodologies described in sections 10.2 and 10.3 for each CSL within each equipment class group. Table 10.4.1 to Table 10.4.6 present NES and NPV results for each equipment class group, disaggregated by sector and motor horsepower ranges. Table 10.4.7 and Table 10.4.8 summarize the NES and NPV results for all equipment class groups.

Table 10.4.1 National Energy Savings for NEMA Designs A and B Motors (trillion Btu)

Primary	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
Industry					
1-5 hp	139.8	494.5	782.4	1100.8	1400.3
6-20 hp	106.9	455.1	743.9	1072.7	1202.6
21-50 hp	66.6	275.9	486.8	703.7	703.7
51-100 hp	83.4	405.4	721.5	1060.6	1377.4
101-200 hp	64.2	339.2	688.1	1046.7	1390.5
201-500 hp	53.6	489.4	828.4	1147.9	1466.1
Commercial					
1-5 hp	129.9	459.4	726.8	1022.6	1300.9
6-20 hp	177.6	756.0	1236.0	1782.3	1998.1
21-50 hp	94.8	392.4	692.3	1000.7	1000.7
51-100 hp	20.3	98.5	175.3	257.6	334.6
101-200 hp	11.8	62.6	126.9	193.1	256.5
201-500 hp	15.5	141.8	239.9	332.5	424.7
Agriculture					
1-5 hp	0.0	0.0	0.0	0.0	0.0
6-20 hp	0.0	0.0	0.0	0.0	0.0
21-50 hp	0.0	0.0	0.0	0.0	0.0
51-100 hp	4.7	22.8	40.5	59.6	77.3
101-200 hp	1.5	8.1	16.3	24.8	33.0
201-500 hp	1.4	12.9	21.8	30.1	38.5
Full-Fuel Cycle	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
Industry					
1-5 hp	147.5	521.8	825.5	1161.4	1477.5
6-20 hp	112.8	480.1	784.9	1131.8	1268.9
21-50 hp	70.3	291.2	513.7	742.4	742.4
51-100 hp	88.0	427.7	761.3	1119.0	1453.3
101-200 hp	67.8	357.9	726.1	1104.4	1467.1
201-500 hp	56.6	516.4	874.1	1211.2	1547.0

Commercial					
1-5 hp	137.0	484.7	766.9	1078.9	1372.6
6-20 hp	187.4	797.7	1304.2	1880.5	2108.3
21-50 hp	100.0	414.1	730.5	1055.9	1055.9
51-100 hp	21.4	103.9	184.9	271.8	353.0
101-200 hp	12.5	66.0	133.9	203.7	270.6
201-500 hp	16.4	149.6	253.2	350.8	448.1
Agriculture					
1-5 hp	0.0	0.0	0.0	0.0	0.0
6-20 hp	0.0	0.0	0.0	0.0	0.0
21-50 hp	0.0	0.0	0.0	0.0	0.0
51-100 hp	4.9	24.0	42.8	62.8	81.6
101-200 hp	1.6	8.5	17.2	26.2	34.8
201-500 hp	1.5	13.6	23.0	31.8	40.6

Table 10.4.2 Net Present Value for NEMA Designs A and B Motors (million 2011$)

7% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
Industry					
1-5 hp	345.5	707.1	1093.4	-1302.5	-1836.1
6-20 hp	263.5	809.4	1235.7	-586.2	-765.1
21-50 hp	145.8	460.6	759.9	-79.5	-79.5
51-100 hp	168.7	701.0	1135.6	19.8	-11.1
101-200 hp	113.1	535.2	1024.8	248.7	365.5
201-500 hp	67.3	675.6	1171.6	727.3	975.4
Commercial					
1-5 hp	387.2	685.8	1143.5	-3164.1	-4253.3
6-20 hp	495.3	1337.4	2016.7	-3786.0	-4491.3
21-50 hp	238.5	665.0	1041.9	-1821.9	-1821.9
51-100 hp	45.5	175.7	264.8	-390.7	-515.8
101-200 hp	19.5	89.7	163.6	-111.3	-134.6
201-500 hp	18.3	187.5	314.1	67.1	101.7
Agriculture					
1-5 hp	0.0	0.0	0.0	0.0	0.0
6-20 hp	0.0	0.0	0.0	0.0	0.0
21-50 hp	0.0	0.0	0.0	0.0	0.0
51-100 hp	7.4	25.0	33.3	-133.1	-174.9
101-200 hp	1.6	6.7	11.0	-34.8	-44.3
201-500 hp	0.6	8.1	13.3	-21.0	-25.1

3% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
Industry					
1-5 hp	757.7	1650.9	2528.7	-1765.0	-2606.6
6-20 hp	585.3	1884.3	2900.4	-245.6	-489.2
21-50 hp	342.8	1132.0	1894.3	534.7	534.7
51-100 hp	400.9	1710.5	2827.8	1071.5	1309.7
101-200 hp	283.2	1365.9	2661.9	1598.7	2178.0
201-500 hp	179.0	1758.4	3060.8	2579.4	3387.4
Commercial					
1-5 hp	915.3	1918.4	3121.2	-4528.1	-6203.4
6-20 hp	1197.0	3630.7	5601.2	-4422.9	-5432.5
21-50 hp	596.9	1851.6	3017.5	-1852.5	-1852.5
51-100 hp	117.3	482.6	768.4	-327.0	-442.3
101-200 hp	59.2	286.3	547.3	159.7	235.2
201-500 hp	62.9	614.1	1040.3	756.7	997.7
Agriculture					
1-5 hp	0.0	0.0	0.0	0.0	0.0
6-20 hp	0.0	0.0	0.0	0.0	0.0
21-50 hp	0.0	0.0	0.0	0.0	0.0
51-100 hp	19.8	75.5	113.1	-173.7	-230.0
101-200 hp	5.4	24.8	45.6	-26.8	-32.3
201-500 hp	3.2	34.0	57.7	6.6	11.8

Table 10.4.3 National Energy Savings for NEMA Design C Motors (trillion Btu)

Primary	**CSL 1**	**CSL 2**	**CSL 3**
Industry			
1-5 hp	1.579	2.200	2.846
6-20 hp	1.551	2.232	2.889
21-50 hp	0.905	1.383	1.869
51-100 hp	0.881	1.714	2.478
101-200 hp	0.927	1.651	2.415
Commercial			
1-5 hp	1.603	2.232	2.887
6-20 hp	2.783	4.004	5.184
21-50 hp	1.177	1.798	2.430
51-100 hp	0.228	0.444	0.642
101-200 hp	0.175	0.312	0.457
Agriculture			
1-5 hp	0.000	0.000	0.000
6-20 hp	0.000	0.000	0.000
21-50 hp	0.000	0.000	0.000

51-100 hp	0.044	0.085	0.123
101-200 hp	0.019	0.034	0.049
Full-Fuel Cycle	**CSL 1**	**CSL 2**	**CSL 3**
Industry			
1-5 hp	1.667	2.322	3.003
6-20 hp	1.637	2.355	3.048
21-50 hp	0.955	1.459	1.972
51-100 hp	0.930	1.808	2.614
101-200 hp	0.978	1.742	2.548
Commercial			
1-5 hp	1.691	2.356	3.047
6-20 hp	2.936	4.225	5.470
21-50 hp	1.242	1.897	2.564
51-100 hp	0.241	0.469	0.678
101-200 hp	0.185	0.329	0.482
Agriculture			
1-5 hp	0.000	0.000	0.000
6-20 hp	0.000	0.000	0.000
21-50 hp	0.000	0.000	0.000
51-100 hp	0.046	0.090	0.130
101-200 hp	0.020	0.035	0.052

Table 10.4.4 Net Present Value for NEMA Design C Motors (million 2011$)

7% discount rate	**CSL 1**	**CSL 2**	**CSL 3**
Industry			
1-5 hp	2.890	-2.629	-2.831
6-20 hp	2.771	0.185	0.480
21-50 hp	1.664	1.256	1.724
51-100 hp	1.537	2.025	2.877
101-200 hp	1.599	2.617	3.515
Commercial			
1-5 hp	2.980	-6.705	-7.376
6-20 hp	4.681	-3.731	-3.889
21-50 hp	1.777	-0.702	-0.719
51-100 hp	0.362	0.298	0.439
101-200 hp	0.256	0.414	0.542
Agriculture			
1-5 hp	0.000	0.000	0.000
6-20 hp	0.000	0.000	0.000
21-50 hp	0.000	0.000	0.000
51-100 hp	0.026	-0.044	-0.063

101-200 hp	0.012	0.016	0.014
3% discount rate	**CSL 1**	**CSL 2**	**CSL 3**
Industry			
1-5 hp	6.679	-3.290	-3.313
6-20 hp	6.546	2.246	3.298
21-50 hp	4.080	3.773	5.112
51-100 hp	3.814	5.543	7.870
101-200 hp	4.107	6.814	9.310
Commercial			
1-5 hp	7.983	-9.279	-9.683
6-20 hp	13.113	-0.769	0.683
21-50 hp	5.257	1.589	2.535
51-100 hp	1.055	1.278	1.855
101-200 hp	0.829	1.389	1.902
Agriculture			
1-5 hp	0.000	0.000	0.000
6-20 hp	0.000	0.000	0.000
21-50 hp	0.000	0.000	0.000
51-100 hp	0.108	0.028	0.040
101-200 hp	0.054	0.084	0.104

Table 10.4.5 National Energy Savings for Fire Pump Electric Motors (trillion Btu)

Primary	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**
Industry				
1-5 hp	0.006	0.008	0.011	0.013
6-20 hp	0.185	0.258	0.333	0.361
21-50 hp	0.072	0.106	0.141	0.141
51-100 hp	1.169	1.655	2.216	2.714
101-200 hp	0.954	1.475	1.988	2.457
201-500 hp	0.708	1.190	1.616	2.038
Commercial				
1-5 hp	0.002	0.004	0.005	0.006
6-20 hp	0.005	0.006	0.008	0.009
21-50 hp	0.002	0.003	0.004	0.004
51-100 hp	0.000	0.001	0.001	0.001
101-200 hp	0.000	0.000	0.000	0.000
201-500 hp	0.000	0.000	0.000	0.001
Agriculture				
1-5 hp	0.000	0.000	0.000	0.000
6-20 hp	0.000	0.000	0.000	0.000
21-50 hp	0.000	0.000	0.000	0.000

51-100 hp	0.000	0.000	0.000	0.000
101-200 hp	0.000	0.000	0.000	0.000
201-500 hp	0.000	0.000	0.000	0.000

Full-Fuel Cycle	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**
Industry				
1-5 hp	0.006	0.009	0.012	0.014
6-20 hp	0.195	0.272	0.352	0.381
21-50 hp	0.076	0.112	0.149	0.149
51-100 hp	1.233	1.746	2.338	2.864
101-200 hp	1.006	1.556	2.098	2.592
201-500 hp	0.747	1.255	1.706	2.150
Commercial				
1-5 hp	0.003	0.004	0.005	0.006
6-20 hp	0.005	0.007	0.009	0.010
21-50 hp	0.002	0.003	0.004	0.004
51-100 hp	0.000	0.001	0.001	0.001
101-200 hp	0.000	0.000	0.000	0.001
201-500 hp	0.000	0.000	0.001	0.001
Agriculture				
1-5 hp	0.000	0.000	0.000	0.000
6-20 hp	0.000	0.000	0.000	0.000
21-50 hp	0.000	0.000	0.000	0.000
51-100 hp	0.000	0.000	0.000	0.000
101-200 hp	0.000	0.000	0.000	0.000
201-500 hp	0.000	0.000	0.000	0.000

Table 10.4.6 Net Present Value for Fire Pump Electric Motors (million 2011$)

7% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**
Industry				
1-5 hp	-2.594	-3.674	-8.310	-10.487
6-20 hp	-1.499	-2.182	-5.863	-6.607
21-50 hp	-0.614	-0.941	-2.794	-2.794
51-100 hp	1.143	1.481	-0.192	-0.438
101-200 hp	0.956	1.379	0.161	0.086
201-500 hp	0.639	1.049	0.297	0.386
Commercial				
1-5 hp	-2.252	-2.949	-9.700	-12.263
6-20 hp	-3.293	-4.645	-14.543	-16.304
21-50 hp	-1.440	-2.178	-7.217	-7.217
51-100 hp	-0.334	-0.523	-1.718	-2.178
101-200 hp	-0.155	-0.263	-0.815	-1.027

201-500 hp	-0.190	-0.332	-0.902	-1.127
Agriculture				
1-5 hp	0.000	0.000	0.000	0.000
6-20 hp	0.000	0.000	0.000	0.000
21-50 hp	0.000	0.000	0.000	0.000
51-100 hp	-0.079	-0.123	-0.403	-0.510
101-200 hp	-0.022	-0.038	-0.117	-0.147
201-500 hp	-0.021	-0.036	-0.097	-0.121
3% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**
Industry				
1-5 hp	-6.436	-9.292	-18.784	-23.687
6-20 hp	-3.343	-4.924	-12.094	-13.656
21-50 hp	-1.327	-2.043	-5.627	-5.627
51-100 hp	3.680	4.909	2.471	2.585
101-200 hp	3.063	4.525	2.893	3.317
201-500 hp	2.118	3.515	2.653	3.349
Commercial				
1-5 hp	-4.860	-6.506	-19.450	-24.580
6-20 hp	-6.728	-9.544	-28.303	-31.741
21-50 hp	-2.894	-4.380	-13.908	-13.908
51-100 hp	-0.674	-1.050	-3.312	-4.200
101-200 hp	-0.313	-0.526	-1.571	-1.984
201-500 hp	-0.382	-0.664	-1.746	-2.183
Agriculture				
1-5 hp	0.000	0.000	0.000	0.000
6-20 hp	0.000	0.000	0.000	0.000
21-50 hp	0.000	0.000	0.000	0.000
51-100 hp	-0.159	-0.247	-0.776	-0.984
101-200 hp	-0.045	-0.076	-0.225	-0.285
201-500 hp	-0.041	-0.072	-0.188	-0.235

Table 10.4.7 National Energy Savings Summary (quads)

Primary	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B	0.972	4.414	7.527	10.836	13.005
NEMA Design C	0.012	0.018	0.024	-	-
Fire Pump Electric Motors	0.003	0.005	0.006	0.008	-
All Motors[h]	0.987	4.437	7.558	10.843	13.005
Full-Fuel Cycle	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B	1.026	4.657	7.942	11.433	13.722
NEMA Design C	0.013	0.019	0.026	-	-
Fire Pump Motors	0.003	0.005	0.007	0.008	-
All Motors[h]	1.041	4.681	7.974	11.441	13.722

Table 10.4.8 Net Present Value Summary (billion 2011$)

7% discount rate	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B	2.318	7.070	11.423	-10.368	-12.710
NEMA Design C	0.021	-0.007	-0.005	-	-
Fire Pump Electric Motors	-0.010	-0.014	-0.052	-0.061	-
All Motors[h]	2.329	7.049	11.366	-10.429	-12.710
3% discount rate	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B	5.526	18.420	30.186	-6.634	-8.634
NEMA Design C	0.054	0.009	0.020	-	-
Fire Pump Electric Motors	-0.018	-0.026	-0.098	-0.114	-
All Motors[h]	5.561	18.403	30.108	-6.748	-8.634

10.4.2 Scenario Analysis

DOE also performed a scenario analysis to assess how changes in economic growth would affect the former NPV results reported in Table 10.4.8. Table 10.4.9 and Table 10.4.10 present NPV results for both the low- and high economic growth scenarios.

Table 10.4.9 Net Present Value Summary for the Low Economic Growth Scenario (billion 2011$)

7% discount rate	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B	1.790	5.257	8.439	-10.171	-12.425
NEMA Design C	0.015	-0.008	-0.008	-	-
Fire Pump Electric Motors	-0.008	-0.012	-0.044	-0.051	-
All Motors[h]	1.797	5.236	8.387	-10.223	-12.425
3% discount rate	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B	4.131	13.326	21.728	-9.536	-11.983
NEMA Design C	0.039	0.001	0.007	-	-
Fire Pump Electric Motors	-0.016	-0.023	-0.082	-0.096	-
All Motors[h]	4.154	13.303	21.652	-9.632	-11.983

Table 10.4.10 Net Present Value Summary for the High Economic Growth Scenario (billion 2011$)

7% discount rate	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B	2.892	9.082	14.744	-10.144	-12.491
NEMA Design C	0.026	-0.005	-0.002	-	-
Fire Pump Electric Motors	-0.011	-0.016	-0.060	-0.070	-
All Motors[h]	2.907	9.061	14.682	-10.214	-12.491
3% discount rate	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
NEMA Design A and B	7.001	23.872	39.252	-2.885	-4.265
NEMA Design C	0.069	0.019	0.035	-	-
Fire Pump Electric Motors	-0.020	-0.029	-0.114	-0.132	-
All Motors[h]	7.050	23.862	39.173	-3.017	-4.265

10.4.3 Sensitivity Analysis

Besides calculating NES and NPV values for the inputs described in sections 10.2.2 and 10.3.2 above, DOE performed a sensitivity analysis for some of those inputs, namely the annual hours of operation, MSP and repair cost. While changes in the annual hours of operation affect both the NES and NPV, a variation in the MSP and repair cost impacts only the NPV. Table 10.4.11 through Table 10.4.14 summarize the impacts that a change of ±10 percent in these variables has on the former NES and NPV values, as reported in Table 10.4.7 and Table 10.4.8.

Table 10.4.11 National Energy Savings Variation in Response to ±10 Percent Changes in Hours of Operation* (trillion Btu)

Primary	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
NEMA Design A and B	±97.2	±441.4	±752.7	±1083.6	±1300.5
NEMA Design C	±1.2	±1.8	±2.4	-	-
Fire Pump Electric Motors	±0.3	±0.5	±0.6	±0.8	-
All Motors[h]	±98.7	±443.7	±755.8	±1084.3	±1300.5
Full-Fuel Cycle	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
NEMA Design A and B	±102.6	±465.7	±794.2	±1143.3	±1372.2
NEMA Design C	±1.3	±1.9	±2.6	-	-
Fire Pump Electric Motors	±0.3	±0.5	±0.7	±0.8	-
All Motors[h]	±104.1	±468.1	±797.4	±1144.1	±1372.2

* NES and hours of operation are positively correlated, which means that a positive increase in NES results from a positive increase in hours of operation.

Table 10.4.12 Net Present Value Variation in Response to ±10 Percent Changes in Hours of Operation* (million 2011$)

7% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
NEMA Design A and B	±281.9	±1257.2	±2134.8	±3071.6	±3669.3
NEMA Design C	±3.5	±5.2	±7.0	-	-
Fire Pump Electric Motors	±0.6	±0.9	±1.2	±1.5	-
All Motors[h]	±285.9	±1263.3	±2142.9	±3073.1	±3669.3
3% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
NEMA Design A and B	±657.8	±2950.4	±5016.3	±7218.4	±8627.7
NEMA Design C	±8.1	±12.3	±16.4	-	-
Fire Pump Electric Motors	±1.6	±2.5	±3.3	±4.0	-
All Motors[h]	±667.5	±2965.1	±5036.0	±7222.4	±8627.7

* NPV and hours of operation are positively correlated, which means that a positive increase in NPV results from a positive increase in hours of operation.

Table 10.4.13 Net Present Value Variation in Response to ±10 Percent Changes in Manufacturer Selling Price* (million 2011$)

7% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
NEMA Design A and B	±27.7	±367.0	±729.5	±3557.2	±4257.0
NEMA Design C	±1.0	±5.2	±6.6	-	-
Fire Pump Electric Motors	±0.9	±1.4	±5.0	±5.9	-
All Motors[h]	±29.7	±373.6	±741.1	±3563.1	±4257.0
3% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
NEMA Design A and B	±51.8	±684.7	±1361.1	±6636.8	±7942.4
NEMA Design C	±1.9	±9.7	±12.2	-	-
Fire Pump Electric Motors	±1.7	±2.6	±9.4	±10.9	-
All Motors[h]	±55.4	±697.0	±1382.7	±6647.7	±7942.4

* NPV and MSP are negatively correlated, which means that a positive increase in NPV results from a negative increase in MSP.

Table 10.4.14 Net Present Value Variation in Response to ±10 Percent Changes in Repair Cost* (million 2011$)

7% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
NEMA Design A and B	±15.8	±109.3	±195.1	±289.6	±368.4
NEMA Design C	±0.1	±0.3	±0.5	-	-
Fire Pump Electric Motors	±0.5	±0.7	±1.0	±1.2	-
All Motors[h]	±16.4	±110.3	±196.6	±290.8	±368.4
3% discount rate	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
NEMA Design A and B	±41.2	±285.7	±510.0	±756.9	±961.3
NEMA Design C	±0.4	±0.9	±1.3	-	-
Fire Pump Electric Motors	±1.4	±2.2	±2.9	±3.6	-
All Motors[h]	±43.0	±288.7	±514.3	±760.5	±961.3

* NPV and repair cost are negatively correlated, which means that a positive increase in NPV results from a negative increase in repair cost.

REFERENCES

1. NEMA. 2007. *Motor Shipments Slip in Third Quarter of 2007*. NEMA News, on 05 Dec 2007.

2. NEMA. 2010. *Motors Index Surges in Second Quarter of 2010*. NEMA News, on 24 Aug 2010.

3. U.S. Census Bureau. *Motors and Generators – 2002.MA335H(02)-1*. (Aug 2003) at http://www.census.gov/manufacturing/cir/historical_data/discontinued/ma335h/ma335h02.xls

4. U.S. Census Bureau. *Motors and Generators – 2003. MA335H(03)-1*. (Nov 2004) at http://www.census.gov/manufacturing/cir/historical_data/discontinued/ma335h/ma335h03.xls

5. U.S. Census Bureau. *2010 Capital Spending report: U.S. Capital spending patterns – 1999-2008.* (2010) http://www.census.gov/econ/aces/report/2010/capitalspendingreport2010.pdf

6. Energy Information Administration. *Annual Energy Outlook 2011*, December, 2010. Washington, DC. http://www.eia.doe.gov/oiaf/aeo

7. Energy Information Administration - Office of Integrated Analysis and Forecasting *The National Energy Modeling System*. (U.S. Department of Energy: Washington DC, 2009).at http://www.eia.doe.gov/oiaf/aeo/overview/

CHAPTER 11. CUSTOMER SUBGROUP ANALYSIS

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CHAPTER 11. CUSTOMER SUBGROUP ANALYSIS

11.1 INTRODUCTION

The customer subgroup analysis evaluates impacts on identifiable groups of customers who may be disproportionately affected by a national energy efficiency standard. The U.S. Department of Energy (DOE) conducts the customer subgroup analysis in preparation for the notice of proposed rulemaking. DOE will conduct this analysis, in part, by analyzing the life-cycle cost (LCC) and payback periods (PBPs) for customers who fall into an identifiable group. DOE plans to evaluate variations in energy use and energy prices and use that might affect the net present value of a standard to customer subpopulations. To the extent possible, DOE will obtain estimates of the variability of each LCC and PBP input parameter and will consider that variability in calculating customer impacts. DOE plans to perform sensitivity analyses to consider how differences in energy use will affect subgroups of customers.

DOE will determine effects on customer subgroups using the LCC spreadsheet model, which allows for different data inputs. The standard LCC analysis (described in Chapter 8 of the Technical Support Document) focuses on various types of electric motors and the customers or users of those motors. DOE uses the spreadsheet model to analyze the LCC for any subgroup of customer-type by sampling only that subgroup. In the case of medium electric motors, some of the subgroups DOE may choose to consider are small businesses or firms that use covered motors in particular applications where energy savings are likely to be small.

11.2 IMPACTS OF PURCHASE PRICE

DOE is especially sensitive to increases in product purchase prices related to new standards. DOE wishes to avoid negative impacts on identifiable population groups that may be unable to afford significant increases in equipment price. Because increases in first costs of equipment can preclude the purchase of a new model, some customers may retain equipment past their useful life. Older equipment is generally less efficient to begin with, and the efficiency of such equipment may deteriorate further if it is retained beyond its useful life. Increases in first cost also can preclude the purchase of new equipment altogether, resulting in a potentially large loss of utility to the customer.

CHAPTER 12 PRELIMINARY MANUFACTURER IMPACT ANALYSIS

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CHAPTER 12 PRELIMINARY MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

The purpose of the manufacturer impact analysis (MIA) is to identify and quantify the likely impacts of amended energy conservation standards on manufacturers. In the notice of the proposed rulemaking (NOPR), the United States Department of Energy (DOE) considers a wide range of quantitative and qualitative industry impacts that might occur due to an amended energy conservation standard. For example, a particular standard level could require changes in manufacturing practices, equipment, raw materials, etc. DOE fully analyzes these impacts during the NOPR stage of analysis.

DOE announced changes to the preliminary analysis MIA format through a report issued to Congress on January 31, 2006 (as required by section 141 of the Energy Policy Act of 2005 (EPACT 2005), entitled "Energy Conservation Standards Activities."[1] As a result, DOE collects, evaluates, and reports preliminary MIA information in the preliminary analysis prior to the NOPR stage. Such preliminary information includes market data, market shares, industry consolidation, equipment mix, key issues, conversion costs, foreign competition, and cumulative regulatory burden information, if available. DOE solicits this information during the preliminary manufacturer interviews and reports the results in this chapter. Appendix 12A includes a copy of the interview guide that DOE distributed to manufacturers.

To the extent appropriate for this rulemaking, DOE plans to apply the methodology described below to evaluate amended energy conservation standards for electric motors rated from 1 to 500 horsepower.

12.2 METHODOLOGY

DOE conducts the MIA in three phases. In Phase I, DOE creates an industry profile to characterize the industries and conducts a preliminary MIA to identify important issues that require consideration. Section 12.3 of this chapter presents initial findings of the Phase I analysis. In Phase II, DOE prepares an industry cash-flow model and a detailed interview questionnaire to guide subsequent interviews with manufacturers. In Phase III, DOE interviews manufacturers and assesses the impacts of amended energy conservation standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash-flow impacts and industry net present value using the Government Regulatory Impact Model (GRIM). DOE also assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interviews and discussions. The *Federal Register* NOPR and technical support document present results of the Phase II and III analyses.

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[1] This report is available on the DOE website at: http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/congressional_report_013106.pdf.

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE collects pertinent qualitative and quantitative financial and market information. This includes data on wages, employment, industry costs, and capacity utilization rates for manufacturers of electric motors. Sources of information include reports published by industry groups, trade journals, the U.S. Census Bureau, and Securities Exchange Commission (SEC) 10-K filings. In addition, DOE relies on information from its own market and technology assessment, engineering analysis, life-cycle cost analysis, shipments analysis, and equipment price determination to characterize the electric motor manufacturing industry.

12.2.2 Phase II: Industry Cash-Flow Analysis and Interview Guide

In Phase II, DOE performs a preliminary industry cash-flow analysis and prepares written guidelines for interviewing manufacturers.

12.2.2.1 Industry Cash-Flow Analysis

DOE uses the GRIM to analyze the financial impacts of amended energy conservation standards. Amended energy conservation standards may require additional investment, higher production costs, and could affect revenue through higher prices and, potentially, lower shipments. The GRIM uses several financial parameters to determine a series of annual cash flows for the year that amended energy conservation standards become effective and for several additional years. These factors include annual expected revenues, costs of goods sold, selling and general administration expenses, research and development expenses, taxes, and capital expenditures. Inputs to the GRIM include those financial parameters, manufacturing costs, shipment forecasts, and markup assumptions. The financial information is developed from publicly available data and confidentially submitted manufacturer information. DOE compares the GRIM results for the standards case at each trial standard level against the results for the base case in which no amended energy conservation standards are in place. The financial impact of amended energy conservation standards is the difference between the two sets of discounted annual cash flows.

12.2.2.2 Interview Guide

DOE conducts interviews with manufacturers to gather information on the effects of amended energy conservation standards on revenues, costs, direct employment, capital assets, and industry competitiveness. Before the interviews, which occur in Phase III, DOE distributes an interview guide to help identify the impacts of amended energy conservation standards on individual manufacturers or subgroups of manufacturers. Interview guide topics include: production costs; shipment projections; market share; equipment mix; conversion costs; markups and profitability; competition; manufacturing capacity; cumulative regulatory burden; and other relevant topics.

12.2.3 Phase III: Subgroup Analysis

Phase III activities take place after publication of the preliminary analysis. These activities include manufacturer interviews, revision of the industry cash-flow analysis, a manufacturer subgroup analysis, and an assessment of the impacts on industry competition, manufacturing capacity, direct employment, and cumulative regulatory burden.

12.2.3.1 Manufacturer Interviews

DOE conducts detailed interviews with manufacturers to gain insight into the potential impacts of amended energy conservation standards on sales, direct employment, capital assets, and industry competitiveness. The interview process is critical to the MIA because it provides an opportunity for interested parties to privately express their views on important issues. Interviews are scheduled well in advance to provide every opportunity for stakeholders to be available for comment. Although a written response to the questionnaire is acceptable, DOE prefers interactive interviews, which help clarify responses and provide the opportunity to identify additional issues not specifically addressed in the interview questionnaire. A non-disclosure agreement allows DOE to consider confidential or sensitive information in its decision-making process. Confidential information will not be made available in the public record. At most, sensitive or confidential information may be aggregated and presented in industry-wide representations.

DOE uses information gathered during manufacturer interviews to supplement the information gathered in Phase I and the cash flow analysis performed in Phase II.

12.2.3.2 Revised Industry Cash-Flow Analysis

As discussed, DOE requests information about profitability impacts, changes in capital expenditures, and other manufacturing impacts during the interview process. DOE revises its industry cash flow model based on the feedback it receives in written comments and during interviews.

12.2.3.3 Manufacturer Subgroup Analysis

Using average cost assumptions to develop an industry cash flow estimate will not adequately assess differential impacts among manufacturer subgroups. Smaller manufacturers, niche players, and manufacturers exhibiting a cost structure that differs greatly from the industry average could be more negatively affected. Ideally, DOE would consider the impact on every firm individually; however, it typically uses the results of the industry characterization to group manufacturers with similar characteristics. During the interviews, DOE discusses the potential subgroups that have been identified for the analysis. DOE asks manufacturers and other interested parties to suggest what subgroups or characteristics are most appropriate for the analysis.

12.2.3.4 Competitive Impact Assessment

Section 342(a)(6)(B)(i)(V) of the Energy Policy and Conservation Act, as amended, (EPCA) directs DOE to consider any lessening of competition likely to result from the imposition of standards. EPCA further directs the U.S. Attorney General to determine the impacts, if any, of any decrease in competition. DOE makes a determined effort to gather and report firm-specific financial information and impacts. DOE bases the competitive impact assessment on manufacturer cost data and other information collected from interviews. When assessing competitive impacts, DOE's interviews generally focus on assessing asymmetrical cost increases, the potential increase in business risks from an increased proportion of fixed costs, and potential barriers to market entry (e.g., proprietary technologies). The competitive analysis may also focus on assessing any differential impacts on smaller manufacturers.

12.2.3.5 Manufacturing Capacity Impact

One of the significant outcomes of amended energy conservation standards can be the obsolescence of existing manufacturing assets, including tooling and other investments. The manufacturer interview guide presents a series of questions to help identify impacts on manufacturing capacity, specifically capacity utilization and plant location decisions in North America with and without amended energy conservation standards. The interview guide also addresses 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 restructuring or other charges, where applicable.

12.2.3.6 Employment Impact

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. To assess how domestic employment patterns might be affected, the interview process explores current employment trends in the electric motor industry and solicits manufacturer views on changes in employment patterns that may result from new or amended standards. The employment impacts section of the interview guide focuses on current employment levels at production facilities, expected future employment levels with and without an amended energy conservation standard, differences in workforce skills, and employee retraining.

12.2.3.7 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers of energy conservation standards and other regulatory actions. DOE analyzes and considers the impact on manufacturers of multiple, equipment-specific regulatory actions.

12.3 PRELIMINARY MANUFACTURER IMPACT ANALYSIS OVERVIEW

During the preliminary analysis phase, DOE conducted a preliminary evaluation of the impact of potential new and amended energy conservation standards on the electric motor industry.

The primary sources of information for this analysis are the U.S. Census Bureau, industry reports, and interviews with manufacturers of electric motors conducted in the first quarter of 2011. To maintain confidentiality, DOE only reports aggregated information here. DOE does not disclose company-specific information, nor does it identify the individual manufacturers that disclosed information.

12.3.1 Industry Overview

The following section summarizes publicly available industry data.

12.3.1.1 Industry Cost Structure

DOE is unaware of any publicly available industry-wide cost data specific to only manufacturers of electric motors. Electric motor manufacturing is classified as a subset under the North American Industry Classification System (NAICS) code 335312 (*Power Motor and Generator Manufacturing*). Therefore, DOE presents the data below as a broader industry proxy for the electric motor industry, which, in combination with information gained in interviews, inform DOE's analysis of the industry cost structures. For simplicity, DOE will refer to these broader categories by the equipment they represent, namely motors. DOE obtained the below data from U.S. Census Bureau, *Annual Survey of Manufacturers, Statistics for Industry Groups and Industries* from 2005-2009.

Table 12.1 presents the motor and generator manufacturing employment levels and payroll from 2005 to 2009. The statistics show a 26.8 percent decrease in the number of production workers from 2005 to 2009 with a corresponding 14.5 percent decrease in the overall industry payroll.

Table 12.1 Motor and Generator Manufacturing Industry Employment and Earnings

Year	Production Workers	All Employees	Payroll for All Employees *thousand current year dollars*
2005	34,193	47,799	1,836,194
2006	33,764	46,477	1,784,902
2007	31,201	44,451	1,732,333
2008	31,121	43,997	1,868,738
2009	25,018	37,640	1,570,853

U.S. Census Bureau. *2009 Annual Survey of Manufacturers: 2009 and 2008*. December 2010; *2008 Annual Survey of Manufacturers: 2008 and 2007*. March 2010; and *2006 Annual Survey of Manufacturers: 2006 and 2005*. November 2008.

Table 12.2 presents the costs of materials and industry payroll as a percentage of shipment value from 2005 to 2009. The cost of materials as a percentage of shipment value fell by 1.9 percent from 2005 to 2009. During the same time period, the cost of total payroll and the cost of payroll for production workers decreased by 12.5 percent and 22.6 percent, respectively.

Table 12.2 Motor and Generator Manufacturing Industry Material and Payroll Costs

Year	Cost of Materials (% of shipment value)	Cost of Payroll for Production Workers (% of shipment value)	Cost of Total Payroll (% of shipment value)
2005	51.67	10.18	16.53
2006	58.10	9.41	15.24
2007	56.96	8.11	13.66
2008	56.44	7.66	13.33
2009	50.70	7.88	14.47

U.S. Census Bureau. *2009 Annual Survey of Manufacturers: 2009 and 2008*. December 2010; *2008*

Annual Survey of Manufacturers: 2008 and 2007. March 2010; and *2006 Annual Survey of Manufacturers: 2006 and 2005*. November 2008.

12.3.1.2 Inventory Levels

Table 12.3 shows the year-end inventory for the motor and generator manufacturing industry obtained from the U.S. Census Bureau and *Annual Survey of Manufacturers: Value of Manufacturers' Inventories by Stage of Fabrication for Industry Groups and Industries* and *Annual Survey of Manufacturers*: *Statistics for Industry Groups and Industries*. The industry's end-of-year inventory from 2005 to 2009 increased 32.5 percent when expressed in dollars, and grew 5.1 percent when expressed as a percentage of shipment value.

Table 12.3 Motor and Generator Manufacturing Industry End-of-Year Inventory

Year	**End-of-Year Inventory** ***thousand current year dollars***	**End-of-Year Inventory** ***percent of shipment value***
2005	1,539,507	13.86%
2006	1,740,148	14.85%
2007	1,780,086	14.03%
2008	1,494,506	13.77%
2009	2,040,169	14.56%

U.S. Census Bureau. *2009 Annual Survey of Manufacturers: 2009 and 2008*. December 2010; *2008 Annual Survey of Manufacturers: 2008 and 2007*. March 2010; and *2006 Annual Survey of Manufacturers: 2006 and 2005*. November 2008.

DOE obtained full production capacity utilization rates from the U.S. Census Bureau, "Current Industrial Reports," *Survey of Plant Capacity* from 2002 to 2006[2]. Table 12.4 presents production capacity utilization rates for NAICS code 335312. Full production capacity is defined as the maximum level of production an establishment can attain under normal operating conditions. In the *Survey of Plant Capacity* report, the full production capacity utilization rate is a ratio of the actual level of operations to the full production level.

Table 12.4 Motor and Generator Manufacturing Industry Full Production Capacity Utilization Rates

Year	**Motor and Generator Manufacturing (%)**
2006	70
2005	59
2004	75
2003	62
2002	60

U.S. Census Bureau. 2007 *Current Industrial Reports: Table 1a - Full Production Capacity Utilization Rates by Industry: Fourth Quarters 2002 through 2006.* November 2007

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[2] Report from the U.S. Census Bureau is available at http://www.census.gov/manufacturing/capacity/historical_data/index.html

12.3.2 Interview Topics and Preliminary Findings

The following section summarizes information gathered during interviews held during the first quarter of 2011 for the preliminary MIA.

12.3.2.1 Market Shares and Industry Consolidation

Amended energy conservation standards can alter the competitive dynamics of the marketplace, prompting companies to enter the market, exit the market, or merge with other companies. The preliminary MIA interview questions asked manufacturers to share their perspectives on industry consolidation both in the absence of amended energy conservation standards and assuming amended standards at various efficiency levels. The interview questions focused on gathering information that assessed:

- current and anticipated market share in the event of standards,
- potential disproportionate cost increases to some manufacturers,
- likelihood of industry consolidation,
- increased proportion of fixed costs potentially increasing business risks, and
- potential barriers to market entry (e.g., proprietary technologies).

The need to assess anti-competitive effects of proposed amended energy conservation standards derives from the need to protect consumer interests. During the interviews, DOE also solicited information to determine whether amended energy conservation standards could result in disproportionate economic or performance penalties for particular consumer or user subgroups. Manufacturers were also asked if amended energy conservation standards could result in equipment that would be more or less desirable to consumers due to changes in equipment functionality, utility, or other features.

Market Shares: DOE inquired about the current market shares of manufacturers in the electric motor industry and how those shares might change after amended energy conservation standards. Manufacturers indicated that increasing efficiency levels would cause domestic production market share to dramatically decline. Multiple manufacturers indicated that increasing efficiency levels above what is currently available will require the motors to be hand-wound, which is a labor intensive practice that is only profitable when the motor is made in a lower-labor rate country. This may shift the advantage to foreign motor manufacturers, decreasing domestic manufacturing market share. Manufacturers also cited tooling upgrade investments, availability of lower loss electrical steels, and lack of enforcement of standards on imported motors as reasons that may cause market share of domestic manufacturers to decline.

Industry Consolidation: DOE inquired about the current market shares of manufacturers in the electric motor industry and how those shares might change after amended energy conservation standards. The electric motor industry is composed of several large manufacturers and a few smaller, niche manufacturers. Many electric motor manufacturers have merged in the past few years, and some manufacturers stated that they believe this trend will continue even in the absence of amended standards. Due to this recent trend of mergers, very few independent electric motor manufacturers remain in the United States. These remaining smaller manufacturers could be forced out of the market if higher efficiency standards are implemented or the scope of this rulemaking is expanded to include equipment manufactured by these smaller companies.

12.3.2.2 Equipment and Profitability

DOE requested manufacturers' feedback on what they perceived to be the possible impact of amended energy conservation standards on the equipment that a manufacturer produces and resultant profits. Higher energy conservation standards would likely result in higher per-unit costs that could cause consumers to shift to less expensive alternative equipment, if such equipment were available. New standards could result in a change in the utility of the equipment to consumers. Manufacturers could also foresee a scenario in which new standards caused margin compression, which could threaten the viability of some firms in the industry.

Equipment Differentiation: Manufacturers indicated that increasing conservation standards may cause some manufacturers to exit specialized portions of the market (i.e. U-frame motors). Manufacturers cited low profitability due to low equipment volume as a reason for exiting the market instead of converting tooling to create motors at higher efficiency levels.

Equipment Utility: DOE received feedback that increased conservation levels may require motors to be built in larger frame sizes for their horsepower rating than those designated in NEMA MG1-2009 Table 13.3. Manufacturers indicated that motors made in a larger frame sizes will no longer fit into existing space-constrained applications, and that this may lead to an increase in motor repair practices instead of replacement with higher efficiency motors. This could also lead to entire machinery being redesigned to fit the larger motors, cause foreign machinery to become more competitive. One manufacturer indicated that relaxing limits on locked-rotor currents may increase efficiency and reduce power consumption but may also decrease the power factor, which could reduce stability of the power grid and increase power consumption. The manufacturer suggested DOE conduct a study on the increased power demand resulting from higher locked-rotor currents.

Profit Margins: Several manufacturers commented on the adverse negative impact new energy conservation standards may have on profit margins. Manufacturers mentioned capital and equipment conversion outlays needed to upgrade or redesign equipment before they have reached the end of their useful life may create significant conversion costs, resulting in reduced cash flow and stranded investments. Higher energy conservation standards could also result in higher per-unit costs that could cause consumers to shift to less expensive equipment. These higher costs could cause manufacturers to see a decrease in profit margins of their equipment. Multiple manufacturers also mentioned users deciding to rewind or repair older motors rather than replace with more expensive, higher-efficiency motors. This would cause a decrease in production volume and therefore a decrease in profit margins.

12.3.2.3 Conversion Costs

DOE asked manufacturers to quantify and explain both the capital and the equipment conversion costs necessary to raise the energy efficiency of their equipment-lines. Depending on the stringency of any amended energy conservation standard levels, manufacturers may be able to meet the levels with existing equipment or they may have to completely redesign their equipment-lines. In either case, more stringent energy conservation standards would cause manufacturers to incur one-time capital and equipment conversion costs. Capital conversion costs are one-time investments in property, plant and equipment. Equipment conversion costs include one-time investments in research, equipment development, testing and marketing.

All manufacturers stated that the conversion costs associated with amended standards would depend on the efficiency level established by those standards. At the highest efficiency level, one manufacturer cited conversion costs as possibly exceeding $100 million, and the time needed for compliance exceeding five years. Copper rotors would require a significant investment in additional die-casting machines, and copper rotors could also cause a decrease in production volume as the process time for each rotor is longer and consumes more energy than the current, aluminum die-casting process. At lower efficiency levels, manufacturers stated that minimal capital investment may be necessary if manufacturers can switch to a more labor-intensive process. Changing the labor content, however, is likely to result in production being moved off-shore.

Manufacturers were also concerned about the potential for assets to be stranded due to higher energy conservation standards for motors. For every new capital investment made by manufacturers, some portion of the manufacturers' existing equipment for core production would be stranded. Additionally, manufacturers indicated that there are often very long lead times for obtaining advanced machinery. Specifically, manufacturers estimated that it would take two years for installation of new machinery to be completed after the purchase request is made for some of these capital investments.

12.3.2.4 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 individual manufacturers, groups of manufacturers, or entire industries. Assessing the impact of a single regulation may overlook this cumulative regulatory burden.

Expenditures associated with meeting other regulations are an important aspect of DOE's consideration of the cumulative regulatory burden the industry faces. The manufacturer interviews helped DOE identify the level and timing of investments manufacturers are expecting to incur because of these regulations. Manufacturers were also asked under what circumstances they might be able to make expenditures related to regulations and energy conservation standards.

Manufacturers expressed concern about the 2015 compliance date for small electric motors being within three years of this rulemaking's effective date. Manufacturers stated that adopting these two regulations in a short timeframe would strain research and development for motor manufacturers. Manufacturers also noted several existing regulations with which they are required to comply: National Fire Protection Association (NFPA) 70, *National Electrical Code*; NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*; and U.S. Occupational Safety and Health Administration regulations.

12.4 OVERALL KEY ISSUES

Perhaps the most important aspect of the preliminary MIA is the opportunity it creates for DOE to identify key manufacturer issues early in the development of amended energy conservation standards. During preliminary interviews, manufacturers identified three major areas of concern: core steel availability, equipment conversion costs, and intellectual property.

12.4.1 Core Steel Availability

Manufacturers commented that there is limited global supply for the types of core steel necessary to build higher efficiency electric motors, particularly high-grade lamination steel. This shortage of higher grade steel could be exacerbated if efficiency standards for other equipment require more widespread use of this steel, causing a sudden increase in demand.

12.4.2 Copper Die Cast Rotors

Manufacturers commented on the impracticability of die-casting copper rotors. Namely, they were concerned with the rising cost of copper, the health hazards of die-casting copper, and the difficulty of purchasing copper die-casting equipment. Several manufacturers noted that copper die-casting equipment cannot be purchased; instead, copper die-casting companies require manufacturers to contract out this procedure.

12.4.3 Increase in Equipment Repair

Manufacturers stated that higher efficiency standards would likely increase the price of electric motors, which would drive consumers to consider rewinding older, less efficient motors rather than purchase a new, more efficient motor. This could not only decrease the shipments of electric motors but also decrease the potential energy savings of higher efficiency standards, particularly because repairing or rewinding a motor may not return that motor to its previous efficiency.

12.4.4 Enforcement

Several manufacturers stated that NEMA manufacturers may be disproportionately affected by amended standards because DOE may not enforce penalties on foreign manufacturers who choose not to comply. Without proper enforcement of standards, domestic manufacturers may incur compliance costs that foreign manufacturers do not incur, decreasing the competitiveness of domestic manufacturers.

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13.1 INTRODUCTION

The U.S. Department of Energy (DOE) utilizes the employment impact analysis to estimate national job creation or elimination resulting from proposed new energy efficiency standards. New standards may result in the reallocation of expenditures for purchasing and operating equipment. DOE will conduct this analysis in preparation for the notice of proposed rulemaking. DOE will estimate national employment impacts on major sectors of the U.S. economy, using publicly available data and incorporating various energy price scenarios. DOE will make all methods and documentation available for review.

The imposition of standards can affect employment both directly and indirectly. Direct employment effects are changes in the numbers of employees at the plants that produce the covered equipment, along with affiliated distribution and service companies. DOE will evaluate direct employment effects as part of its manufacturer impact analysis, as described in Chapter 12. Indirect employment effects from the imposition of standards may reflect expenditures that are shifted between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect).

DOE expects new equipment standards to decrease energy consumption, and therefore to reduce expenditures for energy. The savings in energy expenditures may be spent on new investment and other items. The standards also may increase the purchase price of equipment, including the retail price plus sales tax, and may increase installation costs.

Using an input-output model of the U.S. economy, the employment impact analysis seeks to estimate the year-to-year effect of expenditure impacts on net economic output and employment. A simple model might involve reduced expenditures for energy and reallocation of that money toward other sectors of the economy. DOE intends the employment impact analysis to quantify the indirect employment effects of changes in expenditures. It will evaluate direct employment effects in the manufacturer impact analysis (Chapter 12 of the Technical Support Document).

13.2 METHODOLOGY

To investigate combined direct and indirect employment impacts from new standards, DOE will use the Pacific Northwest National Laboratory's (PNNL's) Impact of Sector Energy Technologies (ImSET) model.[1] PNNL developed ImSET, a spreadsheet model of the U.S. economy that focuses on 187 sectors most relevant to industrial, commercial, and residential building energy use, for DOE's Office of Energy Efficiency and Renewable Energy. ImSET is a special-purpose version of the U.S. benchmark national input-output (I-O) model, designed to estimate the national employment and income effects of energy saving technologies that are deployed by DOE’s Office of Energy Efficiency and Renewable Energy. In comparison with versions of the model used in earlier rulemakings, the current version allows for more complete and automated analysis of the essential features of energy efficiency investments in buildings, industry, transportation, and the electric power sectors. The ImSET software includes a computer-based I-O model that has structural coefficients to characterize economic flows among the 188 sectors. ImSET’s national economic I-O structure is based on the 2003 Benchmark U.S. table,[2] specially aggregated to 187 sectors.

DOE intends to use the ImSet model to estimate changes in employment, industry output, and wage income in the overall U.S. economy resulting from standards-related changes in expenditures in various sectors of the economy. For example, standards for residential clothes washers may reduce energy expenditures and increase equipment prices for consumers. Those expenditure changes are likely to reduce energy sector employment. At the same time, the standards may increase investment. DOE designed the employment impact analysis to estimate the year-to-year net national employment effect of the various expenditure flows associated with each potentially new efficiency standard.

REFERENCE

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[1] Roop, J.M., M.J. Scott, and R.W. Schultz (2005), *ImSET: Impact of Sector Energy Technologie*. Pacific Northwest National Laboratory. Richland WA. Report No. PNNL-15273.

[2] Lawson, A.M., K.S. Bersani, M. Fahim-Nader, and J. Guo (December 2002), “Benchmark Input-Output Accounts of the United States, 1997,” *Survey of Current Business*, pp. 19-110. (Last accessed March 29, 2010.) http://www.bea.gov/scb/pdf/2002/12December/1202I-OAccounts2.pdf

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14.1 INTRODUCTION

The U.S. Department of Energy (DOE) will analyze specific effects of its proposed standards levels for electric motors on the electric utility industry as part of the notice of proposed rulemaking analyses, using a variant of the U.S. DOE's Energy Information Administration (EIA)'s National Energy Modeling System (NEMS). The NEMS is a large, multi-sectoral, partial equilibrium model of the U.S. energy sector. EIA uses NEMS to produce the *Annual Energy Outlook (AEO)*.[1] NEMS produces a widely recognized baseline energy forecast for the United States, and this energy forecast is available in the public domain. DOE will use a variant known as NEMS-BT to provide key inputs to the analysis.[a]

The utility impact analysis will consist of a comparison between model results for the base case and for policy cases in which proposed standards are in place. The use of NEMS-BT for the utility analysis offers several advantages. As the official DOE energy forecasting model, NEMS relies on a set of assumptions that are transparent and have received wide exposure and commentary. NEMS-BT allows an estimate of the interactions between the various energy supply and demand sectors and the economy as a whole. The utility impact analysis will report the changes in installed capacity and generation, by fuel type, which result for each trial standard level, as well as changes in electricity sales.

DOE will conduct the utility impact analysis as a policy deviation from the latest available version of the *AEO*, applying the same basic set of assumptions. For example, the operating characteristics (e.g., energy conversion efficiency, emissions rates) of future electricity generating plants are as specified in the *AEO* reference case, as are the prospects for natural gas supply.

14.2 METHODOLOGY

The electric utility impact analysis will consist of NEMS-BT forecasts for generation by plant type, installed capacity, sales, and prices. The gas utility impact analysis will consist of forecasts of change in sales due to standards. NEMS provides reference-case load shapes for several end uses. The model uses predicted growth in demand for each end use to build up a projection of the total electric system load growth for each region, which it uses in turn to predict the necessary additions to capacity. DOE uses NEMS-BT to account for the implementation of energy conservation standards by decrementing the appropriate reference case load shape. DOE will determine the size of the decrement using data for the per-unit energy savings developed in

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[a] 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 2003*, DOE/EIA-0581(2003), March 2003. 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.

the life-cycle cost analysis (chapter 8 of the Technical Support Document) and the projection of shipments developed for the national impact analysis (chapter 9).

Since the *AEO* version of NEMS forecasts only to the year 2035, DOE must extrapolate results after that year to be consistent with the analysis period being used by DOE in the national impact analysis.

Results of the analysis will include changes in residential electricity sales, installed capacity and generation by fuel type, and residential natural gas sales for each trial standard level, in five-year increments over the forecast period.

REFERENCES

1. Energy Information Administration, *Updated Annual Energy Outlook 2009 Reference Case Service Report*, 2009. Washington, DC. Report No. DOE/EIA-0383(2009). <http://www.eia.gov/forecasts/aeo/ >

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15.1 INTRODUCTION

The U.S. Department of Energy (DOE) will conduct an emissions analysis as part of the notice of proposed rulemaking for electric motors. To assess the impacts of proposed energy conservation standards on certain environmental indicators, DOE will use a variant of the Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[a] EIA uses NEMS to produce the *Annual Energy Outlook (AEO)*.[1] DOE will use a variant known as NEMS-BT to provide key inputs to the analysis, based on the latest version of the *Annual Energy Outlook.*

In the emissions analysis, DOE uses NEMS-BT to estimate the reduction in power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), and mercury (Hg) that may result from new energy conservation standards for electric motors. NEMS-BT is run similarly to the *AEO* NEMS, except that electric motors energy use is reduced by the amount of energy saved (by fuel type) due to each considered efficiency standard level. The inputs of national energy savings come from the NIA spreadsheet model, while the output is the forecasted physical emissions. The net benefit of each considered standard level is the difference between the forecasted emissions estimated by NEMS-BT at that level and the *AEO* Reference Case. DOE conducts the emissions analysis as a policy deviation from the most recent *AEO,* which is likely to be *AEO 2012*. The results of the emissions analysis include changes in NO_X, mercury, and CO_2 emissions in 5-year forecasted increments for each trial standard level.

In addition to estimating impacts of standards on power sector emissions, DOE will estimate emissions impacts in production activities that provide the energy inputs to power plants. (These are referred to as "upstream" emissions.) This full-fuel-cycle analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

15.2 AIR EMISSIONS DESCRIPTIONS AND REGULATION

Below are descriptions of the air emissions that DOE will consider in the emissions analysis, and the regulations that affect these emissions. Each version of NEMS-BT reflects the estimated impacts of all regulations that had been promulgated by a specific date.

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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. EIA approves use of the name NEMS only to describe 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 policy scenarios that are variations on EIA assumptions, DOE refers to the model as NEMS-BT (BT is DOE's Building Technologies Program). NEMS-BT was previously called NEMS-BRS.

15.2.1 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.

15.2.2 Sulfur Dioxide

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs, and DOE has preliminarily determined that these programs create uncertainty about the potential standards' impact on SO_2 emissions. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), at 70 FR 25162 (May 12, 2005), which created an allowance-based trading program. 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, 2011, EPA promulgated a replacement for CAIR, entitled "Federal Implementation Plans: Interstate Transport of Fine Particulate Matter and Ozone and Correction of SIP Approvals," but commonly referred to as the Cross-State Air Pollution Rule or the Transport Rule. 76 FR 48208 (August 8, 2011). On December 30, 2011, however, the D.C. Circuit stayed the new rules while a panel of judges reviews them, and told EPA to continue enforcing CAIR (see *EME Homer City Generation v. EPA*, No. 11-1302, Order at *2 (D.C. Cir. Dec. 30, 2011)).

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.

15.2.3 Nitrogen Oxides

Under CAIR, 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 NO_X emissions by participating in cap-and-trade programs for EGUs. Therefore, energy conservation standards for electric motors 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 NO_X emissions. DOE is using the NEMS-BT to estimate NO_X emissions reductions from possible standards in the States where emissions are not capped.

15.2.4 Mercury

In the absence of caps, a DOE energy conservation standard could reduce Hg emissions and DOE plans to use NEMS-BT to estimate these emission reductions. On December 21, 2011, EPA announced national emissions standards for hazardous air pollutants (NESHAPs) for mercury and certain other pollutants emitted from coal and oil-fired EGUs. 76 FR 24976. The NESHAPs do not include a trading program and, as such, DOE's energy conservation standards would likely reduce Hg emissions. For the emissions analysis for this rulemaking, DOE plans to estimate mercury emissions reductions using NEMS-BT based on *AEO2011*, which does not incorporate the NESHAPs. DOE expects that future versions of the NEMS-BT model will reflect the implementation of the NESHAPs.

15.2.5 Particulate Matter

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, which are now largely regulated by cap and trade systems.

REFERENCES

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1 Energy Information Administration (April 2011), *Annual Energy Outlook 2011 with Projections to 2035*, Washington, DC. Report No. DOE/EIA-0383(2011). http://www.eia.gov/forecasts/aeo/

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16.1 INTRODUCTION

As part of its assessment of energy conservation standards, the U.S. Department of Energy (DOE) considers 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 the standard levels considered for electric motors. To make this calculation similar to the calculation of the net present value (NPV) of consumer benefit, DOE considers the reduced emissions expected to result over the lifetime of the equipment shipped in the forecast period for each standard level. This chapter summarizes the basis for the monetary values used for each of these emissions.

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 (October 4, 1993), government 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, DOE 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 Corporate Average Fuel Economy (CAFE) rule, the U.S. Department of Transportation

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[a] National Research Council. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. National Academies Press: Washington, DC. 2009.

(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 (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, the Environmental Protection Agency’s (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.

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[b] The models are described in Appendix 16-A of the Technical Support Document.

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 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 16-1 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

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[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.

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 research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

DOE recognizes the uncertainties embedded in the estimates of the SCC used for cost-benefit analyses. As such, DOE and others in the U.S. Government intend to periodically review and reconsider those estimates 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.

In summary, in considering the potential global benefits resulting from reduced CO_2 emissions, DOE intends to use the most recent SCC values identified by the interagency process, adjusted to 2011$ using the gross domestic product price deflator values for 2010 and 2011. For each of the four cases specified, the values for emissions in 2011 are $5.0, $22.5, $37.0, and 68.4 per metric ton avoided (values expressed in 2011$). For later years, DOE intends to use 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 2011$.[d] To calculate a present value of the stream of monetary values, DOE discounts 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 considers the potential monetary benefit of reduced NO_X emissions from new or amended energy conservation standards. 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 will estimate the monetized value of NO_X emissions reductions resulting from each of the standard levels 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 $455 to $4,679 per ton in 2011$).[e] In accordance with Office of Management and Budget (OMB) guidance, DOE conducts 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 mercury (Hg) emissions. DOE has

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[d] Table A1 presents SCC values through 2050. For DOE's calculation, it derives 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 (September 17, 2003).

decided to await further guidance regarding consistent valuation and reporting of Hg emissions before it once again monetizes Hg in its rulemakings.

CHAPTER 17. REGULATORY IMPACT ANALYSIS FOR PROPOSED ENERGY CONSERVATION STANDARDS FOR ELECTRIC MOTORS

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CHAPTER 17. REGULATORY IMPACT ANALYSIS FOR PROPOSED ENERGY CONSERVATION STANDARDS FOR ELECTRIC MOTORS

17.1 INTRODUCTION

Under appendix A to subpart C of Title 10 of the Code of Federal Regulations, Part 430, *Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (Process Rule) the U.S. Department of Energy (DOE) is committed to explore non-regulatory alternatives to energy conservation standards. Accordingly, DOE will prepare a draft regulatory impact analysis pursuant to Executive Order 12866, "Regulatory Planning and Review," which will be subject to review by the Office of Management and Budget's Office of Information and Regulatory Affairs. Pursuant to the Process Rule, DOE has identified seven major alternatives to standards that represent feasible policy options to reduce the energy consumption of electric motors. It will evaluate each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and will compare the effectiveness of each alternative to the effectiveness of each trial standard.

Table 17.1.1 lists the non-regulatory means of achieving energy savings that DOE proposes to analyze. The technical support document (TSD) prepared in support of DOE's notice of proposed rulemaking will include a complete quantitative analysis of each alternative, the methodology for which is briefly addressed below.

Table 17.1.1 Non-regulatory Alternatives to Standards

No new regulatory action
Consumer tax credits
Manufacturer tax credits
Performance Standards
Rebates
Voluntary energy efficiency levels
Early replacement
Bulk government purchases

17.2 METHODOLOGY

DOE will use the national impact analysis (NIA) spreadsheet model for electric motors to calculate the national energy savings and the net present value (NPV) corresponding to each alternative to proposed standards. The NIA model for electric motors is discussed in chapter 10 of the TSD. To compare each alternative quantitatively to the proposed energy conservation standards, DOE will need to quantify the effect of each alternative on the purchase and use of energy efficient electric motor. After it has quantified each alternative, DOE will make the appropriate revisions to the inputs in the NIA models. Key inputs that DOE may revise in the models are:

- energy prices and escalation factors;
- implicit market discount rates for trading off purchase price against operating expense when choosing electric motor efficiency;
- consumer purchase price, operating cost, and income elasticity;
- consumer price-versus-efficiency relationships; and
- electric motor stock data (purchase of new equipment or turnover rates for inventories).

The following are the key measures of the impact of each alternative.

- *Energy use*: Cumulative energy use of electric motors from the compliance date of the new standard to 2045. DOE will report electricity consumption as primary energy.
- *National energy savings*: Cumulative national energy use from the base-case projection minus the alternative-policy-case projection.
- *Net present value*: The value of future operating cost savings from the equipment bought during the period from the required compliance date of the new standard (2015) to 2044. DOE will calculate the NPV as the difference between the present value of equipment and operating expenditures (including energy) in the base case, and the present value of expenditures under each alternative-policy case. DOE will discount future operating and equipment expenditures to 2011 using a 7-percent and 3-percent real discount rate. It will calculate operating expenses (including energy costs) for the life of the equipment.

APPENDIX 5A. ENGINEERING DATA

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APPENDIX 5A ENGINEERING DATA

5A.1 INTRODUCTION

This appendix presents baseline specifications and detailed cost-efficiency results for each of the electric motor equipment classes analyzed in the engineering analysis (chapter 5).

5A.2 BASELINE AND MAXIMUM TECHNOLOGY DESIGN SUMMARIES

Table 2.1 and Table 2.2 show the baseline and maximum technology designs for each equipment class analyzed, respectively. In the engineering analysis, all changes to cost and efficiency are measured relative the levels in Table 2.1. The representative motors chosen from each equipment class are all 4-pole, totally enclosed, fan-cooled, continuous duty, 60 hertz, and operate on less than 600 volts.

Table 2.1 Baseline Design Data

Parameter (Units)	Unit	5 hp (Design B)	30 hp (Design B)	75 hp (Design B)	5 hp (Design C)	50 hp (Design C)
Efficiency	%	82.5	89.5	93.0	87.5	93.0
Power Factor	%	0.83	0.86	0.87	0.75	0.85
Cycles	Hz	60	60	60	60	60
Tested Voltage	V	460	460	460	460	460
Speed	RPM	1,745	1,755	1,775	1,750	1,770
Full Load Torque	Nm	20.3	121.6	300.5	20.3	201
Current	A	6.9	37	88	7.2	59.2
Core Steel	-	M56	M56	M56	M47	M47
Stack Length	in	2.8	7.88	8.15	4.75	8.67
Rotor Material	-	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
Main Wire	AWG	19	18	17	18	17
Insulation Class	-	F	F	F	F	F
Temperature Rise	˚C	76.1	74.5	53.5	63.5	64.2
Breakdown Torque	% of Full Load	300	250	205	355	257
Locked-Rotor Torque	% of Full Load	240	200	170	326	211
Locked-Rotor Current	A	46	212	506	45	344
Pull-Up Torque	% of Full Load	187	142	165	248	159

Table 2.2 Maximum Technology Design Data of Software Modeled Motors

Parameter (Units)	Unit	5 hp (Design B)	30 hp (Design B)	75 hp (Design B)	5 hp (Design C)	50 hp (Design C)
Efficiency	%	91.7	94.5	96.5	91.0	95.0
Power Factor	%	0.84	0.79	0.79	0.79	0.80
Hertz	Hz	60	60	60	60	60
Tested Voltage	V	460	460	460	460	460
Speed	RPM	1,776	1,784	1,789	1,776	1,782
Torque	Nm	20.1	119.6	298.5	19.9	199.7
Current	A	6.0	37.3	91.9	6.5	61.3
Core Steel	-	M36	M36	M36	M36	M36
Stack Height	in	5.32	7.0	13.0	5.32	9.55
Rotor Material	-	Copper	Copper	Copper	Copper	Copper
Main Wire	AWG	20	18	14	18	17
Temperature Rise	˚C	70	70	70	70	70
Breakdown Torque	% of Full Load	305	202	202	260.8	233.5
Locked-Rotor Torque	% of Full Load	214	164	163.7	260.8	202.9
Locked-Rotor Current	A	43.9	208	541.3	41.7	359.6
Pull-Up Torque	% of Full Load	214	139	139.3	260.8	202.9

5A.3 DESIGN SPECIFICATIONS AND LOAD PERFORMANCE OF BASELINE MOTORS

Nameplate data and results of the IEEE Standard 112 (Test Method B) (IEEE 112B) testing for the baseline representative motors are displayed in sections 5A.3.1 through 5A.3.5.

5A.3.1 5-Horsepower, NEMA Design B, Baseline Data and IEEE 112B Test Results

Table 3.1 5-Horsepower, NEMA Design B, Nameplate Data

Parameter	Value
Phases	3
Voltage	230/460
Rated Horsepower	5.0
Rated Current	13.7/6.9
Frame	184TP
NEMA Nameplate Nominal Efficiency	82.5%
Hertz	60
RPM	1745
Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	J

Table 3.2 5-Horsepower, NEMA Design B, IEEE 112B Test Results (460 Volts)

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25	73.9	47.8	3.3
50	82.5	67.9	4.2
75	84.4	77.6	5.4
100	82.5	82.7	6.9
115	82.9	84.4	7.7

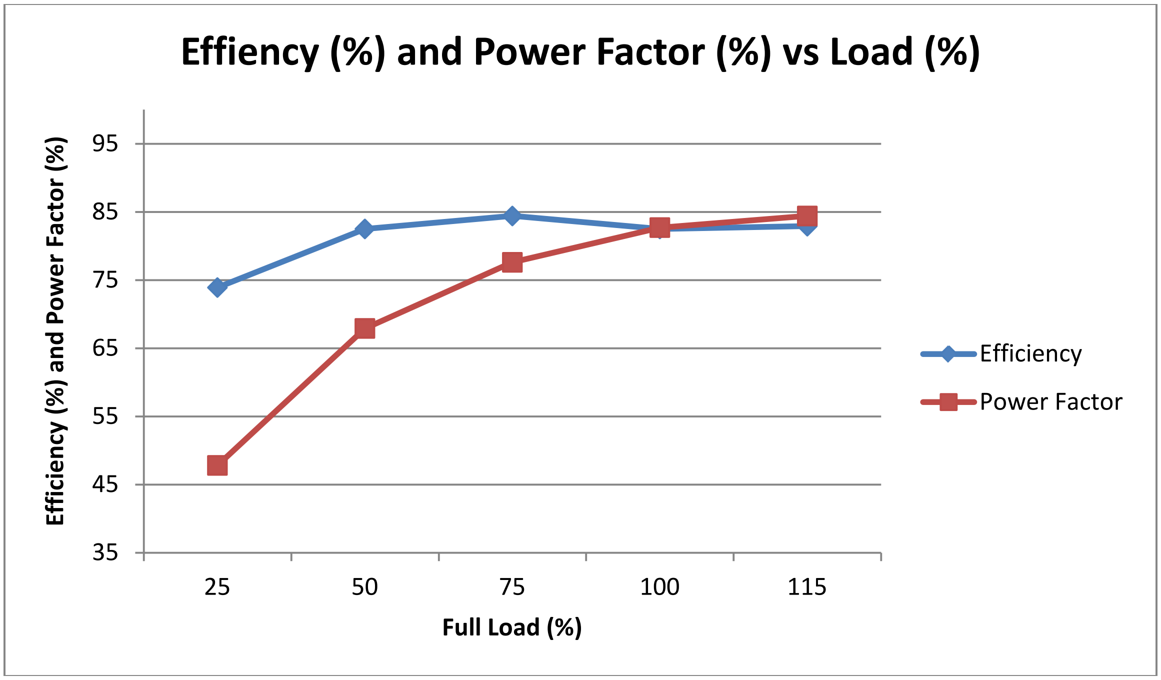

Figure 3.1 5-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.3.2 30-Horsepower, NEMA Design B, Baseline Data and IEEE 112B Test Results

Table 3.3 30-Horsepower, NEMA Design B, Nameplate Data

Parameter	Value
Phases	3
Voltage	230/460
Rated Horsepower	30.0
Rated Current	74/37
Frame	286TPA
NEMA Nameplate Nominal Efficiency	89.5%
Hertz	60
RPM	1755
Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	G

Table 3.4 30-Horsepower, NEMA Design B, IEEE 112B Test Results (460 Volts)

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25	86.7	58.6	13.8
50	90.7	77.2	20.1
75	90.8	83.9	27.6
100	88.5	86.2	37
115	87.4	86.6	43

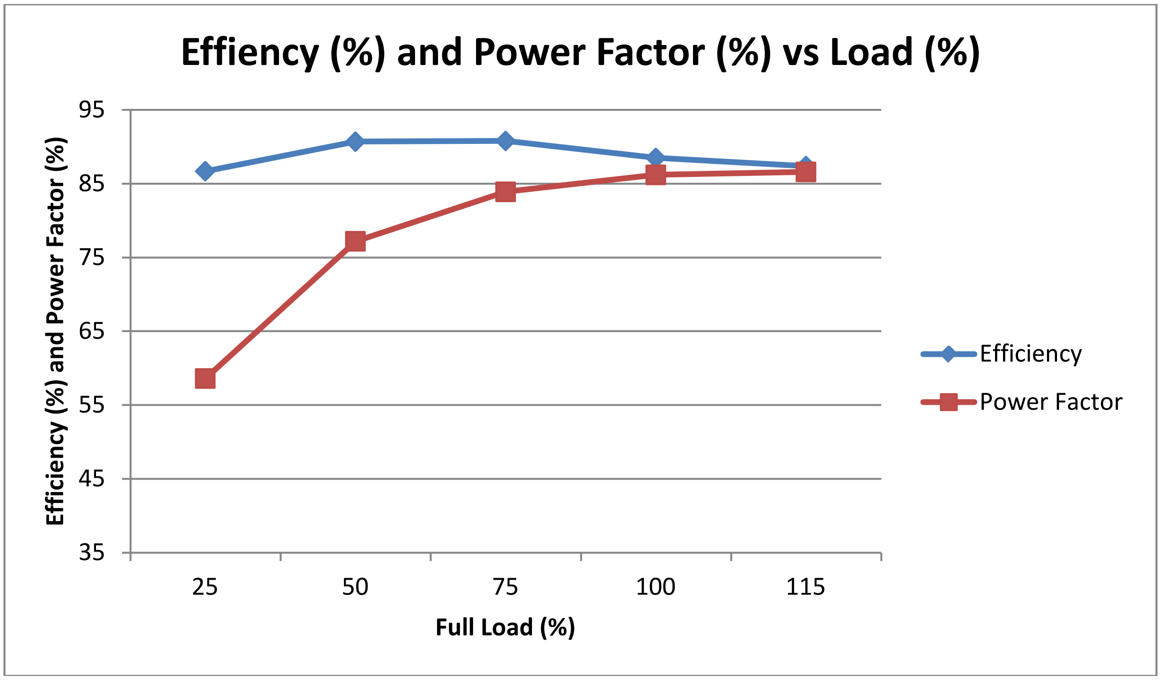

Figure 3.2 30-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.3.3 75-Horsepower, NEMA Design B, Baseline Data and IEEE 112B Test Results

Table 3.5 75-Horsepower, NEMA Design B, Nameplate Data

Parameter	Value
Phases	3
Voltage	460
Rated Horsepower	75.0
Rated Current	88.0
Frame	365TP
NEMA Nameplate Nominal Efficiency	93.0%
Hertz	60
RPM	1775
Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	F

Table 3.6 75-Horsepower, NEMA Design B, IEEE 112B Test Results (460 Volts)

Load	Efficiency	Power Factor	Current
%	%	%	Amperes
25	88.1	64.7	31
50	92.3	81.0	47
75	93.0	85.7	66
100	92.4	86.8	88
115	91.7	86.6	102

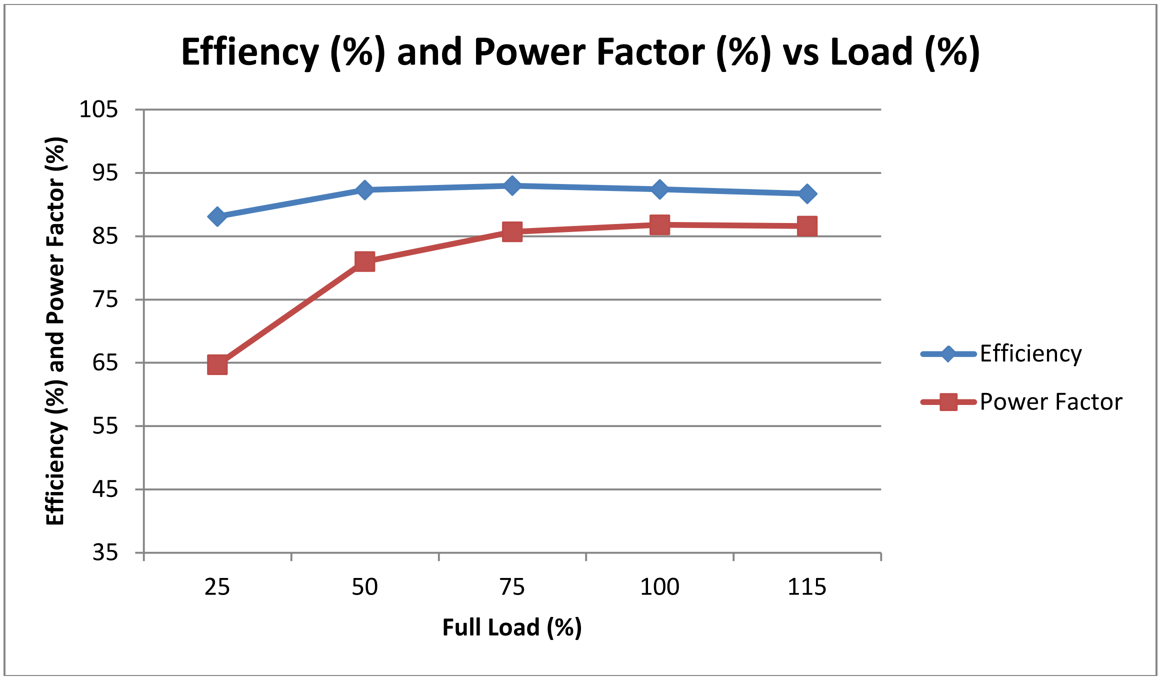

Figure 3.3 75-Horsepower NEMA Design B Efficiency and Power Factor versus Load

5A.3.4 5 Horsepower, NEMA Design C, Baseline Data and IEEE 112B Test Results

Table 3.7 5 Horsepower NEMA Design C Nameplate Data

Parameter	Value
Phases	3
Voltage	208-230/460
Rated Horsepower	5.0
Rated Current	15.3-14.16/7.08
Frame	184T
NEMA Nameplate Nominal Efficiency	87.5%
Hertz	60
RPM	1750
Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	J

**Table 3.8	5-Horsepower, NEMA Design C, IEEE 112B Test Results**

Load	Power	Efficiency	Power Factor	Current
%	HP	%	%	Amperes
25.8	1.29	79.42	37	4.1
51.1	2.55	86.22	57	4.9
76.1	3.81	87.66	68	5.9
100.9	5.04	87.47	75	7.2
116	5.79	86.99	77	8.1
125.7	6.29	86.49	79	8.7

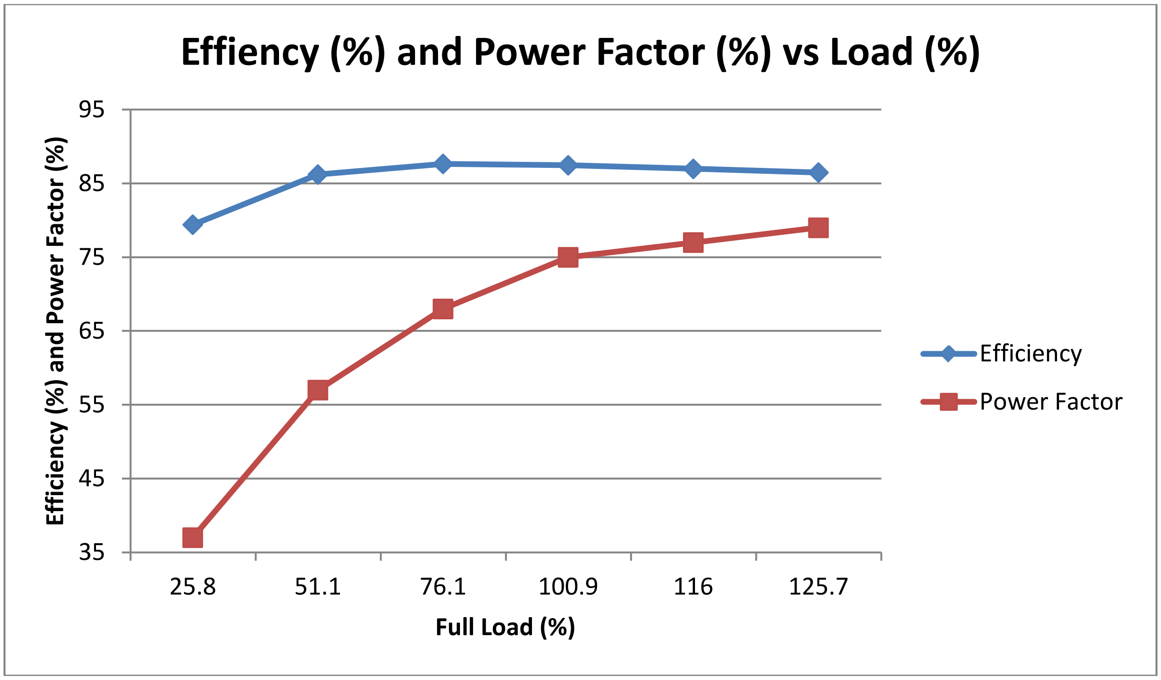

**Figure 3.4	5-Horsepower, NEMA Design C, Efficiency and Power Factor versus Load**

5A.3.5 50-Horsepower, NEMA Design C, Baseline Data and IEEE 112B Test Results

Table 3.9 50-Horsepower, NEMA Design C, Nameplate Data

Parameter	**Value**
Phases	3
Voltage	208-230/460
Rated Horsepower	50.0
Rated Current	130-118/59
Frame	236T
NEMA Nameplate Nominal Efficiency	93.0%
Hertz	60
RPM	1770
Enclosure	TEFC
Insulation Class	F
Service Factor	1.15
Code Letter (for locked-rotor kVA)	F

Table 3.10 50-Horsepower, NEMA Design C, IEEE 112B Test Results

Load	**Power**	**Efficiency**	**Power Factor**	**Current**
%	HP	%	%	Amperes
25.1	12.55	88.04	55	24.5
50.1	25.05	92.25	75	34
75.2	37.57	93.16	82	45.9
100.2	50.07	93.08	85	59.2
115.2	57.56	92.81	86	67.8
125.2	62.59	92.54	86	73.8

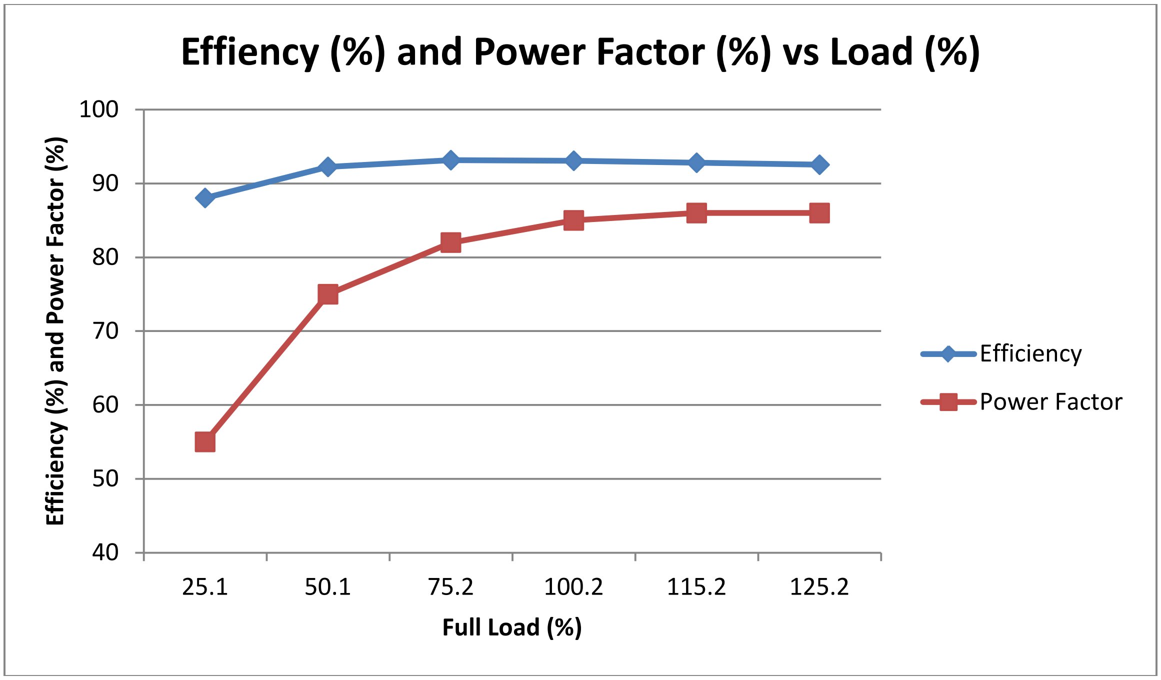

Figure 3.5 50-Horsepower, NEMA Design C, Efficiency and Power Factor versus Load

5A.4 DESIGN SPECIFICATIONS AND LOAD PERFORMANCE OF MAXIMUM TECHNOLOGY MOTORS

Performance data and speed versus torque curves for the maximum-technology, computer-modeled motors are displayed in sections 5A.4.1 through 5A.4.5.

5A.4.1 5-Horsepower, NEMA Design B, Maximum Technology Data and Modeling Results

Table 4.1 5-Horsepower, NEMA Design B, Computer Modeling Data

Load	Power	Efficiency	Power Factor	Current
%	HP	%	%	Amperes
0	0	0	6.9	2.35
25	1.25	86.4	49.5	2.74
50	2.50	91.1	71.3	3.60
75	3.75	92.1	80.5	4.73
100	5.00	92.1	84.4	6.02
115	5.75	91.8	85.4	6.86
125	6.25	91.6	85.7	7.45
150	7.50	90.7	85.7	9.04

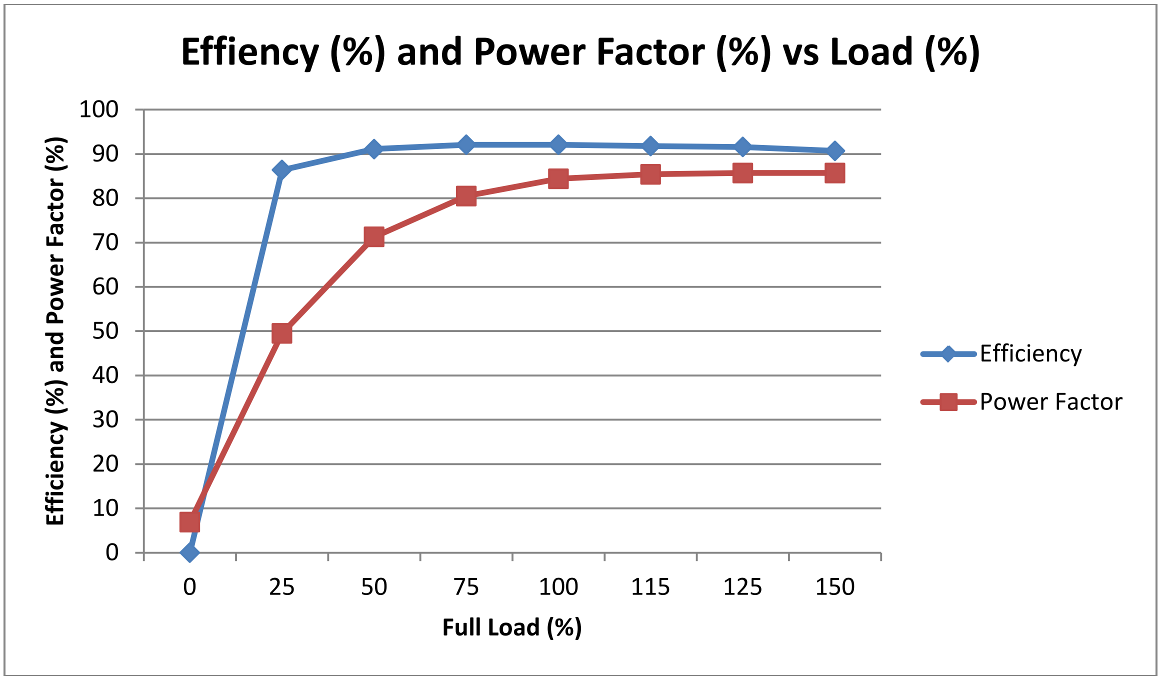

Figure 4.1 **5-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load**

5A.4.2 30-Horsepower, NEMA Design B, Maximum Technology Data and Modeling Results

Table 4.2 **30-Horsepower, NEMA Design B, Computer Modeling Data**

Load	Power	Efficiency	Power Factor	Current
%	HP	%	%	Amperes
0	0	0	5.4	12.44
25	7.50	90.3	51.5	15.10
50	14.98	93.8	71.6	20.87
75	22.49	94.7	78.6	28.28
100	29.98	94.8	80.3	36.88
115	34.49	94.7	79.8	42.76
125	37.48	94.5	78.9	47.08
150	44.95	93.5	73.8	60.97

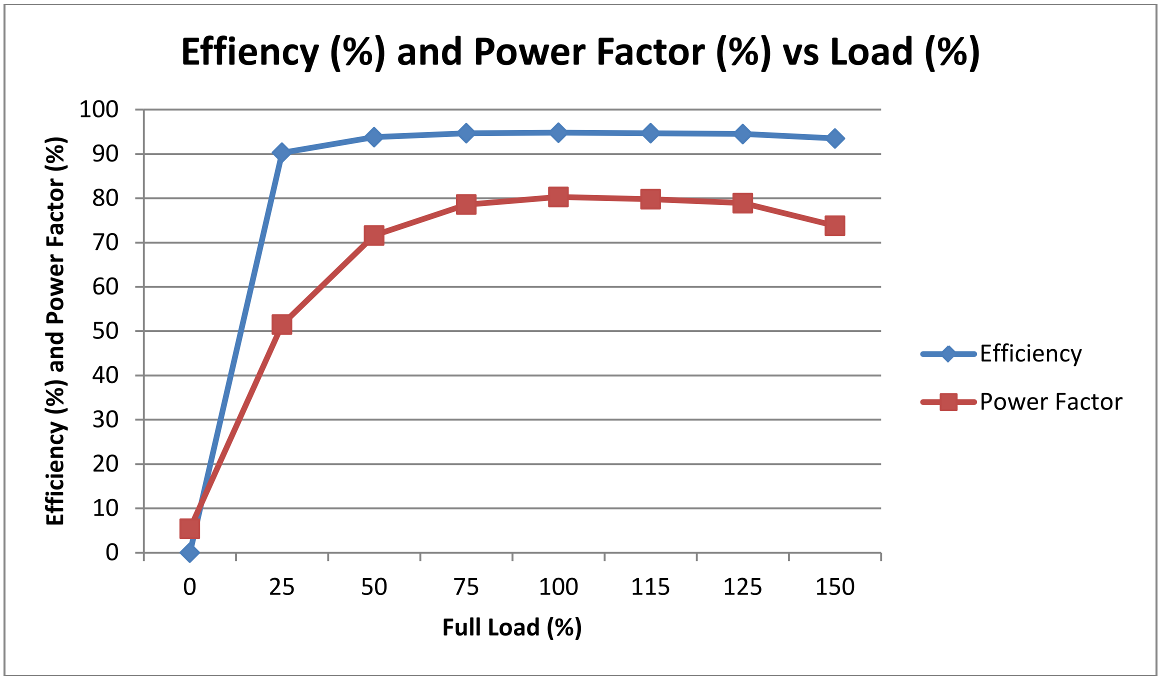

Figure 4.2 30-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.4.3 75-Horsepower, NEMA Design B, Maximum Technology Data and Modeling Results

Table 4.3 75-Horsepower, NEMA Design B, Computer Modeling Data

Load	Power	Efficiency	Power Factor	Current
%	HP	%	%	Amperes
0	0	0.00	3.10	28.96
25	18.74	94.20	52.30	35.63
50	37.43	96.10	72.30	50.47
75	56.20	96.50	78.50	69.47
100	74.98	96.40	79.30	91.88
115	86.22	96.20	78.00	107.56
125	93.71	96.00	76.40	119.64
150	110.58	94.60	65.60	166.98

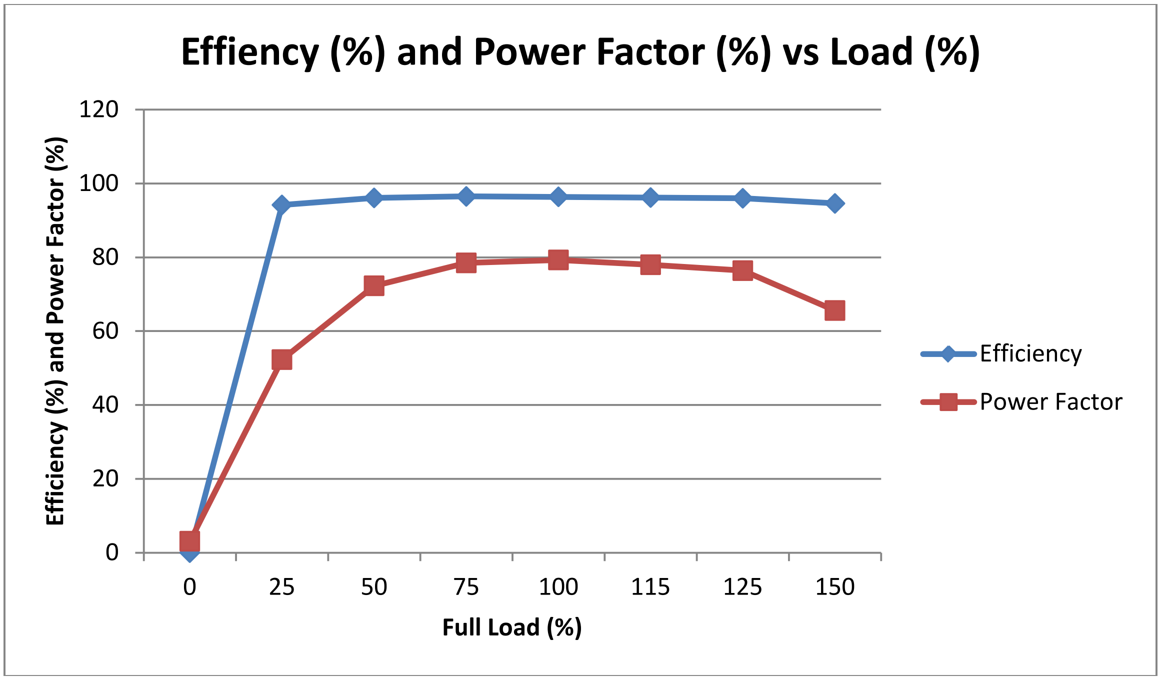

Figure 4.3 75-Horsepower, NEMA Design B, Efficiency and Power Factor versus Load

5A.4.4 5-Horsepower, NEMA Design C, Maximum Technology Data and Modeling Results

Table 4.4 5-Horsepower, NEMA Design C, Computer Modeling Data

Load	Power	Efficiency	Power Factor	Current
%	HP	%	%	Amperes
0	0.00	0.0	7.7	2.94
25	1.25	82.6	43.0	3.29
50	2.48	88.9	64.1	4.10
75	3.75	90.7	74.5	5.20
100	5.00	91.0	79.3	6.49
115	5.75	90.9	80.6	7.35
125	6.25	90.7	81.1	7.96
150	7.50	89.9	81.0	9.64

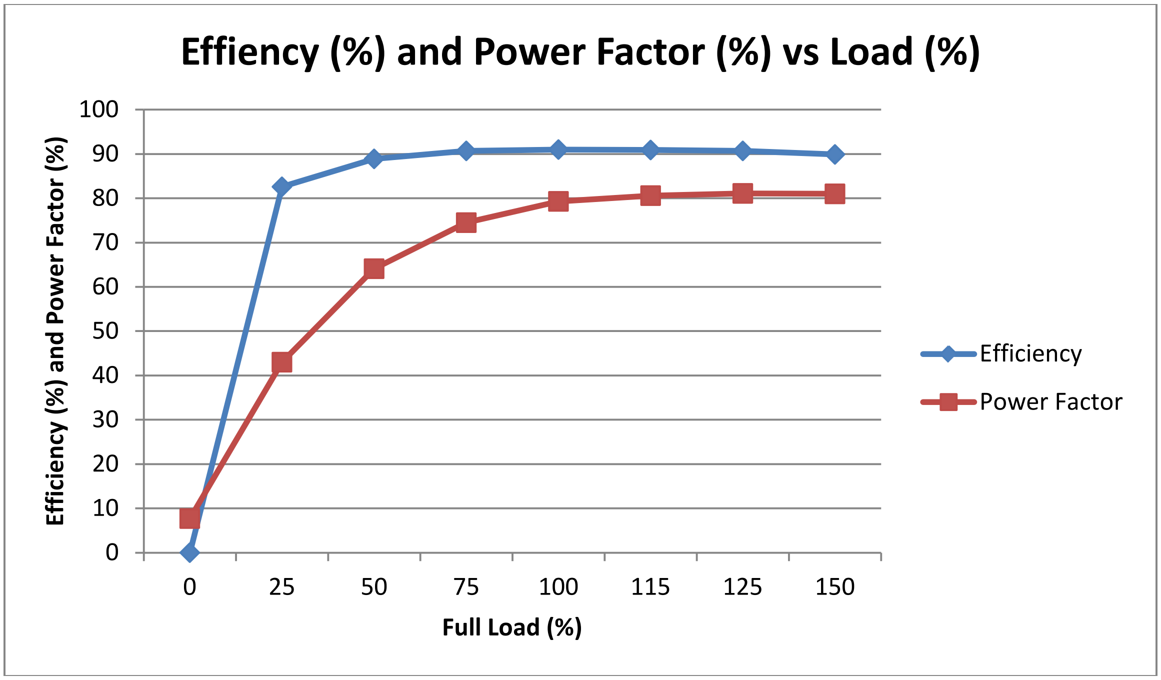

Figure 4.4 5-Horsepower, NEMA Design C, Efficiency and Power Factor versus Load

5A.4.5 50-Horsepower, NEMA Design C, Maximum Technology Data and Modeling Results

Table 4.5 50-Horsepower, NEMA Design C, Computer Modeling Data

Load	Power	Efficiency	Power Factor	Current
%	HP	%	%	Amperes
0	0.00	0.00	4.50	20.08
25	12.49	91.70	52.00	24.51
50	24.96	94.50	72.20	34.25
75	37.47	95.10	78.90	46.75
100	49.96	95.00	80.30	61.35
115	57.47	94.70	79.60	71.42
125	62.47	94.40	78.50	78.96
150	74.77	93.00	72.10	104.42

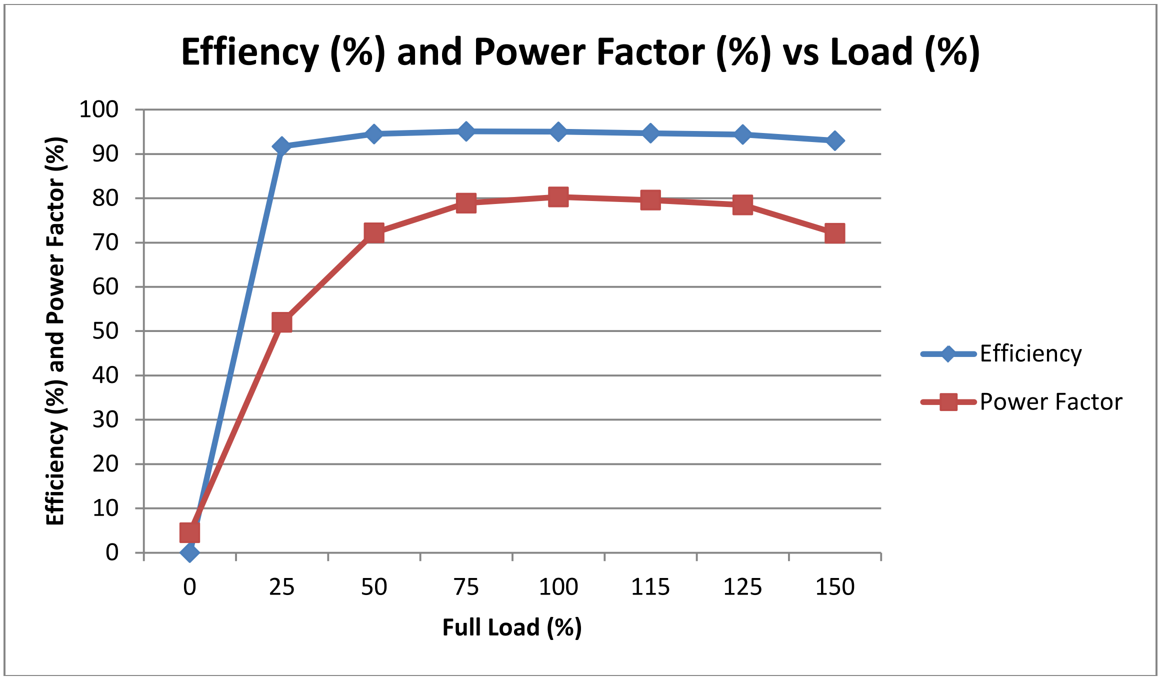

Figure 4.5 **50-Horsepower, NEMA Design C, Efficiency and Power Factor versus Load**

5A.5 CANDIDATE STANDARD LEVELS OF EFFICIENCY

As part of the scaling process, DOE developed candidate standard levels (CSLs) of efficiency for each equipment class group using NEMA efficiency tables and incremental improvements of motor losses. Table 5.1–Table 5.10 show the CSLs that were developed for the various NEMA design letters, pole configurations, and enclosure types.

Table 5.1 NEMA Design A & B Electric Motors at CSL 0

	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	75.5	75.5	75.5	77.0	74.5	80.0	66.0	72.0
1.5	74.0	80.0	77.0	80.0	75.5	75.5	72.0	75.5
2	77.0	82.5	80.0	79.0	78.5	80.0	78.0	80.0
3	80.0	84.0	78.5	80.0	81.5	82.5	80.0	78.5
5	80.0	81.5	82.5	82.5	84.0	85.5	84.5	82.5
7.5	81.5	84.0	84.0	84.0	82.5	81.5	85.5	84.0
10	82.5	85.5	86.5	87.5	84.0	87.5	84.0	85.5
15	85.5	86.5	86.5	87.5	88.5	85.5	88.5	86.5
20	88.5	88.5	87.5	88.5	87.5	87.5	89.5	86.5
25	91.0	89.5	89.5	85.5	91.7	87.5	88.5	87.5
30	89.5	88.5	89.5	87.5	89.5	87.5	91.0	89.5
40	91.0	88.5	91.0	89.5	89.5	88.5	91.0	89.5
50	92.4	88.5	91.0	89.5	90.2	90.2	91.0	91.0
60	92.4	89.5	91.7	90.2	92.4	89.5	91.0	92.4
75	93.0	89.5	93.0	91.0	92.4	89.5	92.0	93.6
100	93.6	91.0	92.4	92.4	93.0	93.0	92.0	93.6
125	94.5	93.6	92.4	93.0	93.6	93.6	92.5	93.6
150	93.6	92.4	93.6	92.4	95.0	93.0	93.6	93.6
200	95.0	93.6	94.5	93.0	94.2	94.1	93.5	93.6
250	94.5	93.6	94.6	93.6	94.0	94.5	94.0	94.5
300	95.4	95.0	94.1	94.5	94.5	95.4	94.5	94.5
350	95.4	95.0	95.0	94.5	94.9	95.0	94.5	94.5
400	95.4	95.4	95.3	95.4	94.9	95.4	94.5	94.5
450	95.4	95.8	95.4	95.4	95.0	95.4	94.5	94.5
500	95.4	95.8	95.4	95.8	95.0	95.4	94.5	94.5

Table 5.2 NEMA Design A & B Electric Motors at CSL 1

	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
Horsepower	**Enclosed**	**Open**	**Enclosed**	**Open**	**Enclosed**	**Open**	**Enclosed**	**Open**
1	75.5	75.5	82.5	82.5	80.0	80.0	74.0	74.0
1.5	82.5	82.5	84.0	84.0	85.5	84.0	77.0	75.5
2	84.0	84.0	84.0	84.0	86.5	85.5	82.5	85.5
3	85.5	84.0	87.5	86.5	87.5	86.5	84.0	86.5
5	87.5	85.5	87.5	87.5	87.5	87.5	85.5	87.5
7.5	88.5	87.5	89.5	88.5	89.5	88.5	85.5	88.5
10	89.5	88.5	89.5	89.5	89.5	90.2	88.5	89.5
15	90.2	89.5	91.0	91.0	90.2	90.2	88.5	89.5
20	90.2	90.2	91.0	91.0	90.2	91.0	89.5	90.2
25	91.0	91.0	92.4	91.7	91.7	91.7	89.5	90.2
30	91.0	91.0	92.4	92.4	91.7	92.4	91.0	91.0
40	91.7	91.7	93.0	93.0	93.0	93.0	91.0	91.0
50	92.4	92.4	93.0	93.0	93.0	93.0	91.7	91.7
60	93.0	93.0	93.6	93.6	93.6	93.6	91.7	92.4
75	93.0	93.0	94.1	94.1	93.6	93.6	93.0	93.6
100	93.6	93.0	94.5	94.1	94.1	94.1	93.0	93.6
125	94.5	93.6	94.5	94.5	94.1	94.1	93.6	93.6
150	94.5	93.6	95.0	95.0	95.0	94.5	93.6	93.6
200	95.0	94.5	95.0	95.0	95.0	94.5	94.1	93.6
250	95.4	94.5	95.0	95.4	95.0	95.4	94.5	94.5
300	95.4	95.0	95.4	95.4	95.0	95.4	94.5	94.5
350	95.4	95.0	95.4	95.4	95.0	95.4	94.5	94.5
400	95.4	95.4	95.4	95.4	95.0	95.4	94.5	94.5
450	95.4	95.8	95.4	95.8	95.0	95.4	94.5	94.5
500	95.4	95.8	95.8	95.8	95.0	95.4	94.5	94.5

Table 5.3 NEMA Design A & B Electric Motors at CSL 2

	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	77.0	77.0	85.5	85.5	82.5	82.5	75.5	75.5
1.5	84.0	84.0	86.5	86.5	87.5	86.5	78.5	77.0
2	85.5	85.5	86.5	86.5	88.5	87.5	84.0	86.5
3	86.5	85.5	89.5	89.5	89.5	88.5	85.5	87.5
5	88.5	86.5	89.5	89.5	89.5	89.5	86.5	88.5
7.5	89.5	88.5	91.7	91.0	91.0	90.2	86.5	89.5
10	90.2	89.5	91.7	91.7	91.0	91.7	89.5	90.2
15	91.0	90.2	92.4	93.0	91.7	91.7	89.5	90.2
20	91.0	91.0	93.0	93.0	91.7	92.4	90.2	91.0
25	91.7	91.7	93.6	93.6	93.0	93.0	90.2	91.0
30	91.7	91.7	93.6	94.1	93.0	93.6	91.7	91.7
40	92.4	92.4	94.1	94.1	94.1	94.1	91.7	91.7
50	93.0	93.0	94.5	94.5	94.1	94.1	92.4	92.4
60	93.6	93.6	95.0	95.0	94.5	94.5	92.4	93.0
75	93.6	93.6	95.4	95.0	94.5	94.5	93.6	94.1
100	94.1	93.6	95.4	95.4	95.0	95.0	93.6	94.1
125	95.0	94.1	95.4	95.4	95.0	95.0	94.1	94.1
150	95.0	94.1	95.8	95.8	95.8	95.4	94.1	94.1
200	95.4	95.0	96.2	95.8	95.8	95.4	94.5	94.1
250	95.8	95.0	96.2	95.8	95.8	95.8	95.0	95.0
300	95.8	95.4	96.2	95.8	95.8	95.8	95.0	95.0
350	95.8	95.4	96.2	95.8	95.8	95.8	95.0	95.0
400	95.8	95.8	96.2	95.8	95.8	95.8	95.0	95.0
450	95.8	96.2	96.2	96.2	95.8	96.2	95.0	95.0
500	95.8	96.2	96.2	96.2	95.8	96.2	95.0	95.0

Table 5.4 NEMA Design A & B Electric Motors at CSL 3

Horsepower	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	78.5	78.5	86.5	86.5	84.0	84.0	77.0	77.0
1.5	85.5	85.5	87.5	87.5	88.5	87.5	80.0	78.5
2	86.5	86.5	87.5	87.5	89.5	88.5	85.5	87.5
3	87.5	86.5	90.2	90.2	90.2	89.5	86.5	88.5
5	89.5	87.5	90.2	90.2	90.2	90.2	87.5	89.5
7.5	90.2	89.5	92.4	91.7	91.7	91.0	87.5	90.2
10	91.0	90.2	92.4	92.4	91.7	92.4	90.2	91.0
15	91.7	91.0	93.0	93.6	92.4	92.4	90.2	91.0
20	91.7	91.7	93.6	93.6	92.4	93.0	91.0	91.7
25	92.4	92.4	94.1	94.1	93.6	93.6	91.0	91.7
30	92.4	92.4	94.1	94.5	93.6	94.1	92.4	92.4
40	93.0	93.0	94.5	94.5	94.5	94.5	92.4	92.4
50	93.6	93.6	95.0	95.0	94.5	94.5	93.0	93.0
60	94.1	94.1	95.4	95.4	95.0	95.0	93.0	93.6
75	94.1	94.1	95.8	95.4	95.0	95.0	94.1	94.5
100	94.5	94.1	95.8	95.8	95.4	95.4	94.1	94.5
125	95.4	94.5	95.8	95.8	95.4	95.4	94.5	94.5
150	95.4	94.5	96.2	96.2	96.2	95.8	94.5	94.5
200	95.8	95.4	96.5	96.2	96.2	95.8	95.0	94.5
250	96.2	95.4	96.5	96.2	96.2	96.2	95.4	95.4
300	96.2	95.8	96.5	96.2	96.2	96.2	95.4	95.4
350	96.2	95.8	96.5	96.2	96.2	96.2	95.4	95.4
400	96.2	96.2	96.5	96.2	96.2	96.2	95.4	95.4
450	96.2	96.5	96.5	96.5	96.2	96.5	95.4	95.4
500	96.2	96.5	96.5	96.5	96.2	96.5	95.4	95.4

Table 5.5 NEMA Design A & B Electric Motors at CSL 4

Horsepower	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	80.0	80.0	87.5	87.5	85.5	85.5	78.5	78.5
1.5	86.5	86.5	88.5	88.5	89.5	88.5	81.5	80.0
2	87.5	87.5	88.5	88.5	90.2	89.5	86.5	88.5
3	88.5	87.5	91.0	91.0	91.0	90.2	87.5	89.5
5	90.2	88.5	91.0	91.0	91.0	91.0	88.5	90.2
7.5	91.0	90.2	93.0	92.4	92.4	91.7	88.5	91.0
10	91.7	91.0	93.0	93.0	92.4	93.0	91.0	91.7
15	92.4	91.7	94.1	94.1	93.0	93.0	91.0	91.7
20	92.4	92.4	94.1	94.1	93.0	93.6	91.7	92.4
25	93.0	93.0	94.5	94.5	94.1	94.1	91.7	92.4
30	93.0	93.0	94.5	95.0	94.1	94.5	93.0	93.0
40	93.6	93.6	95.0	95.0	95.0	95.0	93.0	93.0
50	94.1	94.1	95.4	95.4	95.0	95.0	93.6	93.6
60	94.5	94.5	95.8	95.8	95.4	95.4	93.6	94.1
75	94.5	94.5	96.2	95.8	95.4	95.4	94.5	95.0
100	95.0	94.5	96.2	96.2	95.8	95.8	94.5	95.0
125	95.8	95.0	96.2	96.2	95.8	95.8	95.0	95.0
150	95.8	95.0	96.5	96.5	96.5	96.2	95.0	95.0
200	96.2	95.8	96.8	96.5	96.5	96.2	95.4	95.0
250	96.5	95.8	96.8	96.5	96.5	96.5	95.8	95.8
300	96.5	96.2	96.8	96.5	96.5	96.5	95.8	95.8
350	96.5	96.2	96.8	96.5	96.5	96.5	95.8	95.8
400	96.5	96.5	96.8	96.5	96.5	96.5	95.8	95.8
450	96.5	96.8	96.8	96.8	96.5	96.8	95.8	95.8
500	96.5	96.8	96.8	96.8	96.5	96.8	95.8	95.8

Table 5.6 NEMA Design A & B Electric Motors at CSL 5

	Nominal Full Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	81.5	81.5	88.5	88.5	86.5	86.5	80.0	80.0
1.5	87.5	87.5	89.5	89.5	90.2	89.5	82.5	81.5
2	88.5	88.5	89.5	89.5	91.0	90.2	87.5	89.5
3	89.5	88.5	91.7	91.7	91.7	91.0	88.5	90.2
5	91.0	89.5	91.7	91.7	91.7	91.7	89.5	91.0
7.5	91.7	91.0	93.6	93.0	93.0	92.4	89.5	91.7
10	92.4	91.7	93.6	93.6	93.0	93.6	91.7	92.4
15	92.4	91.7	94.1	94.1	93.0	93.0	91.0	91.7
20	92.4	92.4	94.1	94.1	93.0	93.6	91.7	92.4
25	93.0	93.0	94.5	94.5	94.1	94.1	91.7	92.4
30	93.0	93.0	94.5	95.0	94.1	94.5	93.0	93.0
40	93.6	93.6	95.0	95.0	95.0	95.0	93.0	93.0
50	94.1	94.1	95.4	95.4	95.0	95.0	93.6	93.6
60	95.0	95.0	96.2	96.2	95.8	95.8	94.1	94.5
75	95.0	95.0	96.5	96.2	95.8	95.8	95.0	95.4
100	95.4	95.0	96.5	96.5	96.2	96.2	95.0	95.4
125	96.2	95.4	96.5	96.5	96.2	96.2	95.4	95.4
150	96.2	95.4	96.8	96.8	96.8	96.5	95.4	95.4
200	96.5	96.2	97.1	96.8	96.8	96.5	95.8	95.4
250	96.8	96.2	97.1	96.8	96.8	96.8	96.2	96.2
300	96.8	96.5	97.1	96.8	96.8	96.8	96.2	96.2
350	96.8	96.5	97.1	96.8	96.8	96.8	96.2	96.2
400	96.8	96.8	97.1	96.8	96.8	96.8	96.2	96.2
450	96.8	97.1	97.1	97.1	96.8	97.1	96.2	96.2
500	96.8	97.1	97.1	97.1	96.8	97.1	96.2	96.2

Table 5.7 NEMA Design C Electric Motors at CSL 0

	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	82.5	82.5	80.0	80.0	74.0	74.0
1.5	84.0	84.0	85.5	84.0	77.0	75.5
2	84.0	84.0	86.5	85.5	82.5	85.5
3	87.5	86.5	87.5	86.5	84.0	86.5
5	87.5	87.5	87.5	87.5	85.5	87.5
7.5	89.5	88.5	89.5	88.5	85.5	88.5
10	89.5	89.5	89.5	90.2	88.5	89.5
15	91.0	91.0	90.2	90.2	88.5	89.5
20	91.0	91.0	90.2	91.0	89.5	90.2
25	92.4	91.7	91.7	91.7	89.5	90.2
30	92.4	92.4	91.7	92.4	91.0	91.0
40	93.0	93.0	93.0	93.0	91.0	91.0
50	93.0	93.0	93.0	93.0	91.7	91.7
60	93.6	93.6	93.6	93.6	91.7	92.4
75	94.1	94.1	93.6	93.6	93.0	93.6
100	94.5	94.1	94.1	94.1	93.0	93.6
125	94.5	94.5	94.1	94.1	93.6	93.6
150	95.0	95.0	95.0	94.5	93.6	93.6
200	95.0	95.0	95.0	94.5	94.1	93.6
250	-	-	-	-	-	-
300	-	-	-	-	-	-
350	-	-	-	-	-	-
400	-	-	-	-	-	-
450	-	-	-	-	-	-
500	-	-	-	-	-	-

Table 5.8 NEMA Design C Electric Motors at CSL 1

	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	85.5	85.5	82.5	82.5	77.0	77.0
1.5	86.5	86.5	87.5	86.5	80.0	78.5
2	86.5	86.5	88.5	87.5	85.5	87.5
3	89.5	88.5	89.5	88.5	86.5	88.5
5	89.5	89.5	89.5	89.5	87.5	89.5
7.5	91.0	90.2	91.0	90.2	87.5	90.2
10	91.0	91.0	91.0	91.7	90.2	91.0
15	92.4	92.4	91.7	91.7	90.2	91.0
20	92.4	92.4	91.7	92.4	91.0	91.7
25	93.6	93.0	93.0	93.0	91.0	91.7
30	93.6	93.6	93.0	93.6	92.4	92.4
40	94.1	94.1	94.1	94.1	92.4	92.4
50	94.1	94.1	94.1	94.1	93.0	93.0
60	94.5	94.5	94.5	94.5	93.0	93.6
75	95.0	95.0	94.5	94.5	94.1	94.5
100	95.4	95.0	95.0	95.0	94.1	94.5
125	95.4	95.4	95.0	95.0	94.5	94.5
150	95.8	95.8	95.8	95.4	94.5	94.5
200	95.8	95.8	95.8	95.4	95.0	94.5
250	-	-	-	-	-	-
300	-	-	-	-	-	-
350	-	-	-	-	-	-
400	-	-	-	-	-	-
450	-	-	-	-	-	-
500	-	-	-	-	-	-

Table 5.9 NEMA Design C Electric Motors at CSL 2

	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
Horsepower	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	86.5	86.5	84.0	84.0	78.5	78.5
1.5	87.5	87.5	88.5	87.5	81.5	80.0
2	87.5	87.5	89.5	88.5	86.5	88.5
3	90.2	89.5	90.2	89.5	87.5	89.5
5	90.2	90.2	90.2	90.2	88.5	90.2
7.5	91.7	91.0	91.7	91.0	88.5	91.0
10	91.7	91.7	91.7	92.4	91.0	91.7
15	93.0	93.0	92.4	92.4	91.0	91.7
20	93.0	93.0	92.4	93.0	91.7	92.4
25	94.1	93.6	93.6	93.6	91.7	92.4
30	94.1	94.1	93.6	94.1	93.0	93.0
40	94.5	94.5	94.5	94.5	93.0	93.0
50	94.5	94.5	94.5	94.5	93.6	93.6
60	95.0	95.0	95.0	95.0	93.6	94.1
75	95.4	95.4	95.0	95.0	94.5	95.0
100	95.8	95.4	95.4	95.4	94.5	95.0
125	95.8	95.8	95.4	95.4	95.0	95.0
150	96.2	96.2	96.2	95.8	95.0	95.0
200	96.2	96.2	96.2	95.8	95.4	95.0
250	-	-	-	-	-	-
300	-	-	-	-	-	-
350	-	-	-	-	-	-
400	-	-	-	-	-	-
450	-	-	-	-	-	-
500	-	-	-	-	-	-

Table 5.10 NEMA Design C Electric Motors at CSL 3

Horsepower	Nominal Full Load Efficiency (%)					
	4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	87.5	87.5	85.5	85.5	80.0	80.0
1.5	88.5	88.5	89.5	88.5	82.5	81.5
2	88.5	88.5	90.2	89.5	87.5	89.5
3	91.0	90.2	91.0	90.2	88.5	90.2
5	91.0	91.0	91.0	91.0	89.5	91.0
7.5	92.4	91.7	92.4	91.7	89.5	91.7
10	92.4	92.4	92.4	93.0	91.7	92.4
15	93.6	93.6	93.0	93.0	91.7	92.4
20	93.6	93.6	93.0	93.6	92.4	93.0
25	94.5	94.1	94.1	94.1	92.4	93.0
30	94.5	94.5	94.1	94.5	93.6	93.6
40	95.0	95.0	95.0	95.0	93.6	93.6
50	95.0	95.0	95.0	95.0	94.1	94.1
60	95.4	95.4	95.4	95.4	94.1	94.5
75	95.8	95.8	95.4	95.4	95.0	95.4
100	96.2	95.8	95.8	95.8	95.0	95.4
125	96.2	96.2	95.8	95.8	95.4	95.4
150	96.5	96.5	96.5	96.2	95.4	95.4
200	96.5	96.5	96.5	96.2	95.8	95.4
250	-	-	-	-	-	-
300	-	-	-	-	-	-
350	-	-	-	-	-	-
400	-	-	-	-	-	-
450	-	-	-	-	-	-
500	-	-	-	-	-	-

5A.6 MATERIAL PRICING ASSUMPTIONS

DOE gathered material pricing information from numerous sources, including subject matter experts (SMEs), manufacturers, internal material pricing databases developed from research on other rulemakings, the U.S. Census Bureau’s Producer Price Index, the London Metal Exchange and the Commodity Exchange, Inc. DOE used a 2011 dollar pricing for a majority of the materials, but for copper wire and cast copper prices DOE used a five-year average dating from 2007-2011.

5A.6.1 Copper Wire Pricing

DOE used a five-year average price for copper due to the large price fluctuations in copper wire and copper used for casting. The five-year average copper pricings are displayed in Table 6.1. DOE used a constant price for all wire gauges due to the small pricing differences between the different wire gauges.

Table 6.1 Copper Material Pricing

Material Type	5 Year Average	Year				
Cu Wire ($/lb)	**2011-2007**	**2011**	**2010**	**2009**	**2008**	**2007**
Cu Wire, Gauge 14 & 14.5	$4.35	$4.00	$3.49	$2.45	$3.39	$3.39
Cu Wire, Gauge 15 & 15.5	$4.35	$4.00	$3.49	$2.45	$3.39	$3.39
Cu Wire, Gauge 16 & 16.5	$4.35	$4.00	$3.49	$2.45	$3.39	$3.39
Cu Wire, Gauge 17 & 17.5	$4.35	$4.00	$3.49	$2.45	$3.39	$3.39
Cu Wire, Gauge 18 & 18.5	$4.35	$4.00	$3.49	$2.45	$3.39	$3.39
Cu Wire, Gauge 19 , 19.5, 20 &20.5	$4.35	$4.00	$3.49	$2.45	$3.39	$3.39
Casting Materials ($/lb)						
Casting Materials - Copper	$3.35	$4.00	$3.49	$2.45	$3.39	$3.39

5A.6.2 2011 Material Pricing

DOE used a constant 2011$ pricing for the remaining materials which include electrical steels, aluminum for casting, cast iron, and hot rolled steel. These price assumptions are displayed in Table 6.2.

Table 6.2 Material Pricing in Constant 2011$

Motor Frame/End Bell Material ($/lb)	
Frame Material - Cast Iron 20k-30k psi	$0.60
Frame Material - Steel Fabrication	$0.47
Frame Material - Aluminum (extruded or cast)	$1.30
Casting Materials ($/lb)	
Casting Materials - Aluminum	$1.30
Core Steels - ASTM #, Thickness, Processing ($/lb)	
26M12, .0185", fully/semi-processed	$1.10
26M15, .0185", fully/semi-processed	$1.05
26M19, .0185", fully/semi-processed	$1.02
26M22, .0185", fully/semi-processed	$0.95
26M27, .0185", fully/semi-processed	$0.89
26M36, .0185", fully/semi-processed	$0.80
26M47, .0185", fully/semi-processed	$0.78
26M56, .0185", fully/semi-processed	$0.73
Other AISI Size or Thickness	
Rotor Shaft ($/lb)	
Hot Rolled AISI #1040 Series	$0.52
Bearings ($/each)	
Front Bearing, 5-HP	$10.11
Back Bearing, 5-HP	$5.66
Front Bearing, 30-HP	$31.30
Back Bearing, 30-HP	$14.39
Front Bearing, 50-HP	$49.35
Back Bearing, 50-HP	$25.29
Front Bearing, 75-HP	$67.41
Back Bearing, 75-HP	$36.19

5A.7 LABOR TIME AND COST ASSUMPTIONS

DOE estimated labor hours for each CSL of each representative unit. DOE requested information from manufacturers concerning labor time associated with certain electric motor horsepower ratings. A summary of these labor time estimates is displayed in Table 7.1. Due to the limited manufacturer feedback, DOE relied primarily on SME input to derive the time requirements to build the representative units. For the purchased representative units (CSL 0-3 for the NEMA Design B motors and CSL 0 for the NEMA Design C motors) DOE relied on visual inspection by motor industry experts to determine if a motor was machine or hand wound. All motors above CSL 3 were considered hand wound, regardless of slot fill percentage. Approximate slot fill percentages are displayed in Table 7.2.

Table 7.1 Labor Hour Assumptions by Candidate Standard Level (CSL)

APPENDIX 5A.	**Labor Hours**					
HP Rating	**CSL 0**	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
5, Design B	1.25	1.31	1.38	1.45	3.50*	3.68*
30, Design B	2.00	2.10	2.21	2.32	6.00*	-
75, Design B	3.50	3.68	3.86	4.06	9.00*	9.45*
5, Design C	1.25	1.31	3.50*	3.68*	-	-
50, Design C	2.75	2.89	7.50*	7.88*	-	-

* Based on slot fill measurements, DOE assumed a hand-wound labor hour amount for these motors

Table 7.2 Slot Fill Percentages by Candidate Standard Level (CSL)

APPENDIX 5A.	**Approximate Slot Fill**					
HP Rating	**CSL 0**	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**
5, Design B	43.5%	57.2%	70.0%	68.6%	82.4%	85.2%
30, Design B	48.4%	84.0%	70.0%	70.0%	83.2%	-
75, Design B	48.0%	44.5%	70.0%	70.0%	85.1%	83.4%
5, Design C	67.9%	79.9%	83.9%	82.9%	-	-
50, Design C	79.6%	74.8%	85.3%	81.3%	-	-

APPENDIX 5B. SAMPLE TEAR-DOWN REPORT

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APPENDIX 5B. SAMPLE TEAR-DOWN REPORT

5B.1 FIVE-HORSEPOWER NEMA DESIGN B, 4-POLE ELECTRIC MOTOR TEAR-DOWN REPORT

The U.S. Department of Energy (DOE) derived the electric motor production and material costs for the engineering analysis by purchasing a sample of electric motors, and then having a professional motor testing laboratory disassemble each motor and inventory the component parts. DOE performed tear downs on the electric motors representing candidate standard level (CSL) 0, CSL 1, CSL 2, and CSL 3 for the National Electrical Manufacturers Association (NEMA) Design B equipment-class group (equipment-class group 1), as well as electric motors representing CSL 0 for the NEMA Design C equipment-class group (equipment-class group 2). These tear-downs provided DOE the necessary data to construct a bill of materials that DOE could normalize, using a standard cost model and markup, to produce a projected manufacturer selling price. Table 5B.1 shows a sample tear-down report for one of the five-horsepower (5-HP) NEMA Design B, 4-pole, totally enclosed, fan cooled electric motors purchased by DOE.

Table 5B.1 Sample Tear-Down Report of a 5-HP, NEMA Design B, Electric Motor

Stator Assembly		
Steel Laminations	22.1	lb
Copper Wire	10.1	lb
Rotor Assembly		
Steel Laminations	12.4	lb
Aluminum (Cast)	2.9	lb
Shaft	4.8	lb
Front Bearing	1.0	ea
Back Bearing	1.0	ea
Frame Costs		
Frame and Base Mount	9.1	lb
Static Frame HW Costs		
Terminal Housing	1.0	lb
Rear-End Bell Cast	2.1	lb
Drive-End Bell Cast	12.0	lb
Fan Cover	1.4	lb
Stator Insulation		
Slot Liner (Nomex)	3.7	sq-ft
Top Stick (Nomex)	3.7	sq-ft
Coil Extension Insulation (Phase Paper)	1.0	sq-ft
Lead Wire Thermal Insulation Sleeve	1.0	Ea
Lead Wire	0.25	lb
Lace Cord	37.0	ft

Varnish	0.03	Gal
Miscellaneous Hardware		
Fan Cover (Plastic)	1.0	ea
Fan (Plastic)	1.0	ea
Fan Spring Clip (Steel)	1.0	ea
Axial Thrust Nut Ring 2 Holes (Steel)	1.0	ea
Thrust Bolt Cover (Rubber)	1.0	ea
Wave Spring (Steel)	1.0	ea
Terminal Housing Cover (Steel)	1.0	ea
Terminal Housing Base Gasket (Foam)	1.0	ea
Terminal Housing Cover Gasket (Foam)	1.0	ea
Lifting Eye	1.0	ea
Grease Port Bolts	4.0	ea
Grounding Screw	1.0	ea
Terminal Housing Mounting Bolts (1/4-20 x .5)	4.0	ea
Terminal Housing Cover Bolts (#10 x .375)	2.0	ea
Axial Thrust Bolts (#10 x 1.75)	2.0	ea
Stator Tie Bolts (6 mm x 10.5)	4.0	ea
Fan Cover Bolts (1/4-20 x .5)	2.0	ea

APPENDIX 7-A. ENERGY USE SCENARIO FOR ELECTRIC MOTORS WITH HIGHER OPERATING SPEEDS

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APPENDIX 7-A. ENERGY USE SCENARIO FOR ELECTRIC MOTORS WITH HIGHER OPERATING SPEEDS

7-A.1 BACKGROUND

The installation of a higher efficiency motor alone may increase the energy consumption for a particular application, instead of realizing energy savings. A more efficient squirrel-cage induction motor usually has less slip than an older less efficient motor because of a reduction in the resistance of the rotor. This results in higher operating speed and potential overloading of the motor. The U.S. Department of Energy (DOE) acknowledges that the cubic relationship between speed and power requirement in certain fan, pump, and centrifugal compressor applications can affect the benefits gained by efficient motors which have a lower slip. This appendix describes the methodology DOE used to estimate this effect as a sensitivity analysis in the Life-Cycle-Cost spreadsheet at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/electric_motors.html.

7-A.2 METHOD FOR DETERMINING ENERGY SAVING IN VARIABLE TORQUE APPLICATIONS

DOE based its methodology on a previous publication[i] which states the following:

In the case where there is a cubic relationship between the power and the speed,

$$Po_{EE}(L) = Po_{BE}(L).\frac{\omega_{EE}(L)^3}{\omega_{BE}(L)^3}$$

Where:

L is the load in percentage
$Po_{EE}(L)$ is the output power of the energy efficient motor
$Po_{BE}(L)$ is the output power of the baseline efficiency motor
$\omega_{EE}(L)$ is the operating speed of the energy efficient motor
$\omega_{BE}(L)$ is the operating speed of the baseline efficient motor

When the operating speeds are the same then:

$$Po_{EE}(L) = Po_{BE}(L)$$

If the more efficient motor has a higher speed then it produces more output power then required by the application:

$$Po_{EE}(L) > Po_{BE}(L)$$

If the only useful power is that generated by the baseline motor ($Po_{BE}(L)$), then the "effective" losses[a] of the EE motor are:

$$Losses(L) = Pin_{EE}(L) - Po_{BE}(L)$$

Where:
$Pin_{EE}(L)$ is the input power of the energy efficient motor.

The efficiency of the EE motor is $\eta_{EE}(L)$ and $Pin_{EE}(L)$ is:

$$Pin_{EE}(L) = \frac{Po_{EE}(L)}{\eta_{EE}(L)}$$

And:

$$Pin_{EE}(L) = Po_{BE}(L).\frac{\omega_{EE}(L)^3}{\omega_{BE}(L)^3}.\frac{1}{\eta_{EE}(L)}$$

Then the "effective" losses of the EE motor are:

$$Losses(L) = Po_{BE}(L)(\frac{\omega_{EE}(L)^3}{\omega_{BE}(L)^3}.\frac{1}{\eta_{EE}(L)} - 1) \text{ [Equation 1]}$$

If the end-user does not adjust for the higher speed of the EE motor, then the losses experienced will be greater than if the operating speeds remain constant.

DOE calculated "effective" losses vs. load tables based on Equation 1 and used these values to estimate the energy use of higher efficiency motors in variable torque applications which would not benefit from higher operating speeds.

7-A.3 ASSUMPTIONS TO DETERMINE ENERGY SAVINGS IN VARIABLE TORQUE APPLICATIONS

No sufficient solid data was found to estimate the share of motors which are negatively impacted by higher operating speeds. DOE therefore considered a scenario described by the two following main assumptions: (1) the share of motors which are negatively impacted by higher operating speeds, and (2) the actual operating speed of the motor in the field.

7-A.3.1 Share of motors negatively impacted by higher operating speeds

DOE assumed that 60 percent of pumps, fans and compressor applications are variable torque applications.

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[a] The "effective" losses experienced are not losses, they include the increased load imposed by increased speeds associated with variable torque applications.

Of these 60 percent, DOE assumed that all fans and a majority (70 percent) of compressors and pumps would be negatively impacted by higher operating speeds; and that 30 percent of compressors and pumps would not be negatively impacted from higher operating speeds as their time of use would decrease as the flow increases with the speed (e.g. a pump filling a reservoir). DOE assumed this revolutions per minute (RPM) effect did not impact fire pump motors.

When choosing to run the life-cycle cost (LCC) spreadsheet based on the "RPM scenario" the LCC results are based on the "effective" losses for 60 percent of all fans and 42 percent of all compressors and pumps applications. This does not account for the share of users who adjust for increased motor speed.

7-A.4 SENSITIVITY ANALYSIS

The results provided by applying this methodology do not account for motors which are positively impacted for higher operating speeds and rely on two major assumptions: (1) the share of motors which are negatively impacted by higher operating speeds, and (2) the actual operating speed of the motor in the field. DOE believes the data supporting these assumptions is not sufficiently robust to incorporate this effect in the main analysis and therefore incorporated it as a sensitivity scenario in the LCC spreadsheet.

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[i] P. Pillay. *Practical considerations in applying energy efficient motors in the petrochemical industry* . Petroleum and Chemical Industry Conference, 1995. Record of Conference Papers., Industry Applications Society 42nd Annual

APPENDIX 8-A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

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APPENDIX 8-A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

To execute the life-cycle cost (LCC) spreadsheet, it is necessary for the user to have the appropriate hardware and software tools. The U.S. Department of Energy (DOE) assumed the user has a reasonably current computer operating under the Windows operating system. The development team uses relatively new systems and has not defined the minimum system requirements. At a minimum, users need Microsoft Excel to execute the spreadsheet. For full functionality in running Monte Carlo simulations, users will need a copy of a spreadsheet add-in called Crystal Ball, in addition to Excel. Without Crystal Ball, one can still use the LCC spreadsheet model, but will not be able to examine inputs and outputs as distributions. Approximate results are provided through a sample calculation that uses average values for the inputs and outputs, as displayed in the "Summary" worksheet.

8-A.1 STARTUP

The LCC spreadsheet is a stored Excel file. It can be found on the DOE website at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/electric_motors.html. Open the file. (Each computer system will have a unique setup for loading a file. Users should refer to their software manuals if they have problems loading the spreadsheet file.) For users new to Excel and/or Crystal Ball, section 8.8.2 contains basic instructions for operating the LCC spreadsheets.

8-A.1.1 Electric Motors Worksheet Overview

LCC spreadsheet for electric motors contains the following worksheets:

Summary Results

This worksheet contains the input selections and the summary results tables of installed price, energy use, operating costs, LCC, and payback.

The left-hand section of the worksheet, controlling the Monte Carlo simulation, provides a means to change the user and simulation options. Simulation options are used to set the electricity price trend and the number of trials for the Monte Carlo simulation. In addition, the user may select among several sensitivity scenarios, including varying the equipment price, retail discount factor, whether the calculations consider the effects of the cubic relation between speed and power requirement (RPM effect).

The right-hand section of the worksheet summarizes the mean LCC and payback period (PBP) values from the distribution results produced by the simulation. This is a reporting step – values are not automatically updated. The results presented by DOE on this sheet were calculated using the default input values for electricity price trend, equipment price, retail discount factor, and no RPM effect.

LCC and Payback Calc (Life-Cycle Cost and Payback Calculation)

The spreadsheet reports the results of the calculation for the example scenario on the Summary worksheet. This example scenario allows users to produce provisional answers without performing a Monte Carlo simulation. The Summary worksheet of the LCC spreadsheet shows the results from this worksheet.

Definitions

This worksheet contains values used to populate the spreadsheet's form elements.

Rebuttable Payback

This worksheet calculates and presents the rebuttable presumption payback period for each of the eight representative units.

Energy Use

This worksheet calculates the annual electricity use of the representative equipment classes.

Equipment Price

This worksheet calculates the retail equipment price and total installed cost inputs for each representative unit. Inputs are derived from the baseline and incremental manufacturer costs of the engineering spreadsheet.

Sectors and Applications

This worksheet calculates the input data regarding sector, application, hours of operation, and motor loading for each representative unit.

Energy Price

This worksheet calculates retail electricity price distribution input data for industrial, commercial, and agricultural sectors.

Energy Price Trend

This worksheet contains the price trends of electricity; this trend represents the growth rate of electricity prices relative to the price in 2010. DOE took price data and forecasts from the DOE Energy Information Administration (EIA)'s *Annual Energy Outlook 2011(AEO 2011)* and the American Recovery and Reinvestment Act AEO-release for the period up to year 2035. To estimate the trend after 2035, DOE followed past guidelines provided to the Federal Energy

Management Program by EIA and used the average rate of change during 2025–2035 for electricity prices.

Discount Rate

This worksheet contains the discount rate analysis.

Lifetime

This worksheet contains the distributions of the age (in years) for each representative unit which equipment is retired from service. Motor lifetime is, in part, a function of the hours of operation.

Base Case Eff Dist (Base Case Efficiency Distribution)

Contains market efficiency distribution in the year the standard takes effect.

Forecast Cells

This worksheet contains the statistical results from the most recent simulation.

8-A.2 BASIC INSTRUCTIONS FOR OPERATING THE LIFE-CYCLE COST SPREADSHEETS

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 "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. You can interact with the spreadsheet by clicking choices or entering data using the graphical interface that comes with the spreadsheet. Select choices from the various user-selectable options.
4. Click the "Run" button to run the simulation using DOE's parameters.

To produce custom sensitivity results using directly Crystal Ball, 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 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 either Monte Carlo or Latin Hypercube.[a] Select number of Trials (DOE suggests 10,000).
4. To run the simulation, choose the following sequence (on the Crystal Ball toolbar): *Run, Reset, Run*
5. Now wait until the program informs you that the simulation is completed.

DOE provides the following instructions to view the output generated by Crystal Ball:

1. After the simulation has finished, click on the Windows tab bar labeled Crystal Ball to see the distribution charts.

2. The LCC savings and paybacks 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 cumulative or frequency plots are to be shown.

    2a. 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.

    2b. To calculate the certainty of the payback period being below a certain number of years, insert that value in the far-right box.

3. To generate a printed 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, refer to *Understanding the Forecast Chart* in the Crystal Ball manual.

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[a] Because of the nature of the program, there is some variation in results due to random sampling when MonteCarlo or Latin Hypercube sampling is used.

APPENDIX 8B. LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

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APPENDIX 8B. LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

8B.1 DISTRIBUTION OF LIFE-CYCLE COST RESULTS

The distributions presented in this section each correspond to example runs of 10,000 Monte Carlo samples. As a result, their means may not correspond exactly with the mean values presented in the life-cycle cost (LCC) section, which were generated by a different Monte Carlo run.

8B.1.1 Representative Unit 1, NEMA Design B, 5 hp, 4 Poles, Enclosed

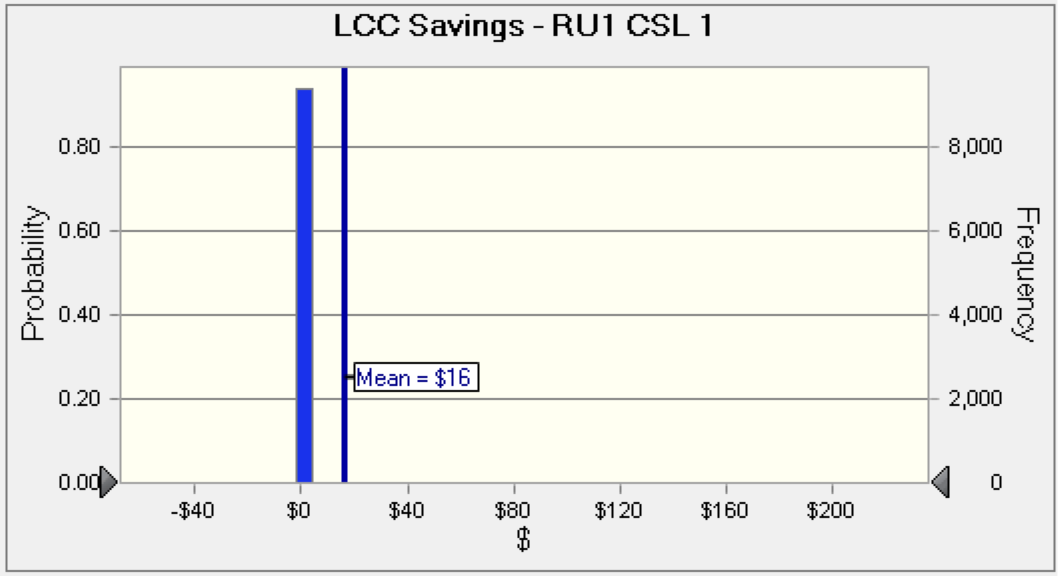

Figure 8B.1.1 Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 1

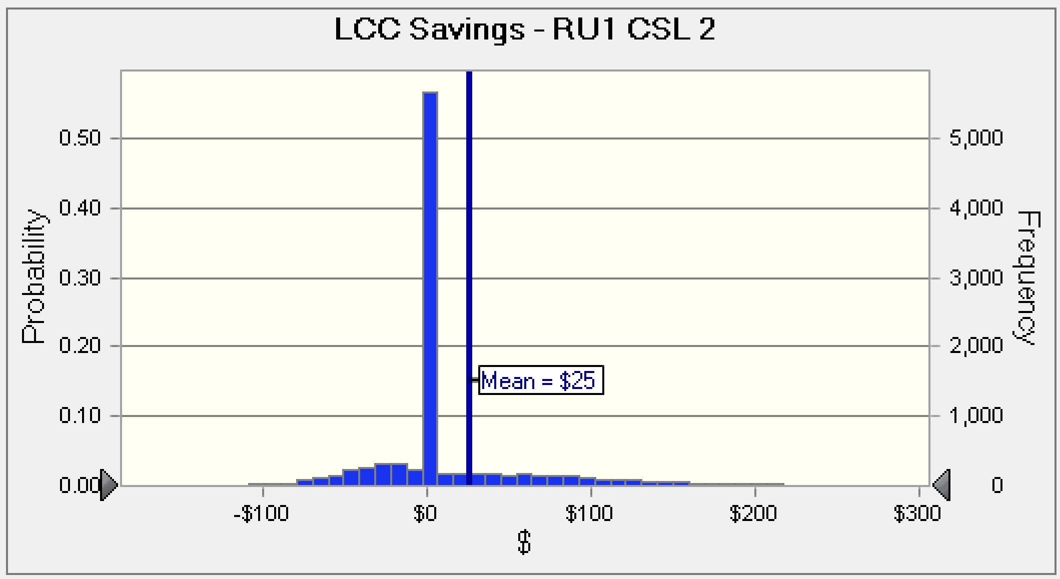

Figure 8B.1.2 **Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 2**

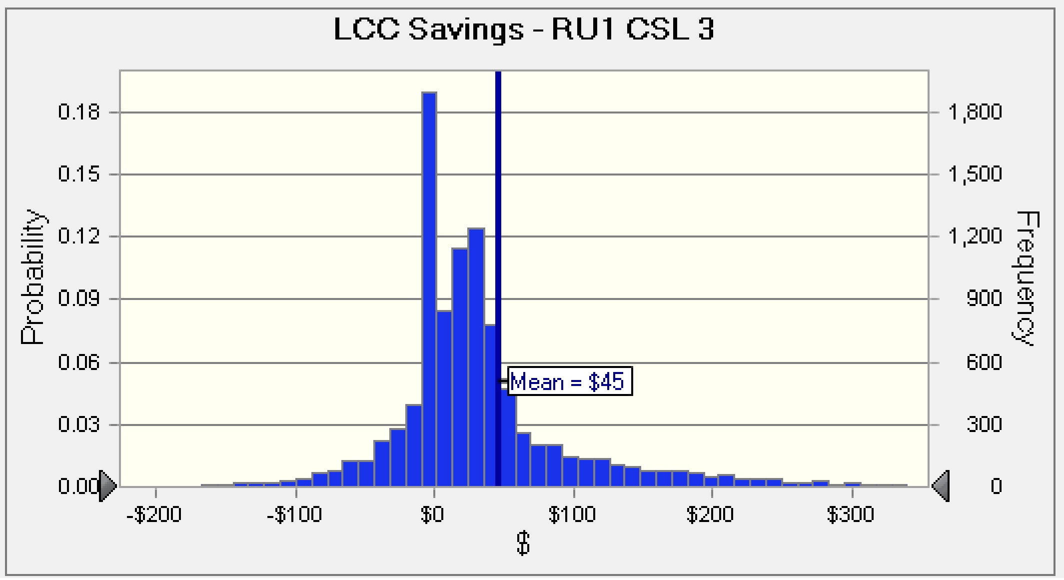

Figure 8B.1.3 **Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 3**

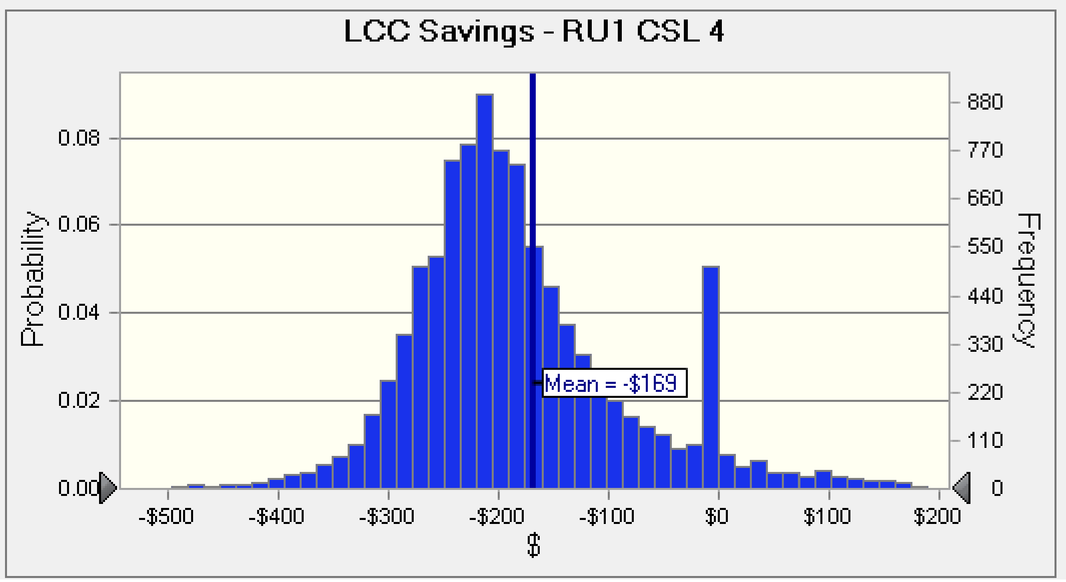

Figure 8B.1.4 Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 4

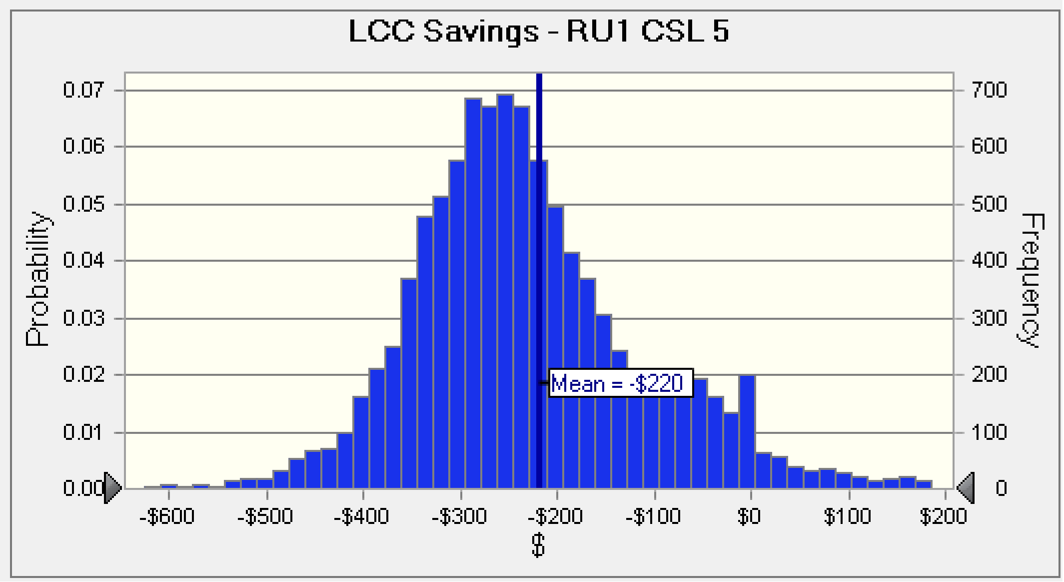

Figure 8B.1.5 Representative Unit 1: Distribution of Life-Cycle Cost Savings for CSL 5

8B.1.2 Representative Unit 2, Design B, 30 hp, 4 Poles, Enclosed

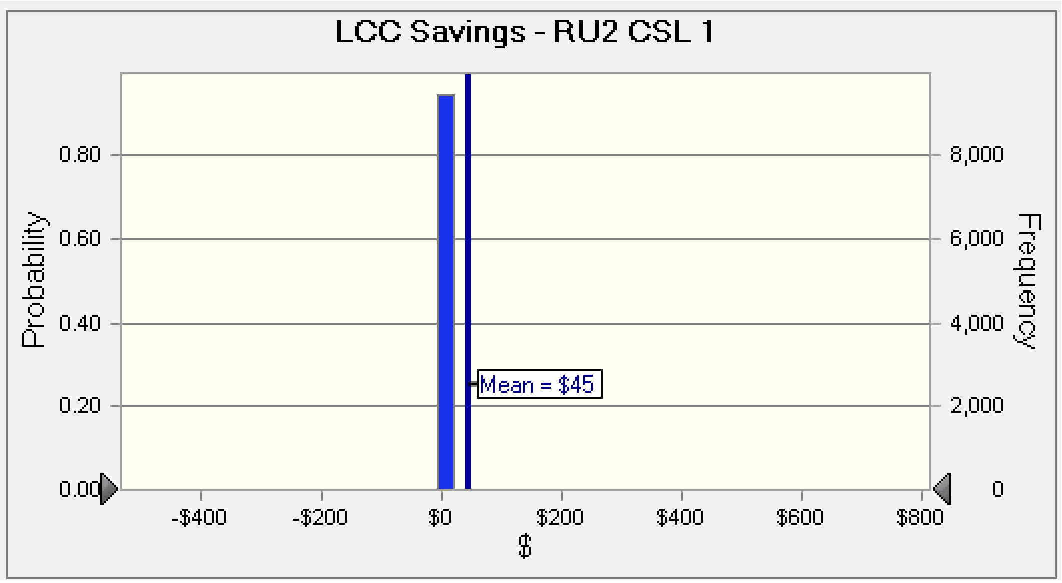

Figure 8B.1.6 Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 1

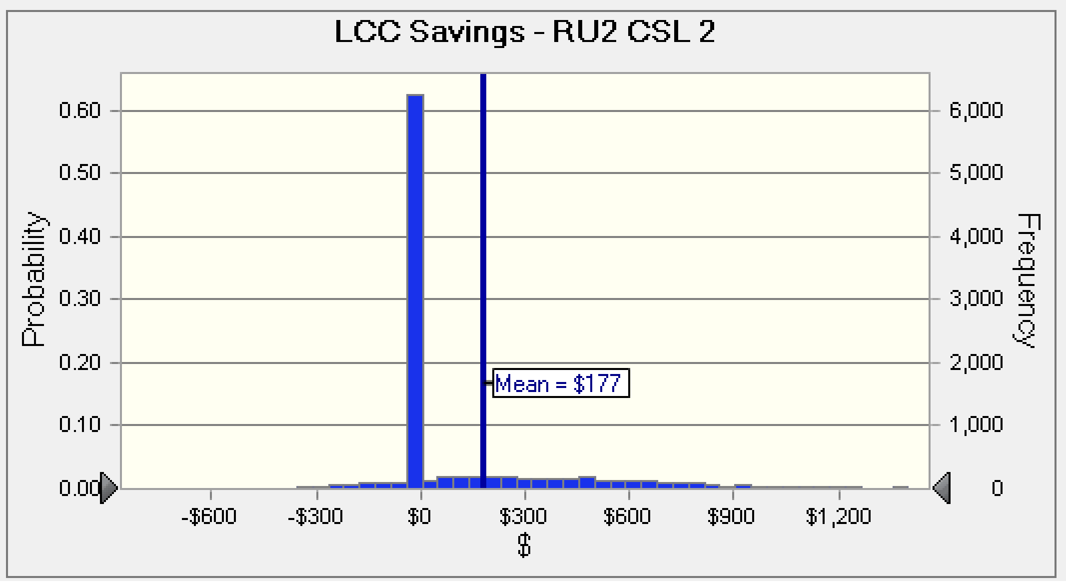

Figure 8B.1.7 Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 2

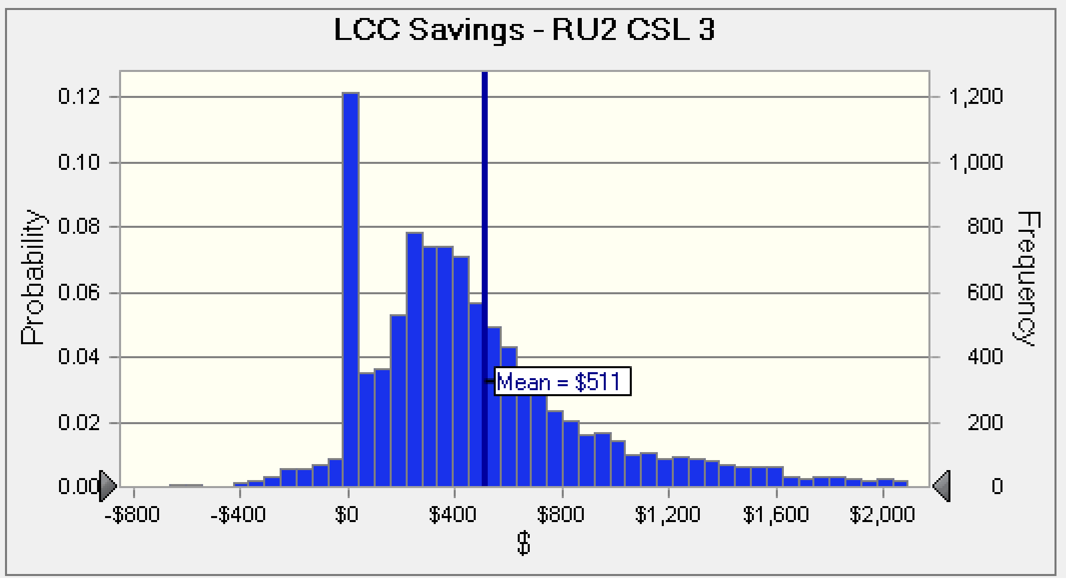

Figure 8B.1.8 **Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 3**

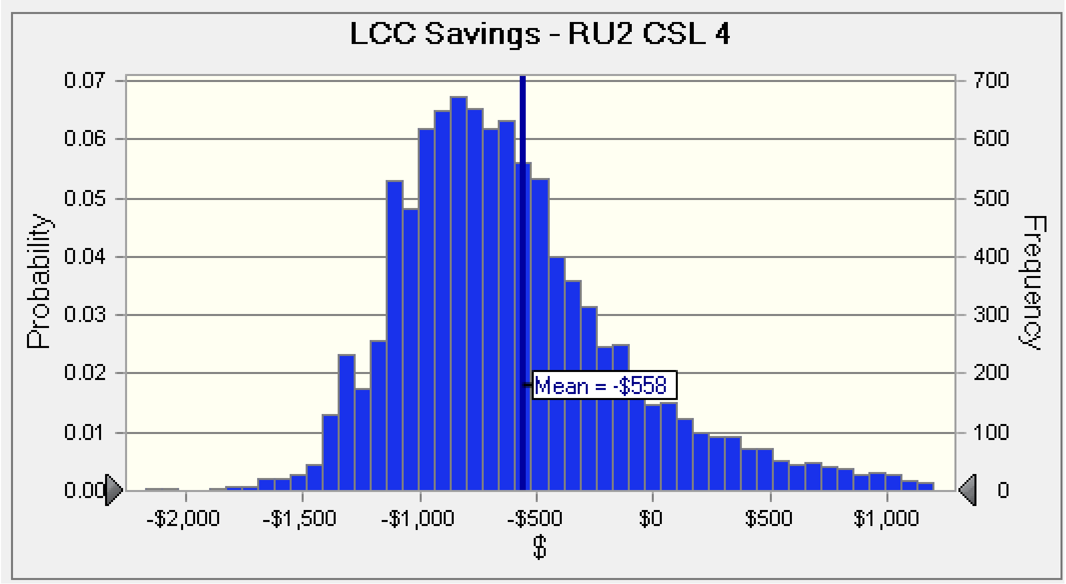

Figure 8B.1.9 **Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 4**

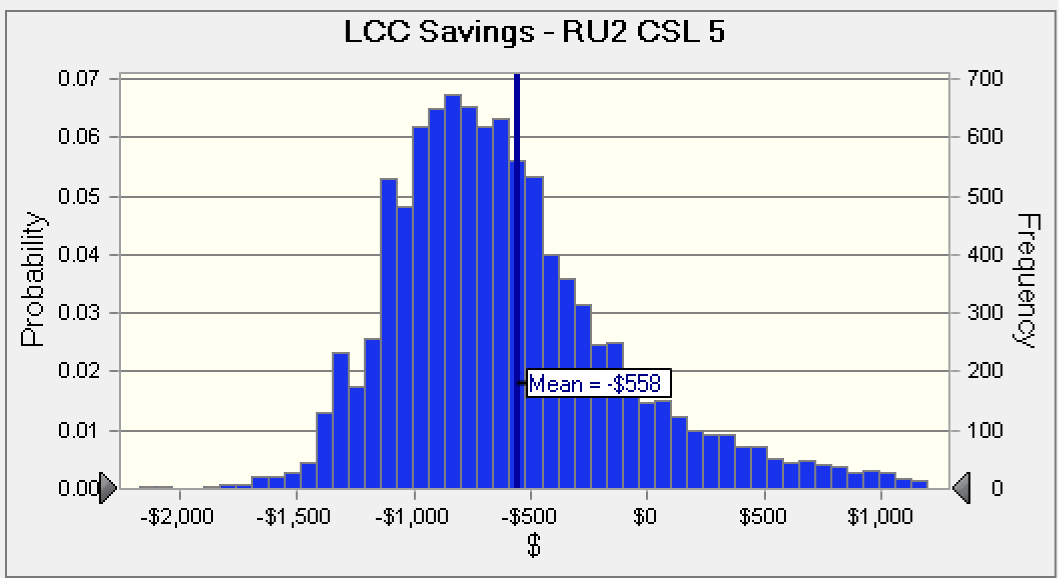

Figure 8B.1.10 Representative Unit 2: Distribution of Life-Cycle Cost Savings for CSL 5

8B.1.3 Representative Unit 3, Design B, 75 hp, 4 Poles, Enclosed

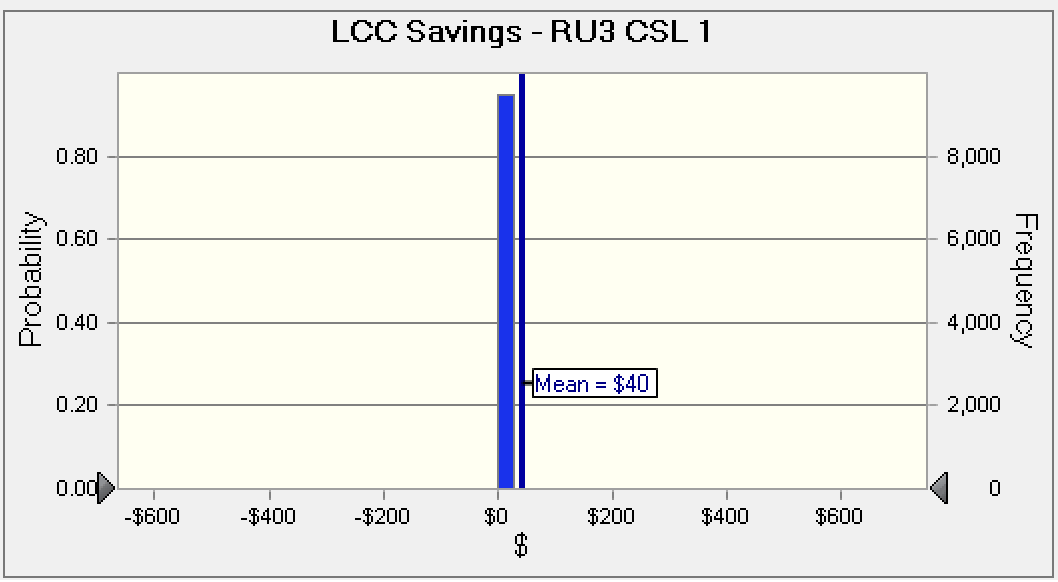

Figure 8B.1.11 Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 1

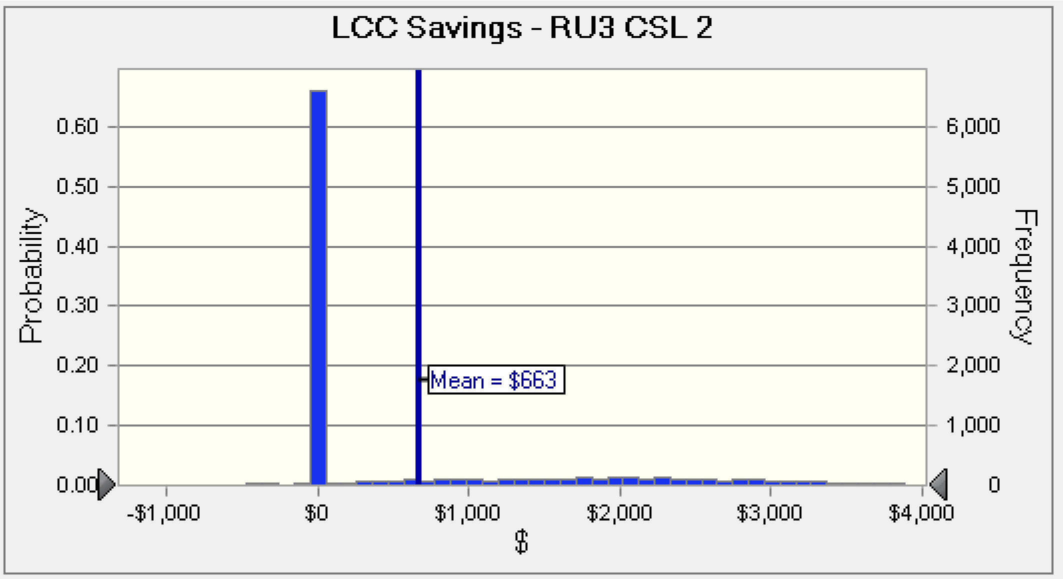

Figure 8B.1.12 **Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 2**

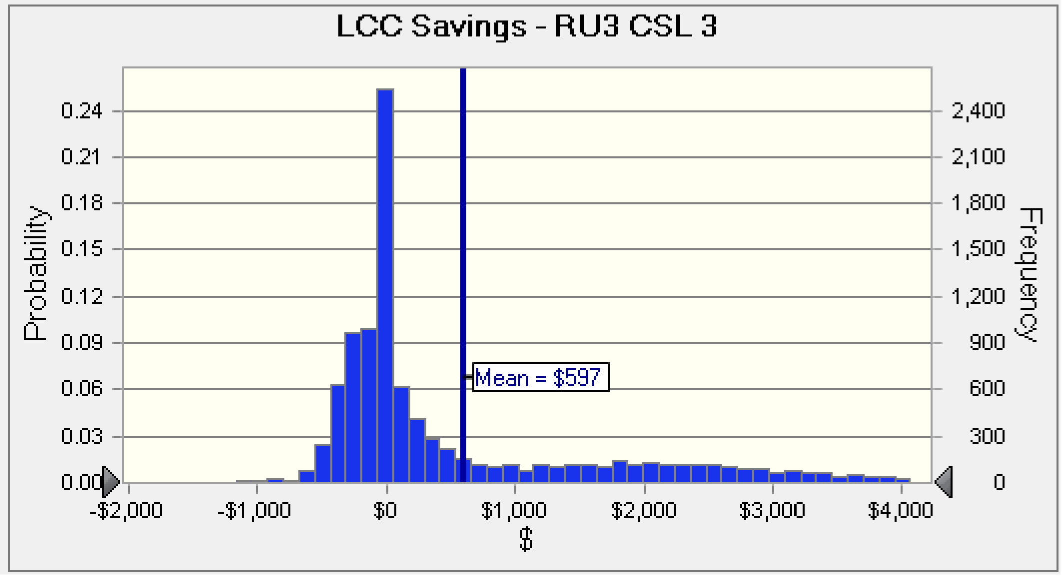

Figure 8B.1.13 **Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 3**

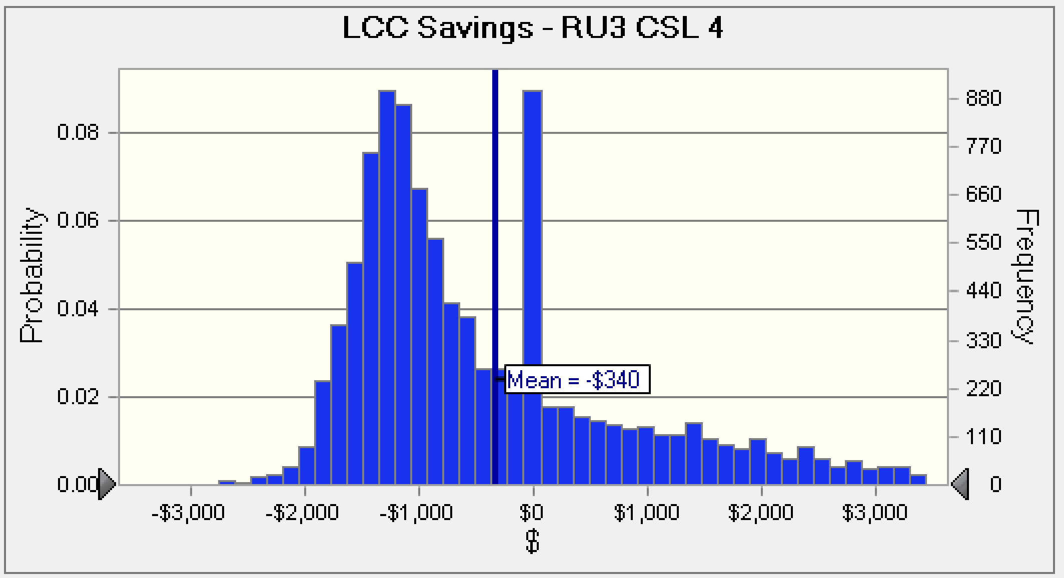

Figure 8B.1.14 **Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 4**

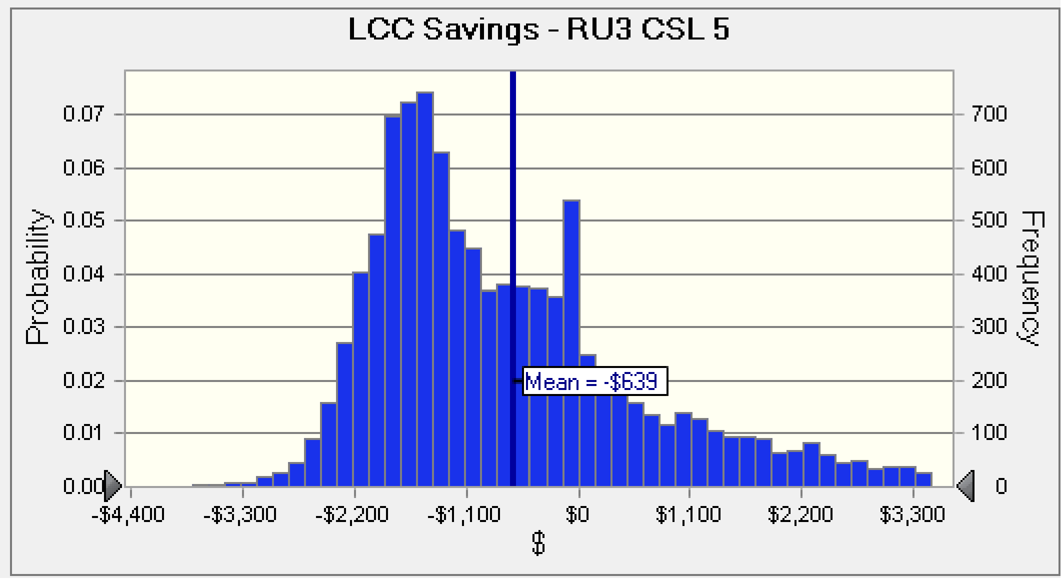

Figure 8B.1.15 **Representative Unit 3: Distribution of Life-Cycle Cost Savings for CSL 5**

8B.1.4 Representative Unit 4, Design C, 5 hp, 4 Poles, Enclosed

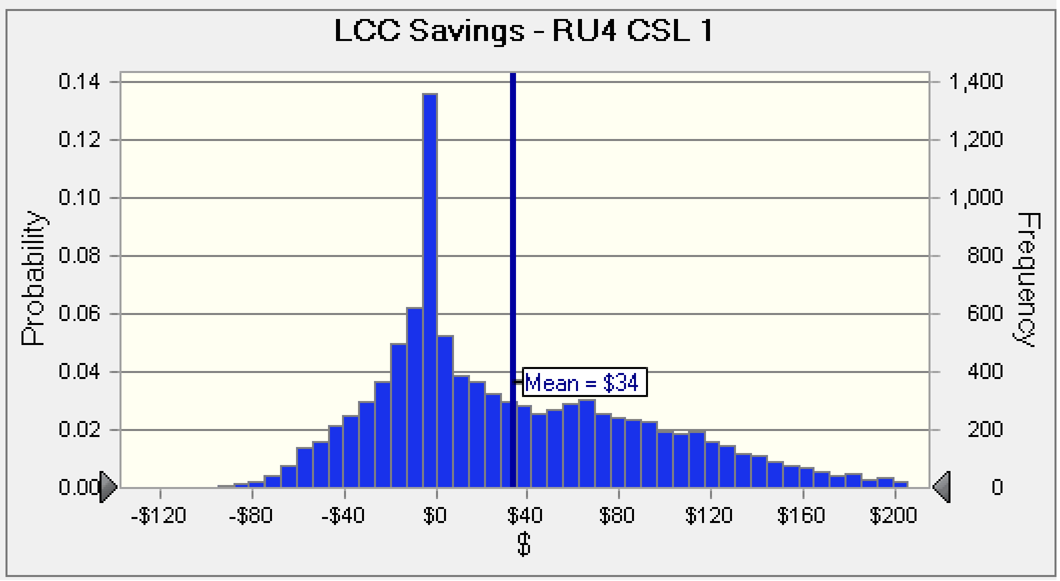

Figure 8B.1.16 Representative Unit 4: Distribution of Life-Cycle Cost Savings for CSL 1

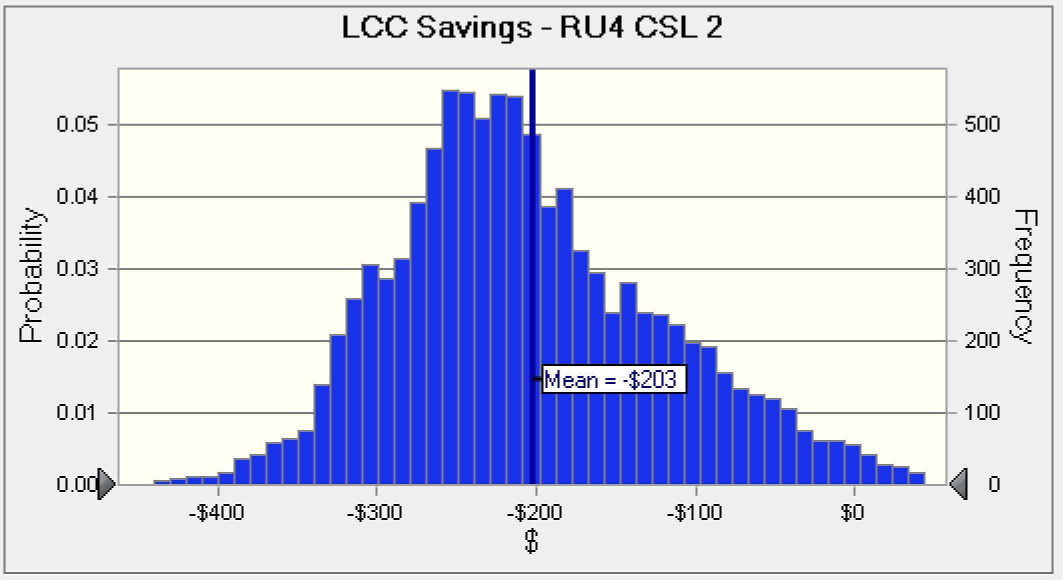

Figure 8B.1.17 Representative Unit 4: Distribution of Life-Cycle Cost Savings for CSL 2

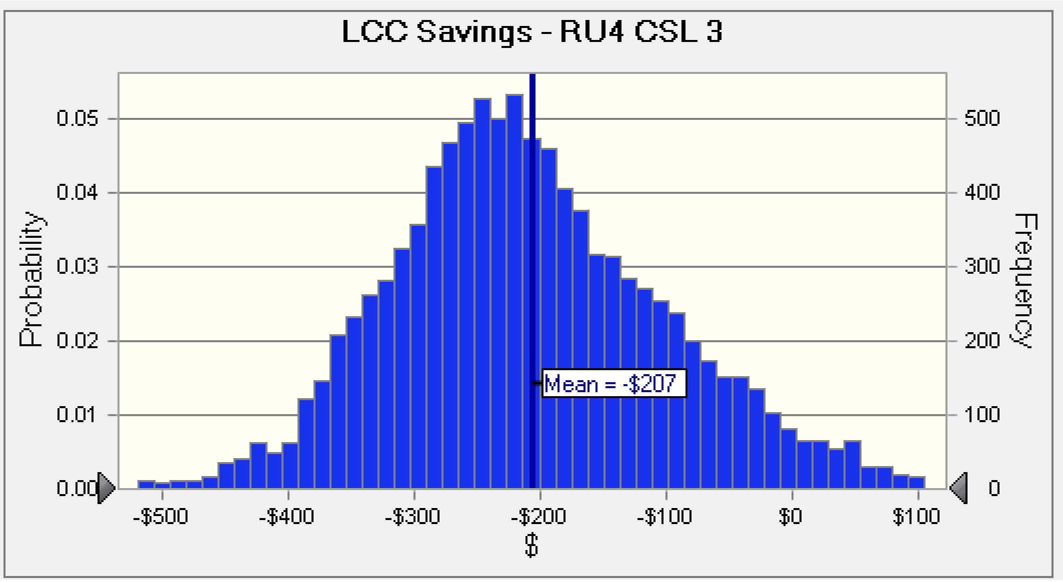

Figure 8B.1.18 **Representative Unit 4: Distribution of Life-Cycle Cost Savings for CSL 3**

8B.1.5 Representative Unit 5, Design C, 50 hp, 4 Poles, Enclosed

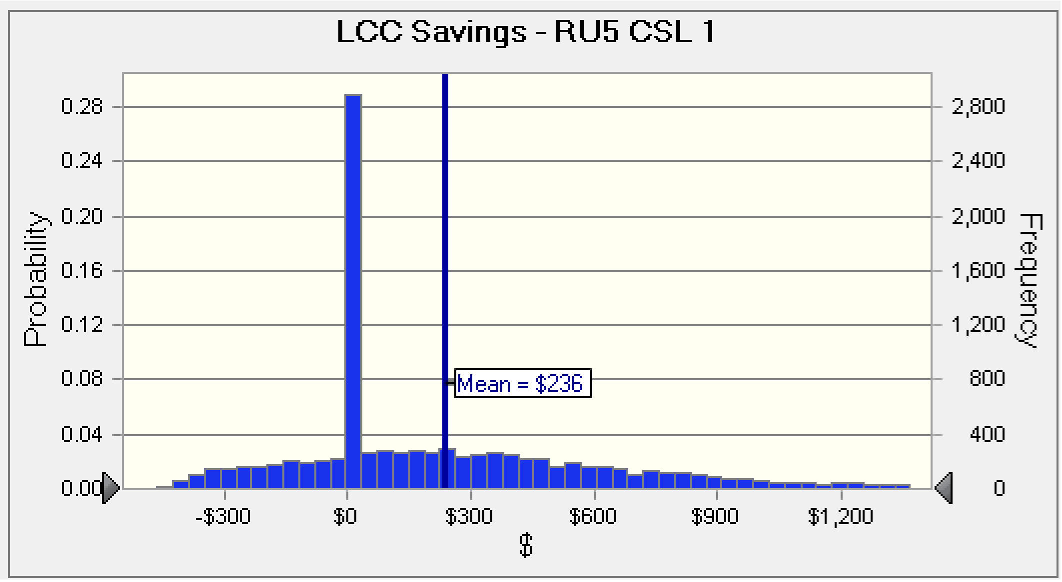

Figure 8B.1.19 **Representative Unit 5: Distribution of Life-Cycle Cost Savings for CSL 1**

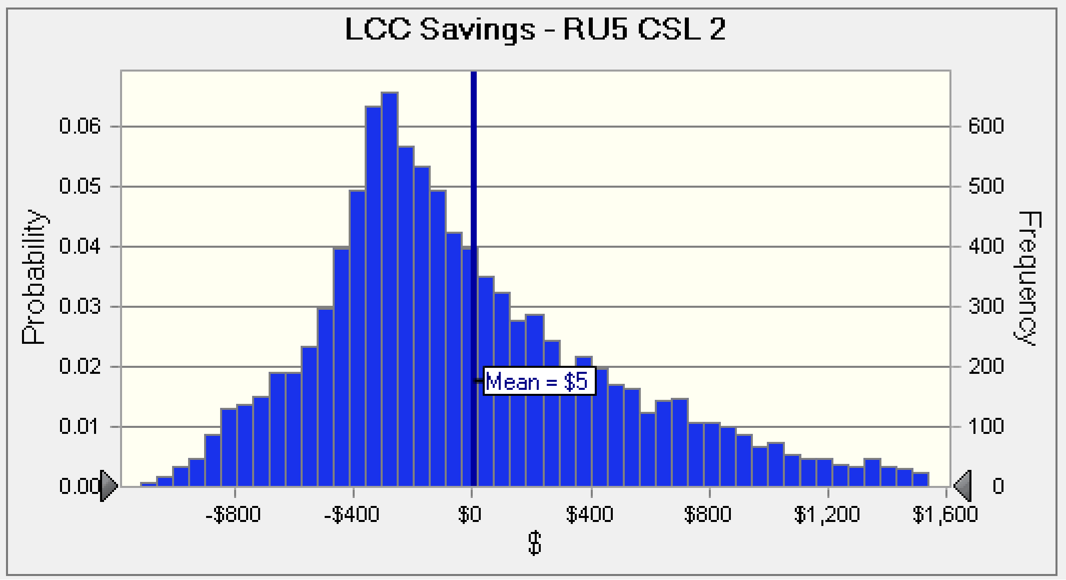

Figure 8B.1.20 **Representative Unit 5: Distribution of Life-Cycle Cost Savings for CSL 2**

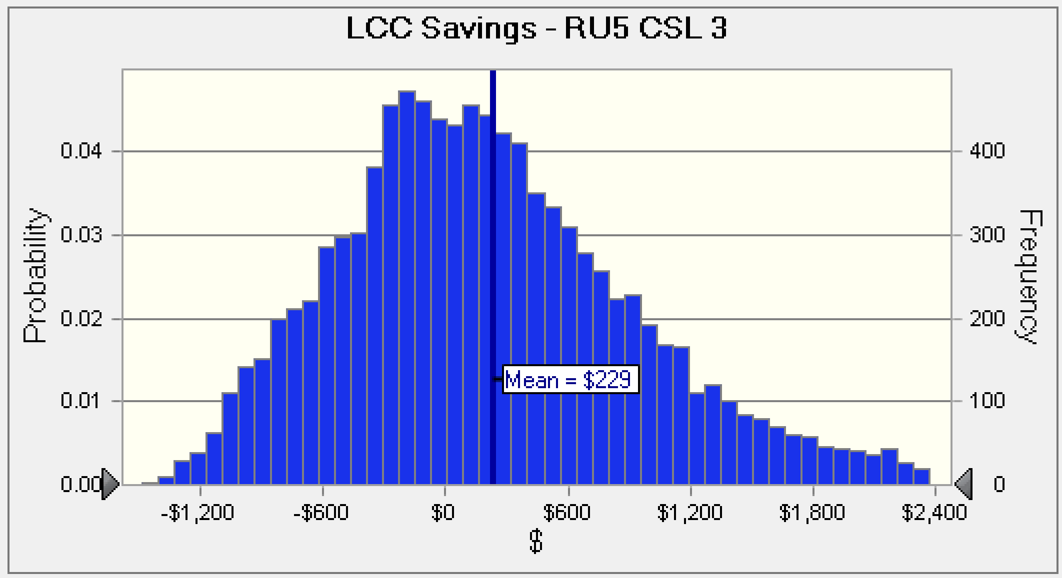

Figure 8B.1.21 **Representative Unit 5: Distribution of Life-Cycle Cost Savings for CSL 3**

8B.1.6 Representative Unit 6, Fire Pump, 5 hp, 4 Poles, Enclosed

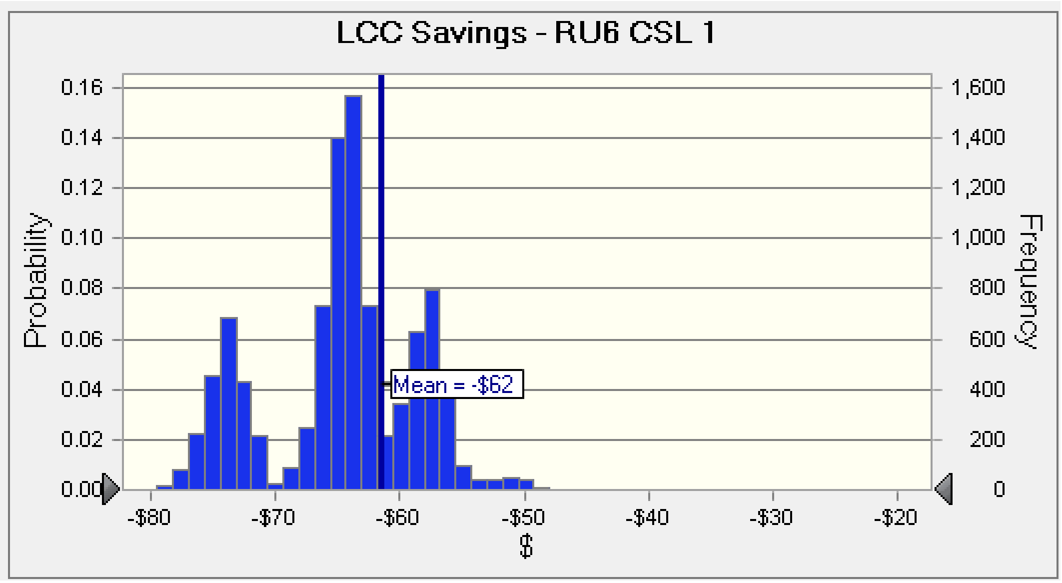

Figure 8B.1.22 Representative Unit 6: Distribution of Life-Cycle Cost Savings for CSL 1

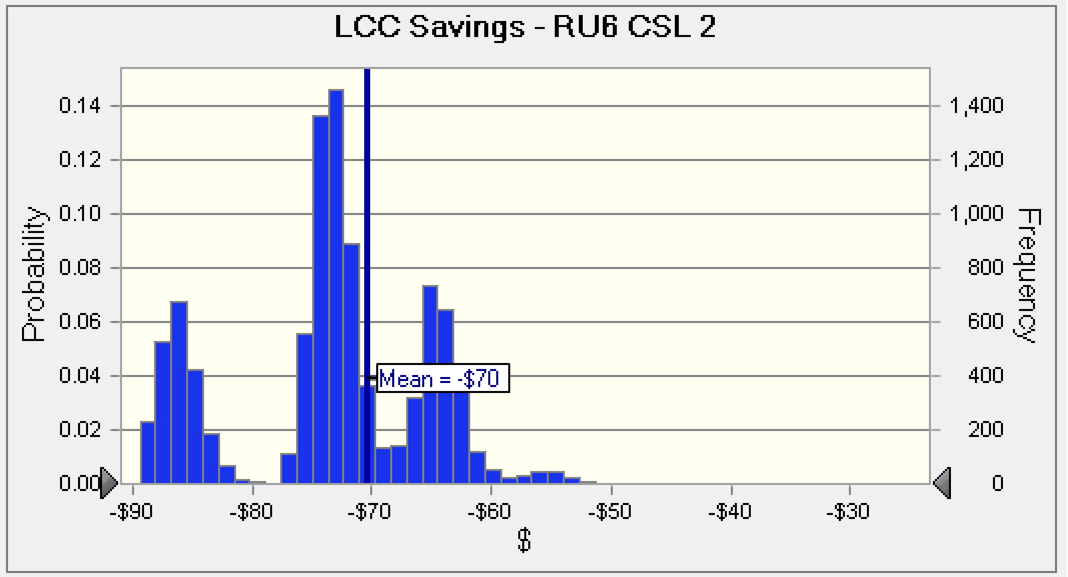

Figure 8B.1.23 Representative Unit 6: Distribution of Life-Cycle Cost Savings for CSL 2

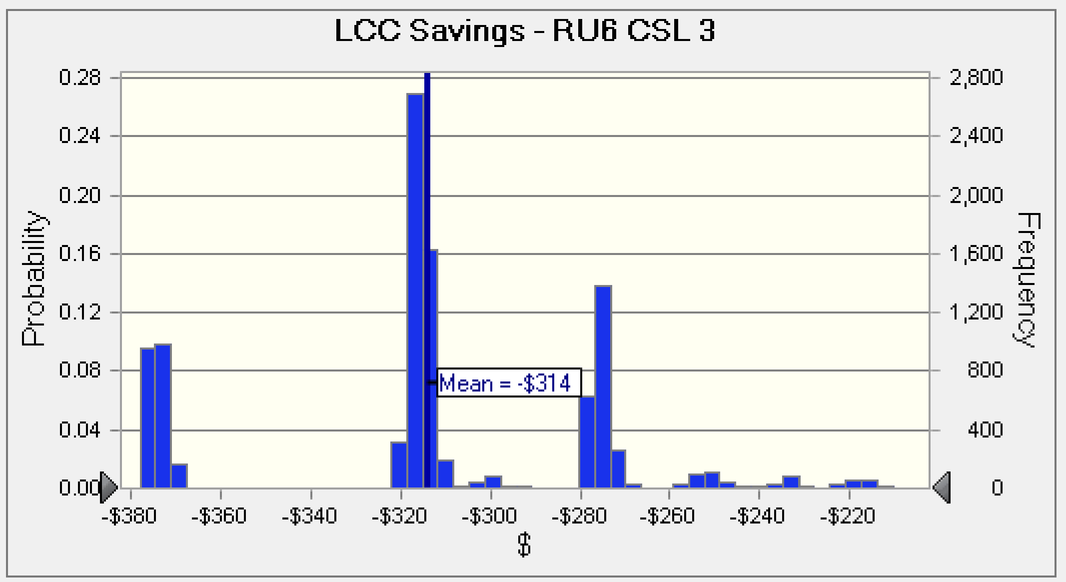

Figure 8B.1.24 **Representative Unit 6: Distribution of Life-Cycle Cost Savings for CSL 3**

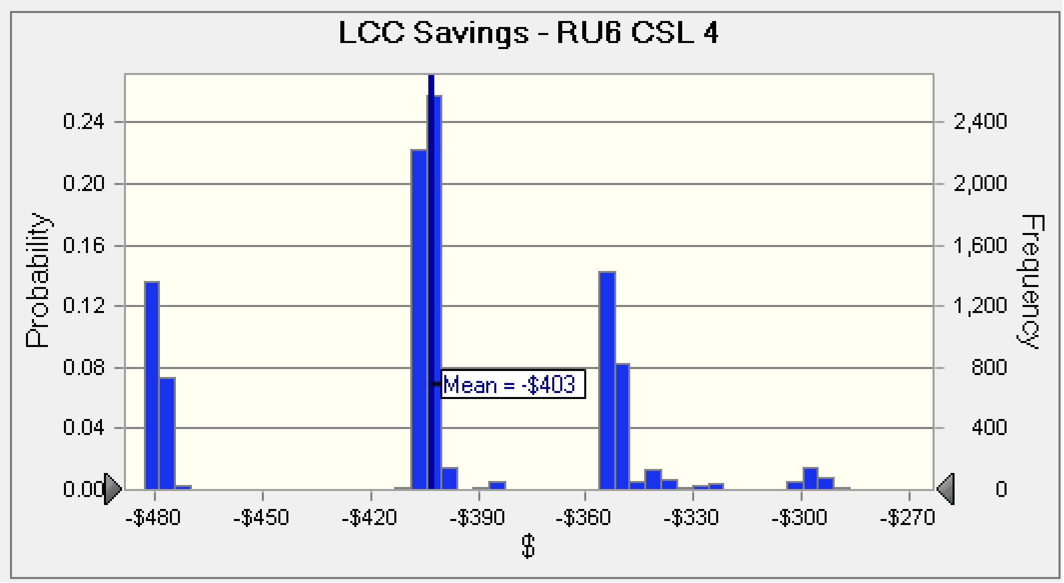

Figure 8B.1.25 **Representative Unit 6: Distribution of Life-Cycle Cost Savings for CSL 4**

8B.1.7 Representative Unit 7, Fire Pump, 30 hp, 4 Poles, Enclosed

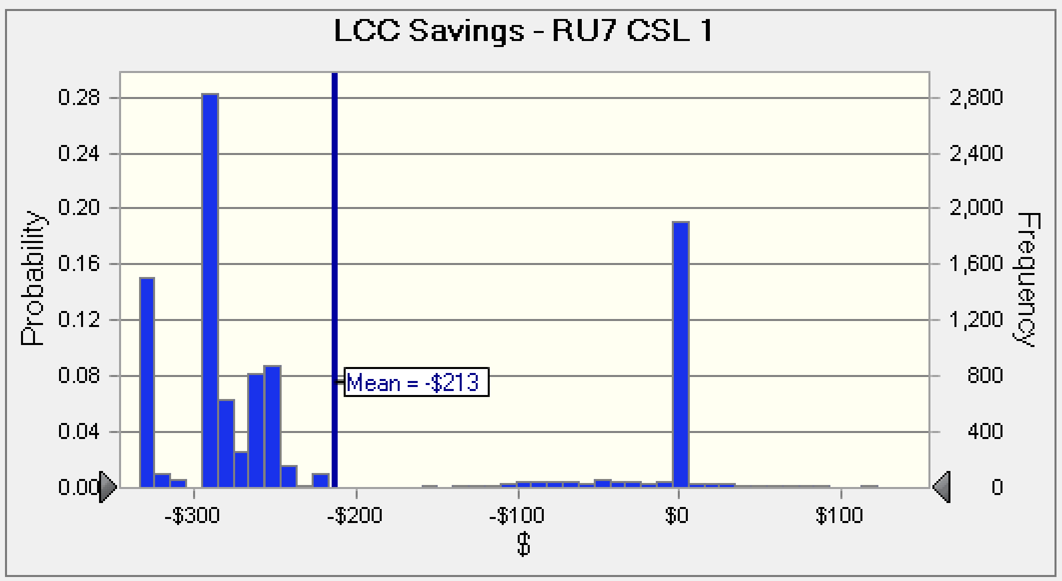

Figure 8B.1.26 Representative Unit 7: Distribution of Life-Cycle Cost Savings for CSL 1

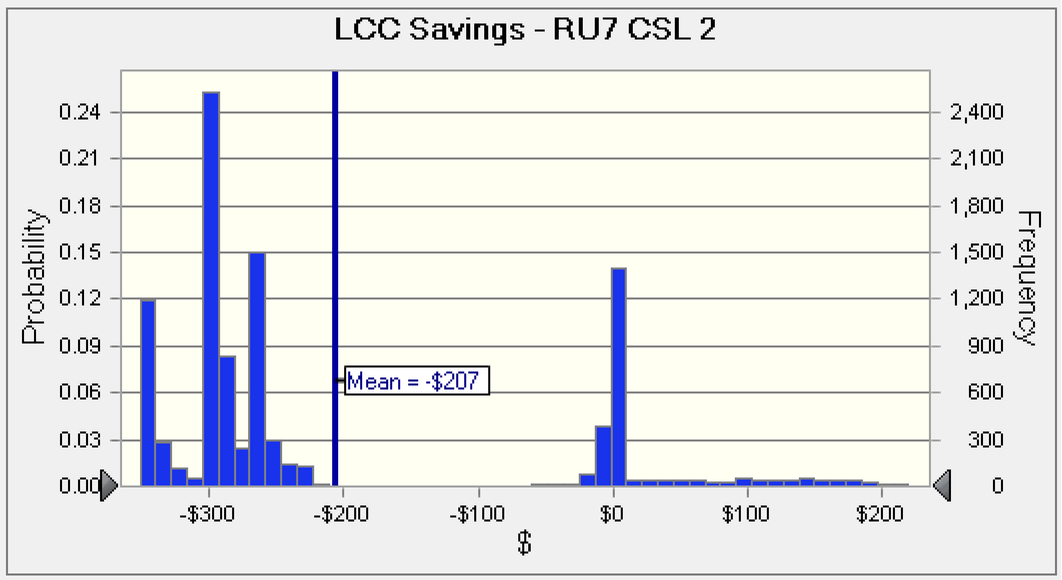

Figure 8B.1.27 Representative Unit 7: Distribution of Life-Cycle Cost Savings for CSL 2

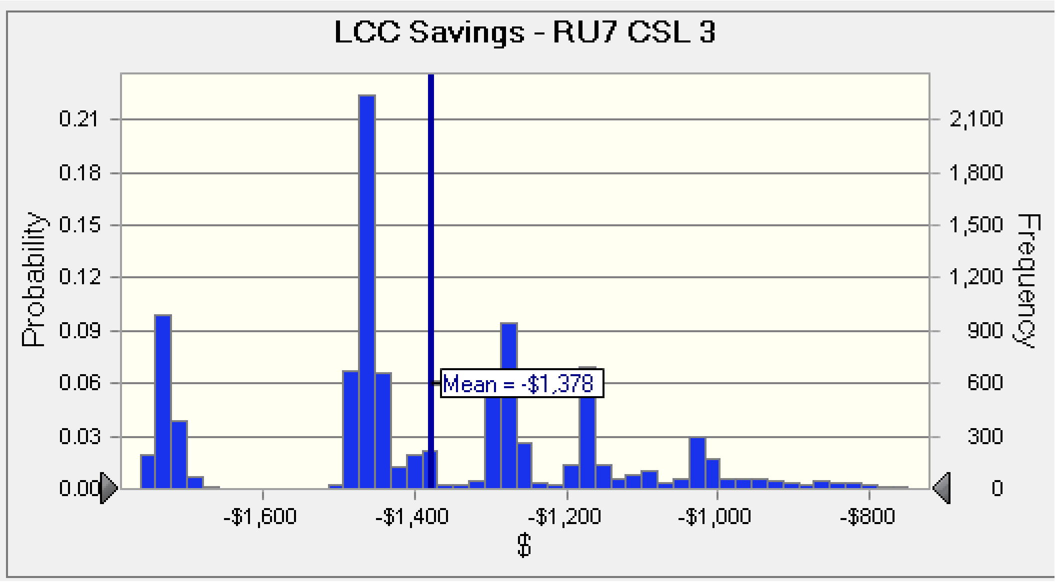

Figure 8B.1.28 **Representative Unit 7: Distribution of Life-Cycle Cost Savings for CSL 3**

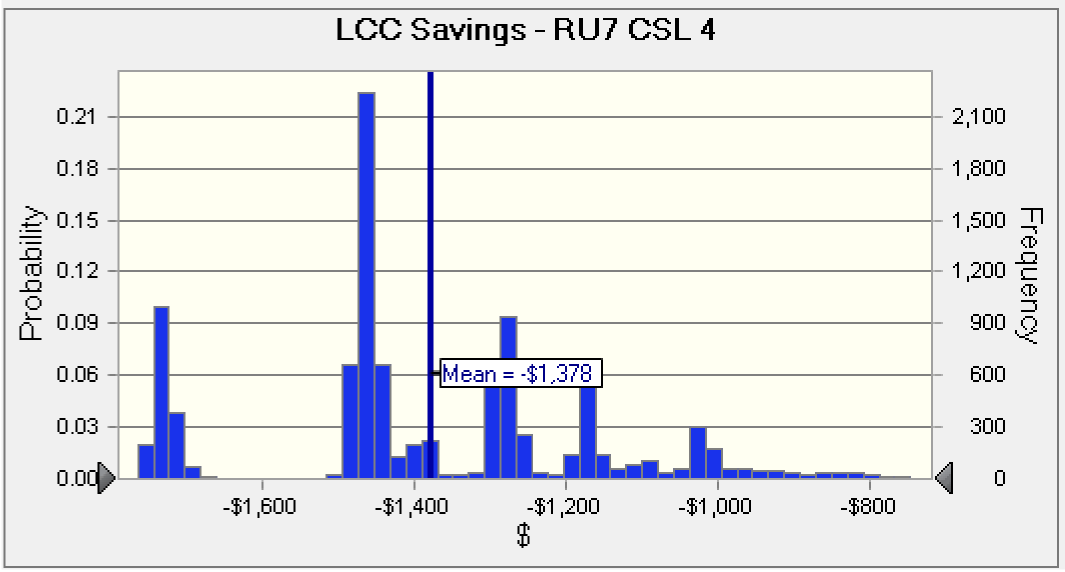

Figure 8B.1.29 **Representative Unit 7: Distribution of Life-Cycle Cost Savings for CSL 4**

8B.1.8 Representative Unit 8, Fire Pump, 75 hp, 4 Poles, Enclosed

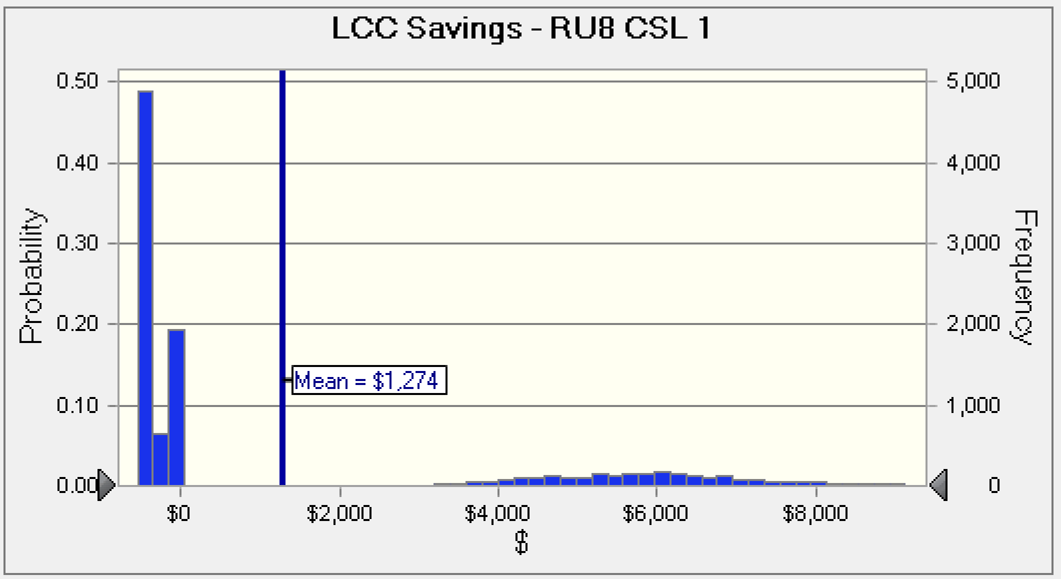

Figure 8B.1.30 Representative Unit 8: Distribution of Life-Cycle Cost Savings for CSL 1

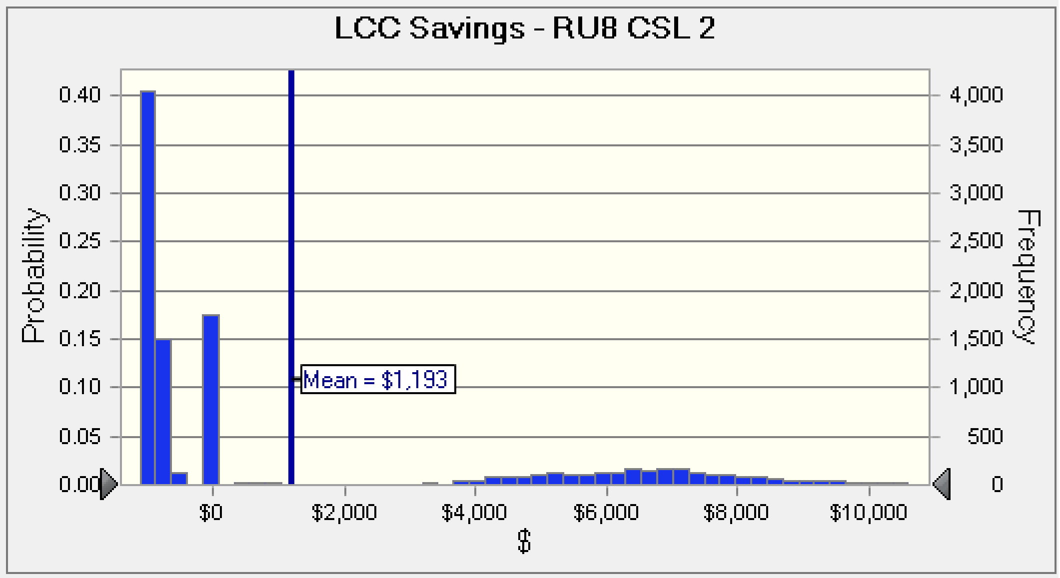

Figure 8B.1.31 Representative Unit 8: Distribution of Life-Cycle Cost Savings for CSL 2

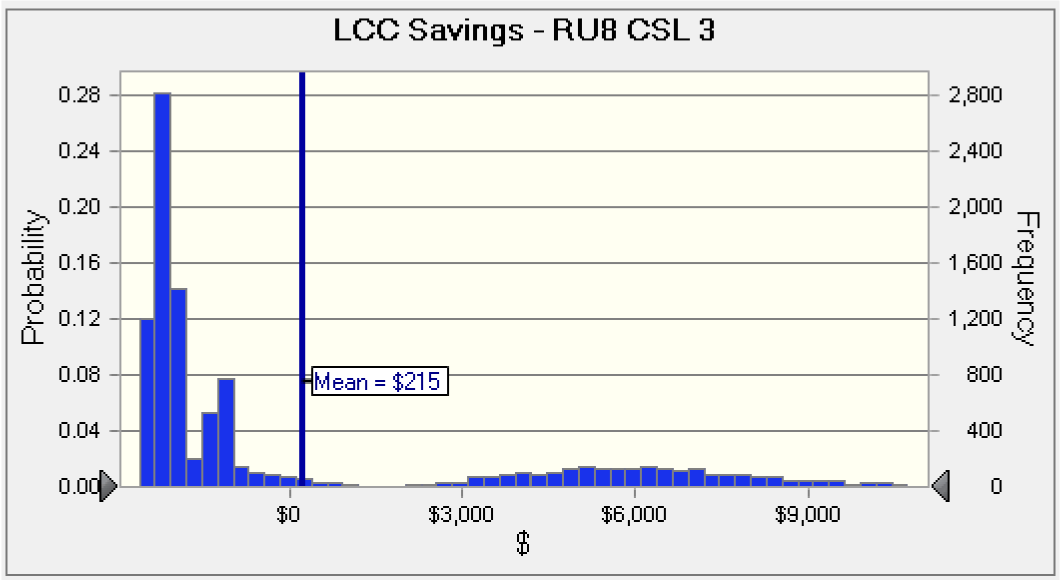

Figure 8B.1.32 **Representative Unit 8: Distribution of Life-Cycle Cost Savings for CSL 3**

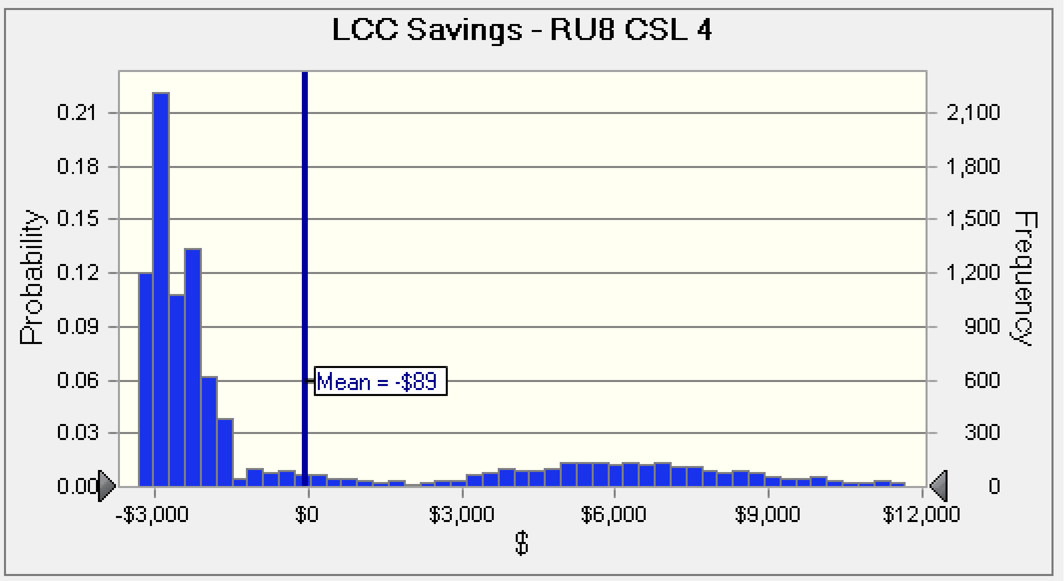

Figure 8B.1.33 **Representative Unit 8: Distribution of Life-Cycle Cost Savings for CSL 4**

8B.2 DISTRIBUTION OF PAYBACK PERIOD RESULTS

8B.2.1 Representative Unit 1, Design B, 5 hp, 4 Poles, Enclosed

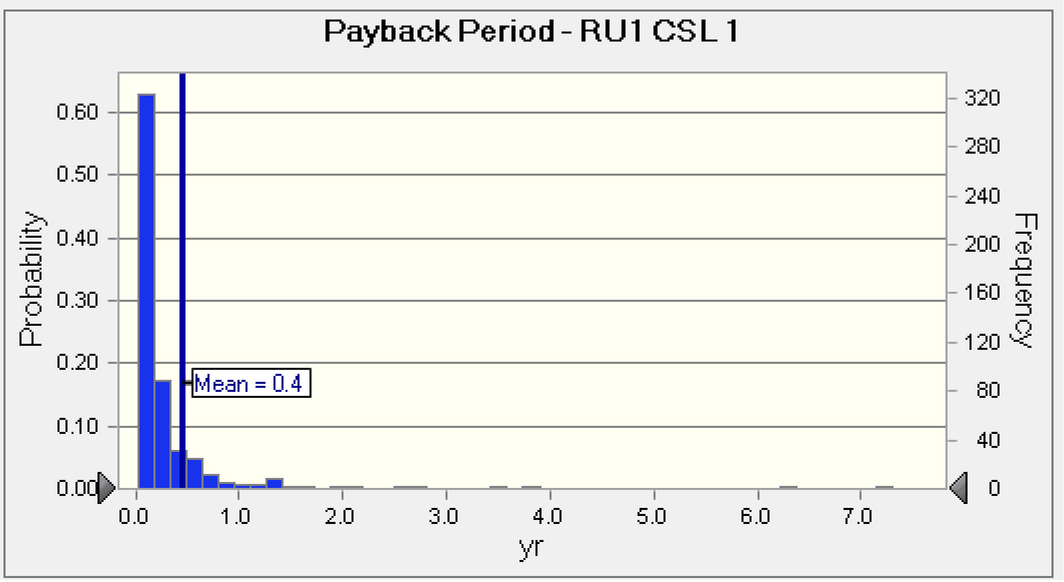

Figure 8B.2.1 Representative Unit 1: Distribution of Payback Periods for CSL 1

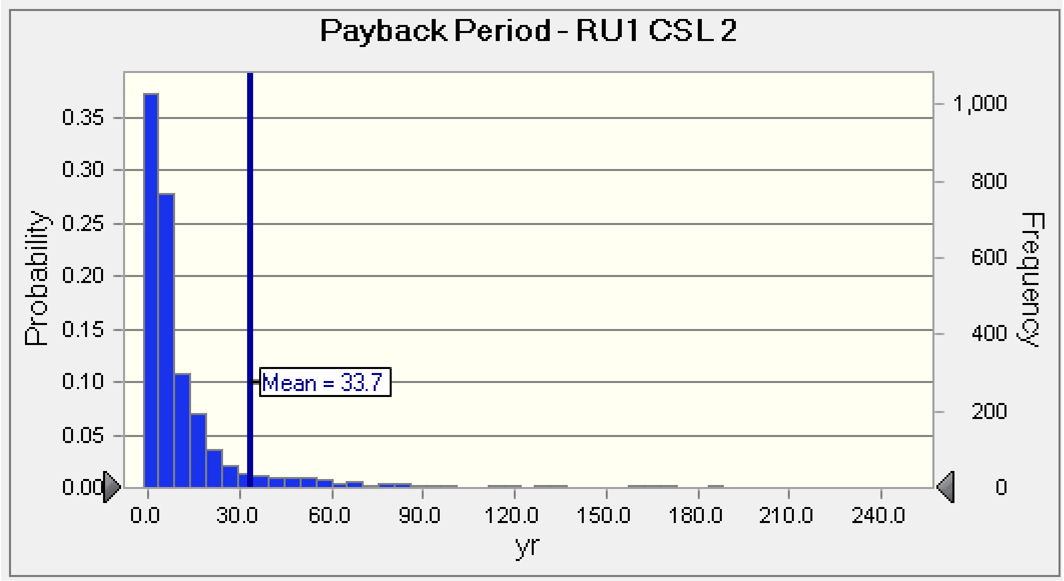

Figure 8B.2.2 Representative Unit 1: Distribution of Payback Periods for CSL 2

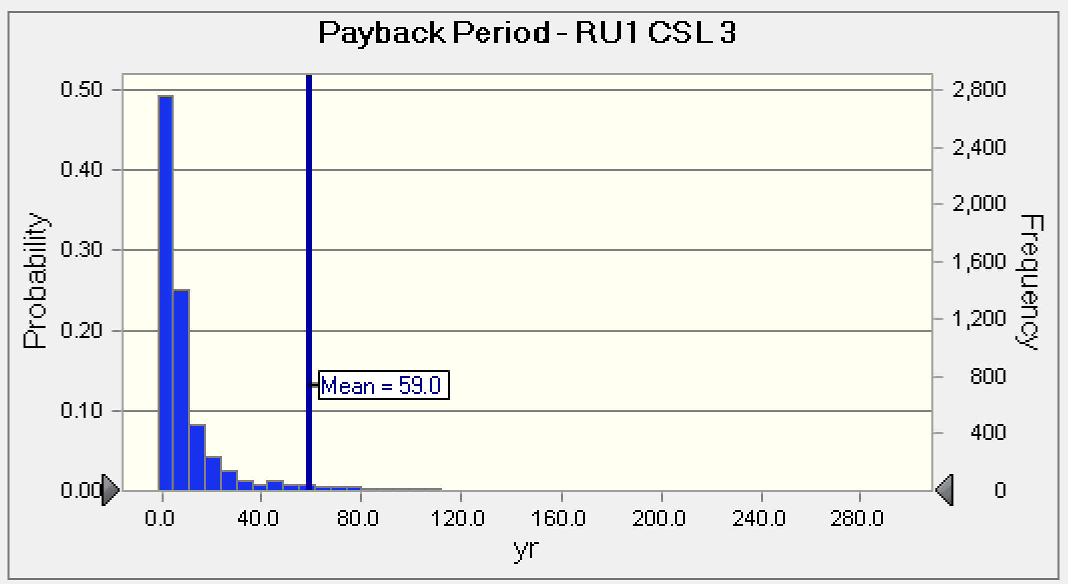

Figure 8B.2.3 **Representative Unit 1: Distribution of Payback Periods for CSL 3**

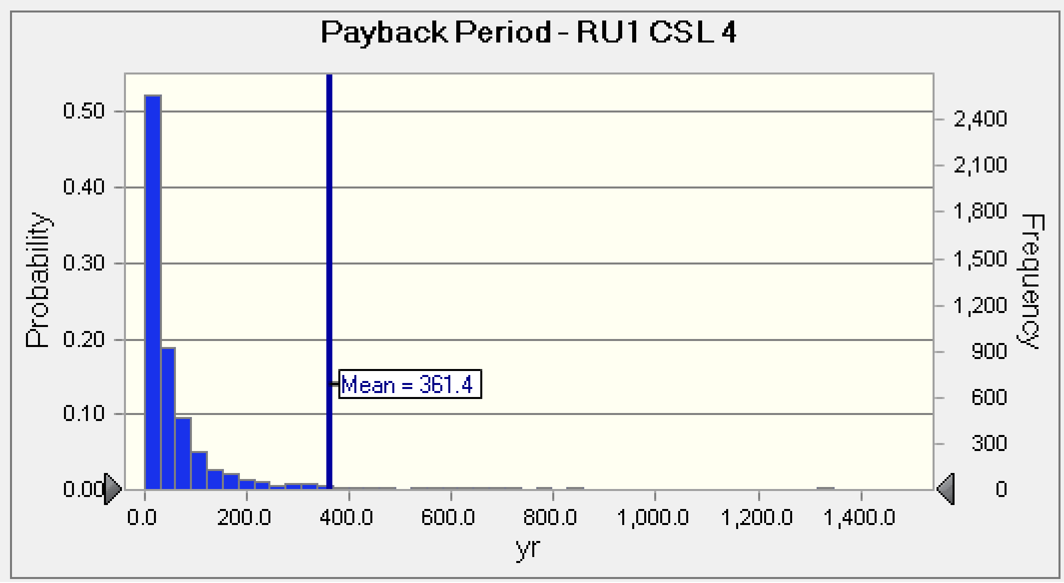

Figure 8B.2.4 **Representative Unit 1: Distribution of Payback Periods for CSL 4**

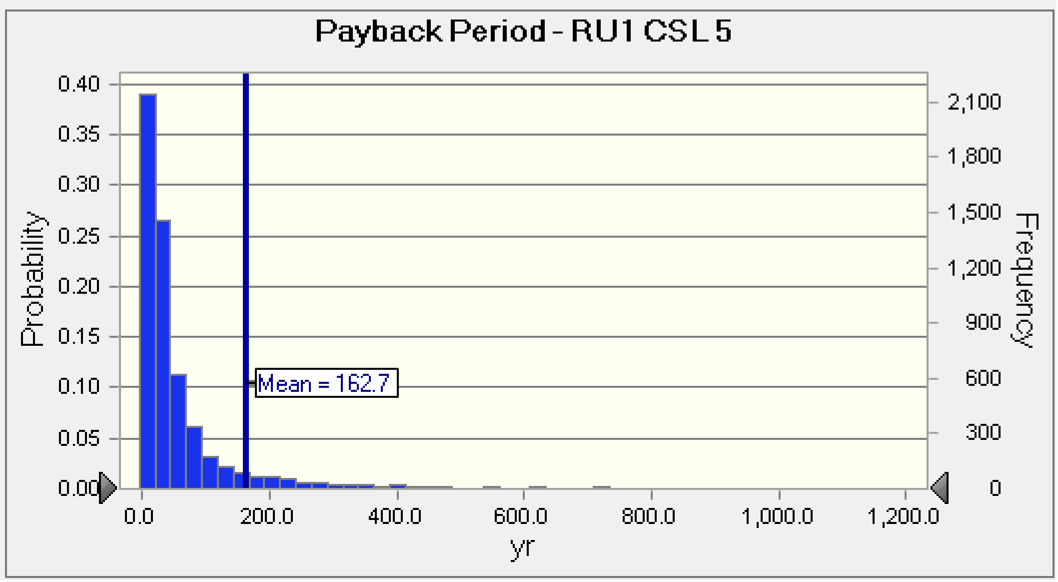

Figure 8B.2.5 Representative Unit 1: Distribution of Payback Periods for CSL 5

8B.2.2 Representative Unit 2, Design B, 30 hp, 4 Poles, Enclosed

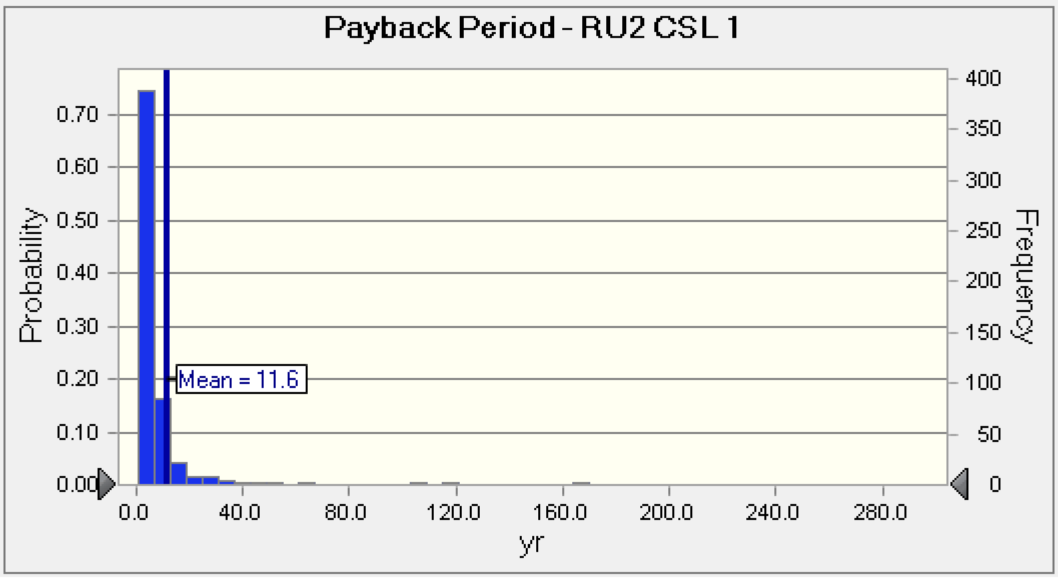

Figure 8B.2.6 Representative Unit 2: Distribution of Payback Periods for CSL 1

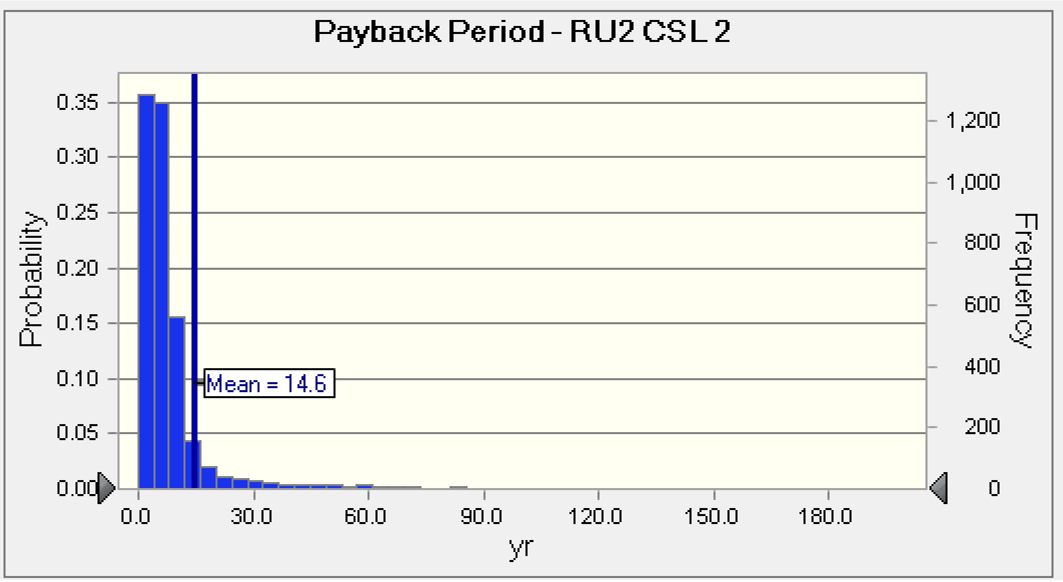

Figure 8B.2.7 **Representative Unit 2: Distribution of Payback Periods for CSL 2**

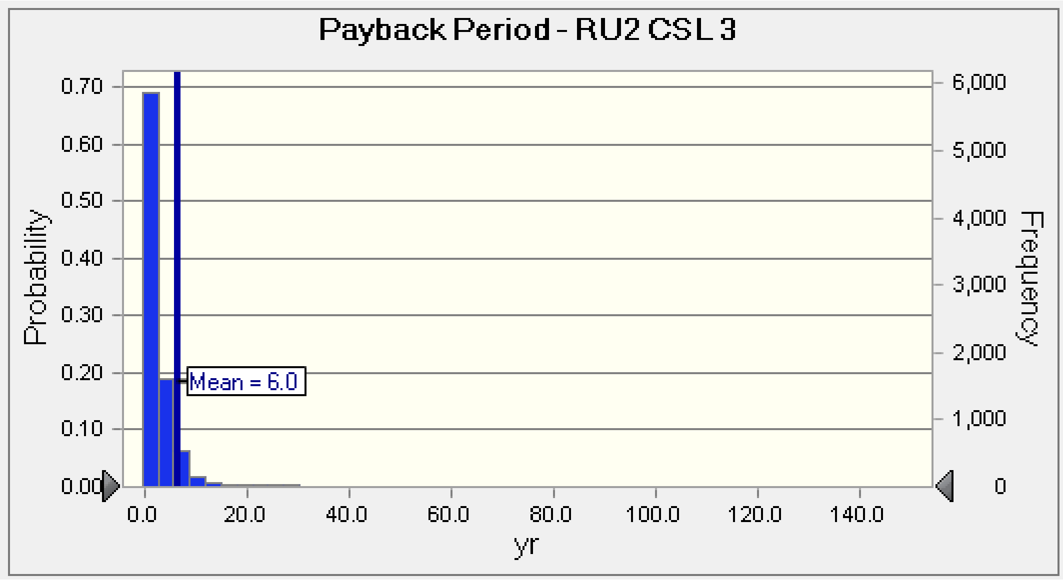

Figure 8B.2.8 **Representative Unit 2: Distribution of Payback Periods for CSL 3**

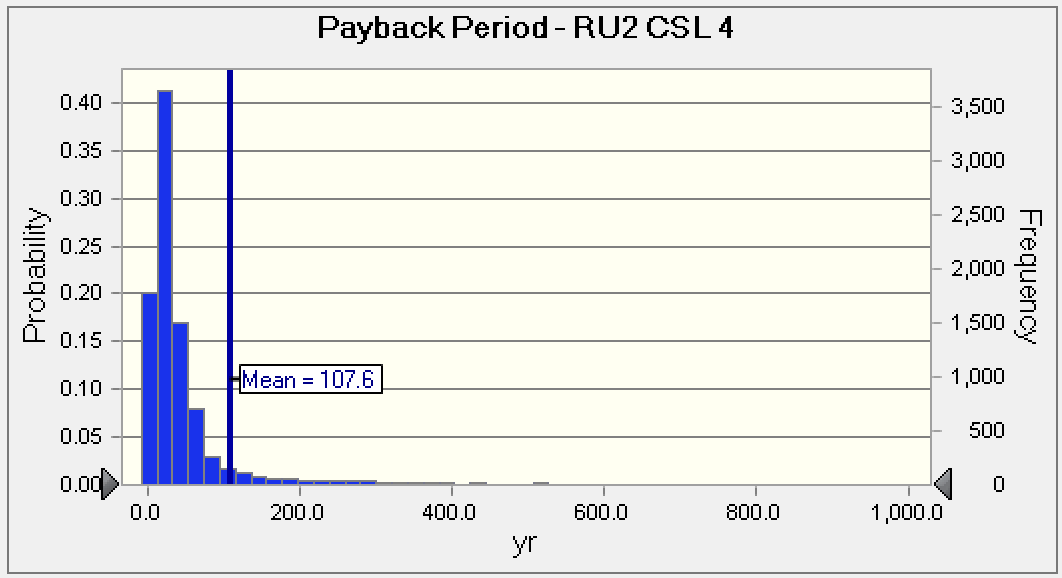

Figure 8B.2.9 Representative Unit 2: Distribution of Payback Periods for CSL 4

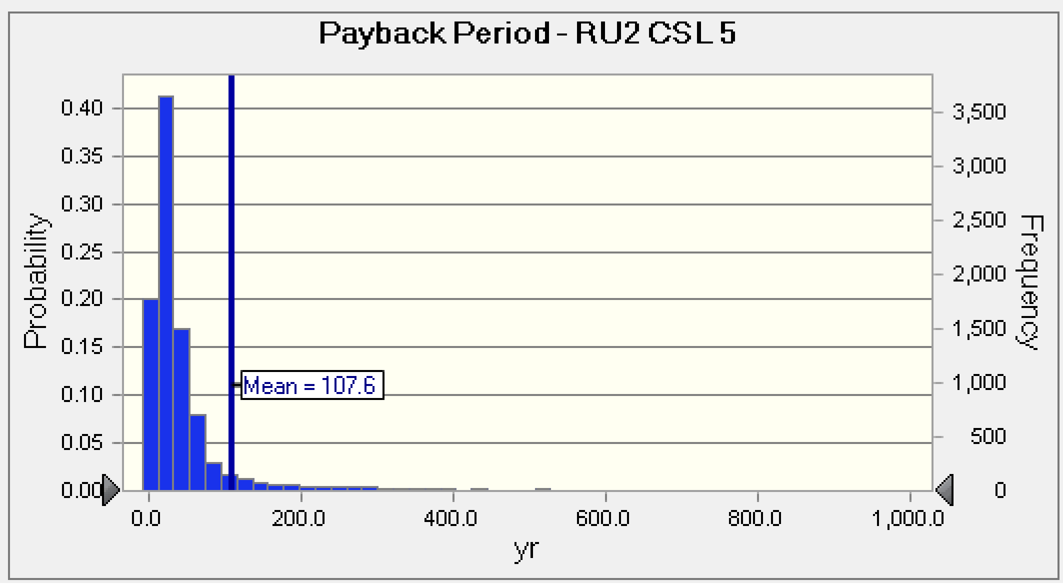

Figure 8B.2.10 Representative Unit 2: Distribution of Payback Periods for CSL 5

8B.2.3 Representative Unit 3, Design B, 75 hp, 4 Poles, Enclosed

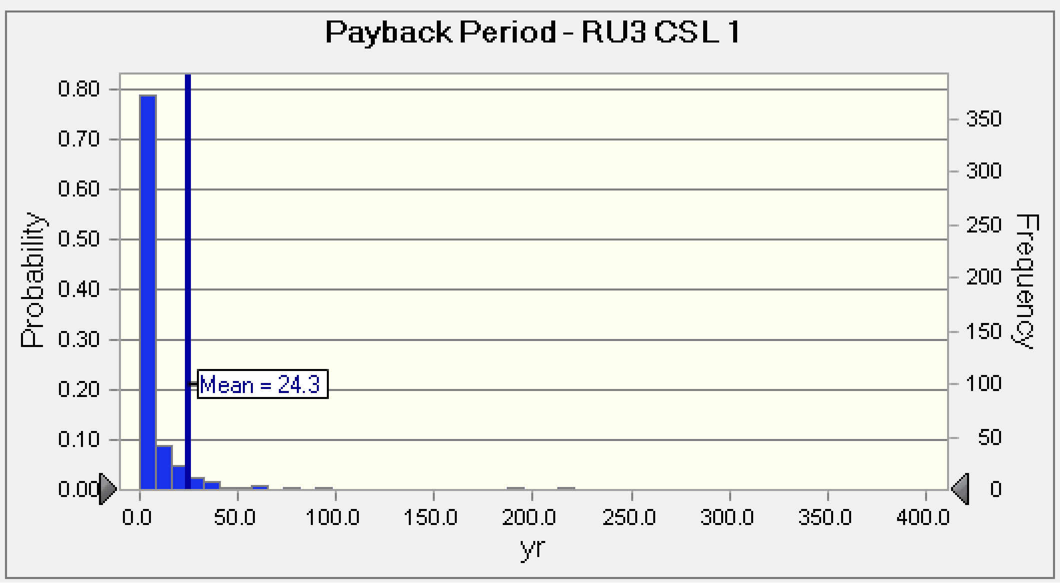

Figure 8B.2.11 Representative Unit 3: Distribution of Payback Periods for CSL 1

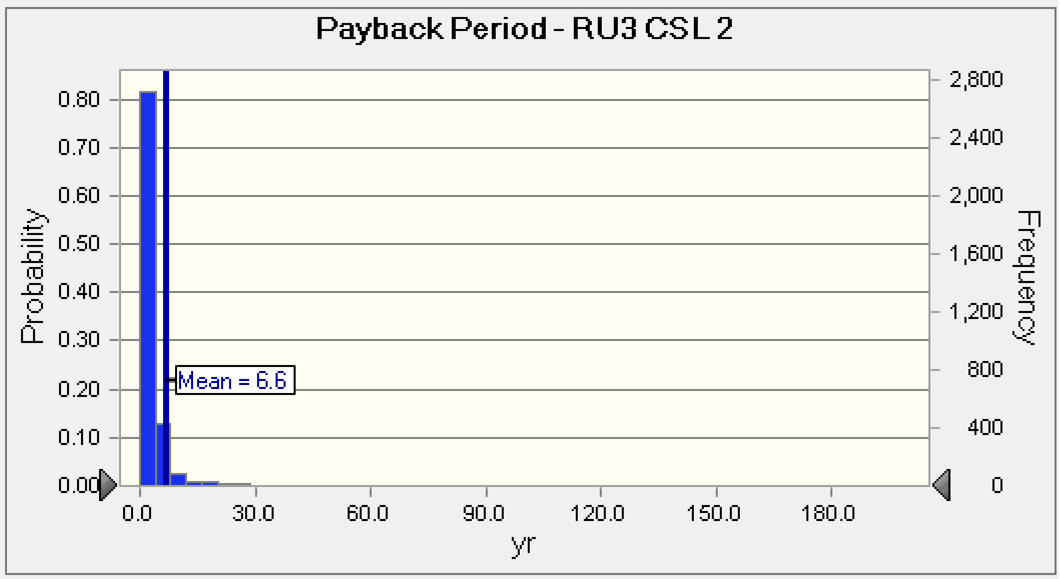

Figure 8B.2.12 Representative Unit 3: Distribution of Payback Periods for CSL 2

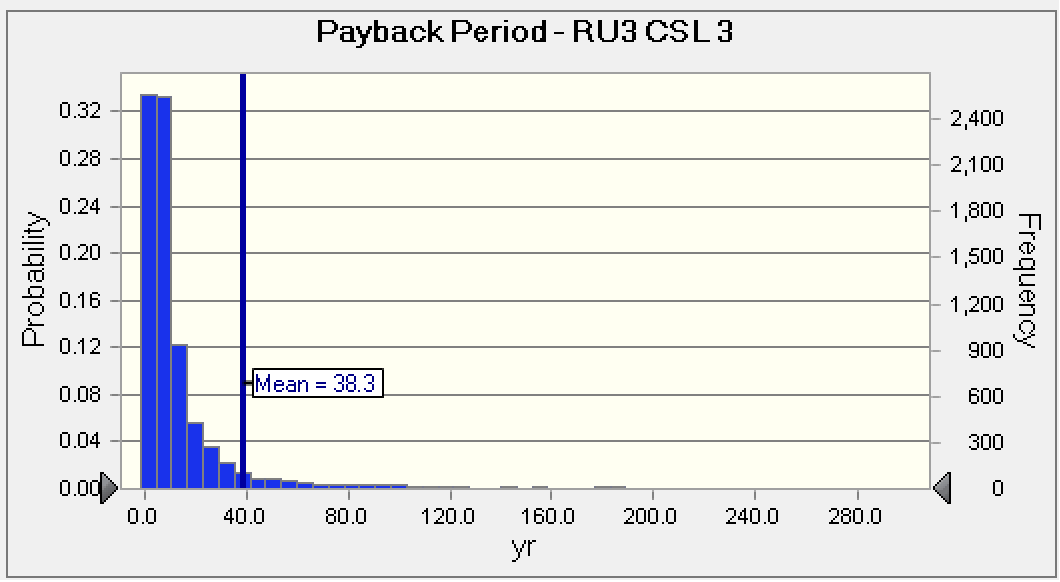

Figure 8B.2.13 **Representative Unit 3: Distribution of Payback Periods for CSL 3**

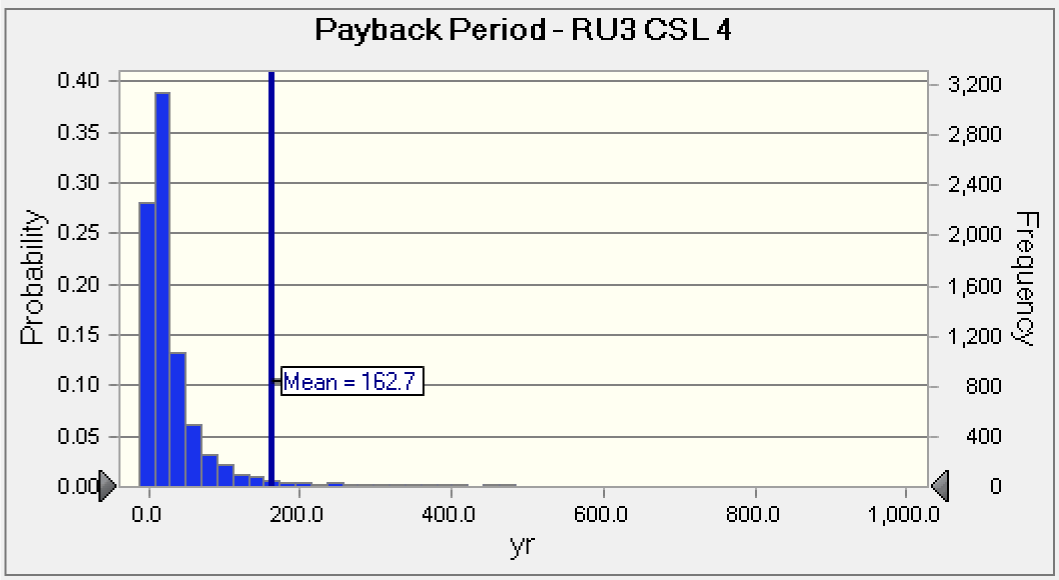

Figure 8B.2.14 **Representative Unit 3: Distribution of Payback Periods for CSL 4**

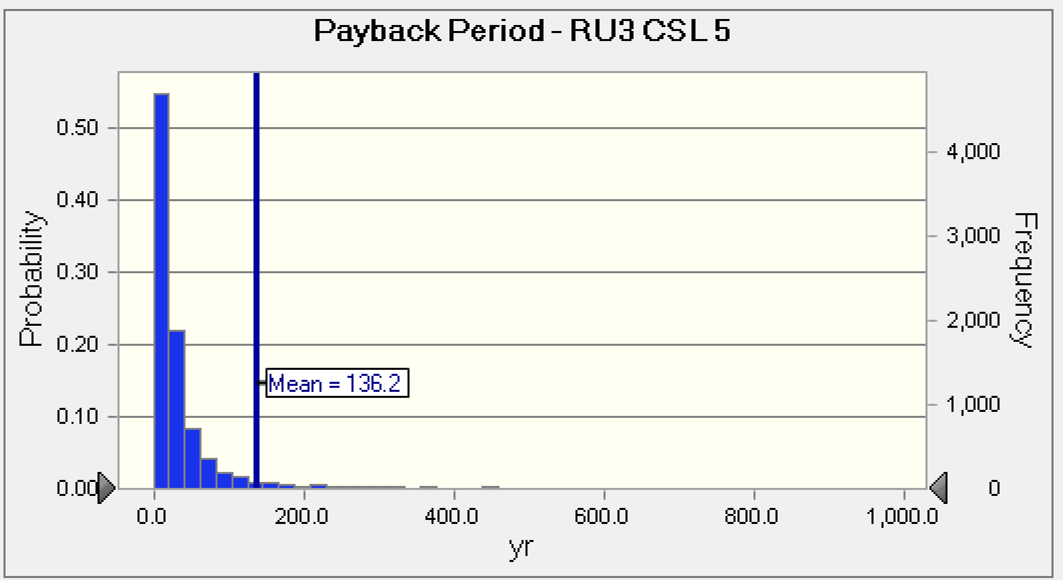

Figure 8B.2.15 Representative Unit 3: Distribution of Payback Periods for CSL 5

8B.2.4 Representative Unit 4, Design C, 5 hp, 4 Poles, Enclosed

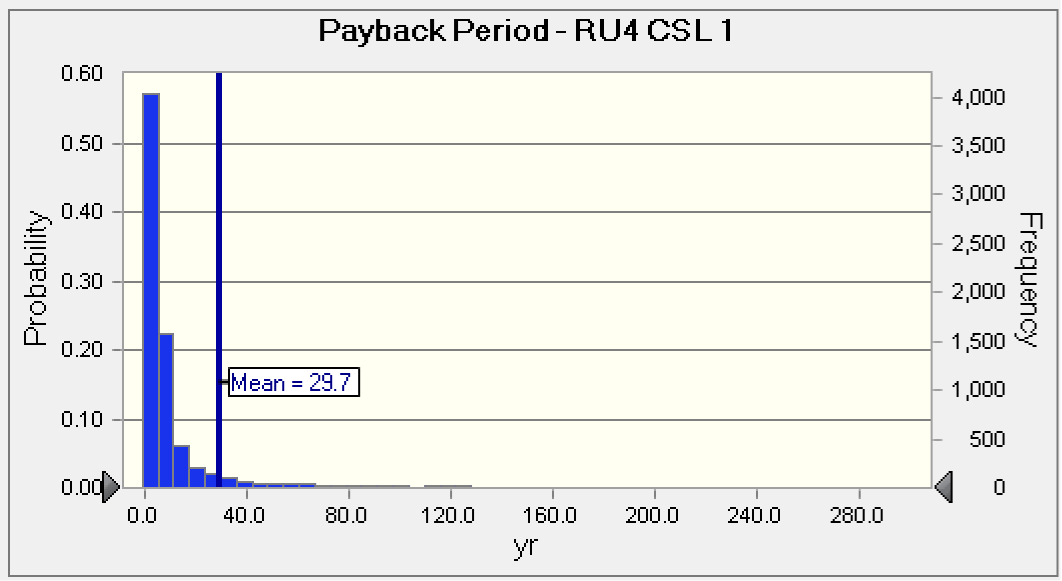

Figure 8B.2.16 Representative Unit 4: Distribution of Payback Periods for CSL 1

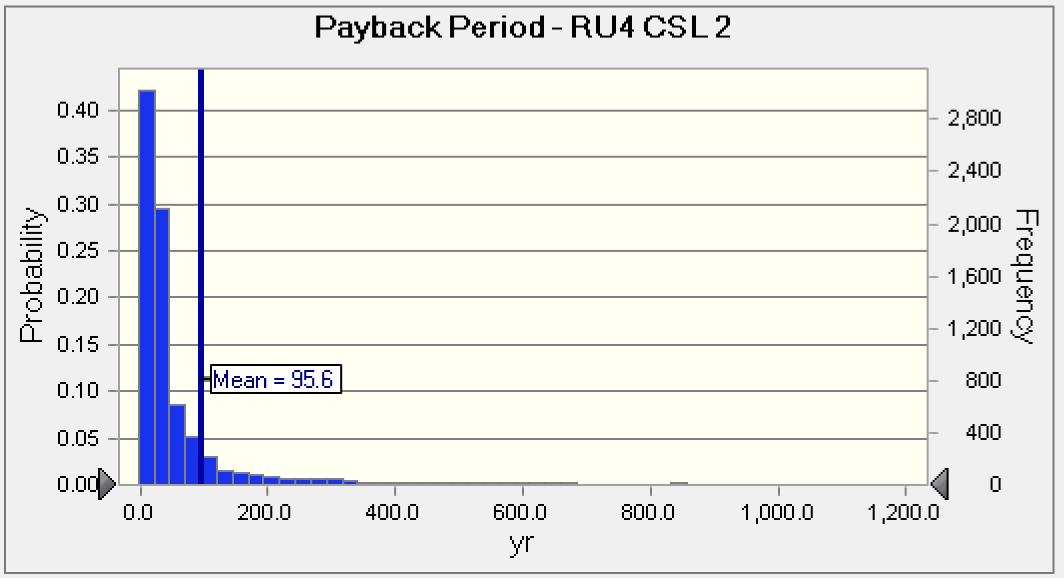

Figure 8B.2.17 **Representative Unit 4: Distribution of Payback Periods for CSL 2**

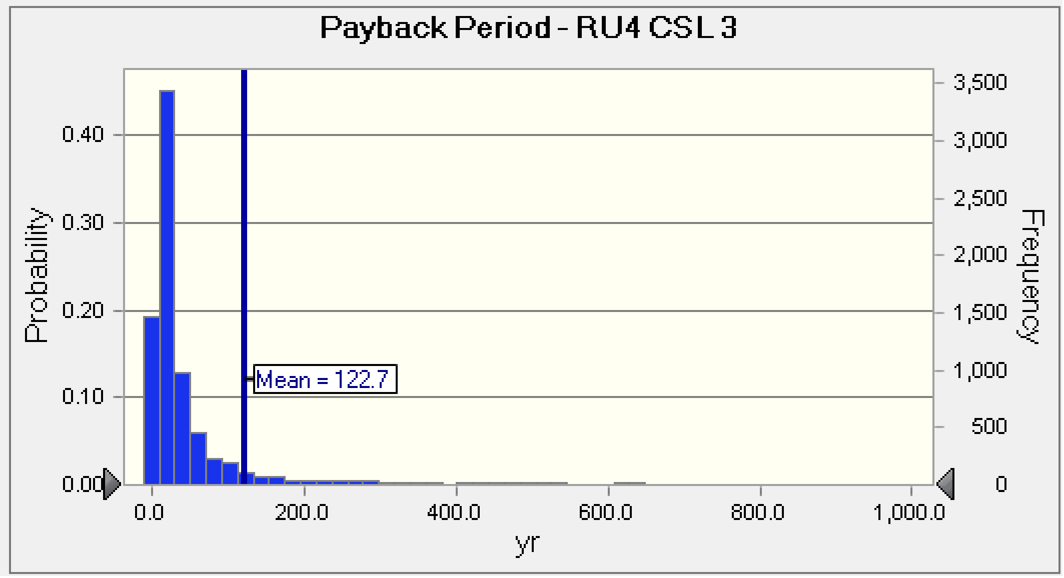

Figure 8B.2.18 **Representative Unit 4: Distribution of Payback Periods for CSL 3**

8B.2.5 Representative Unit 5, Design C, 50 hp, 4 Poles, Enclosed

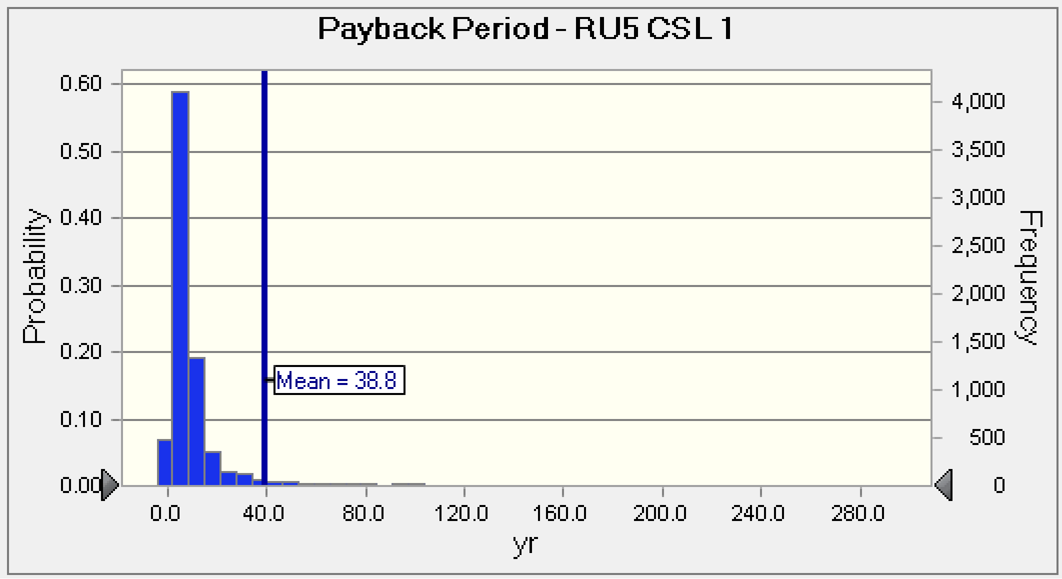

Figure 8B.2.19 Representative Unit 5: Distribution of Payback Periods for CSL 1

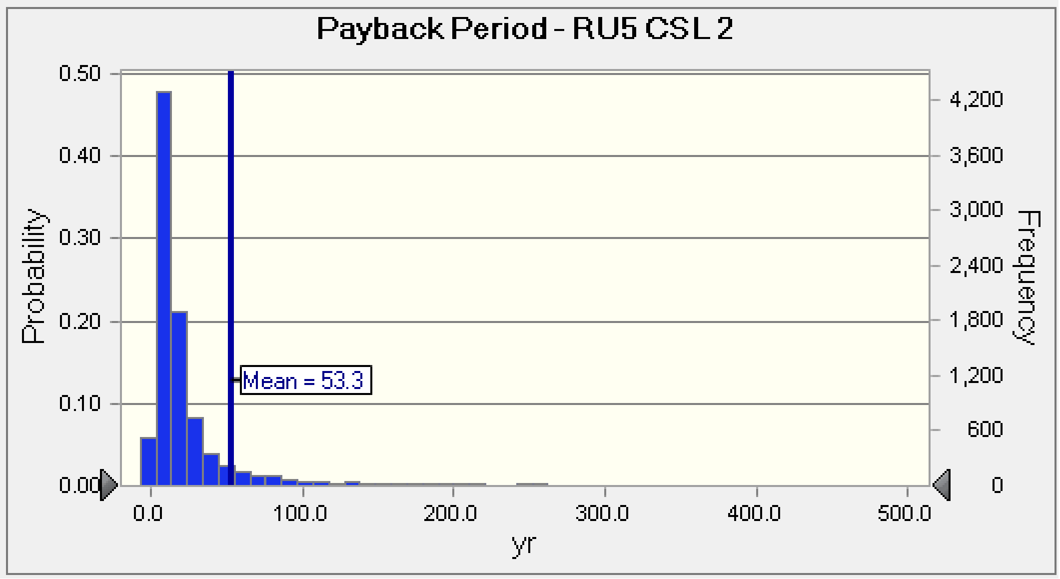

Figure 8B.2.20 Representative Unit 5: Distribution of Payback Periods for CSL 2

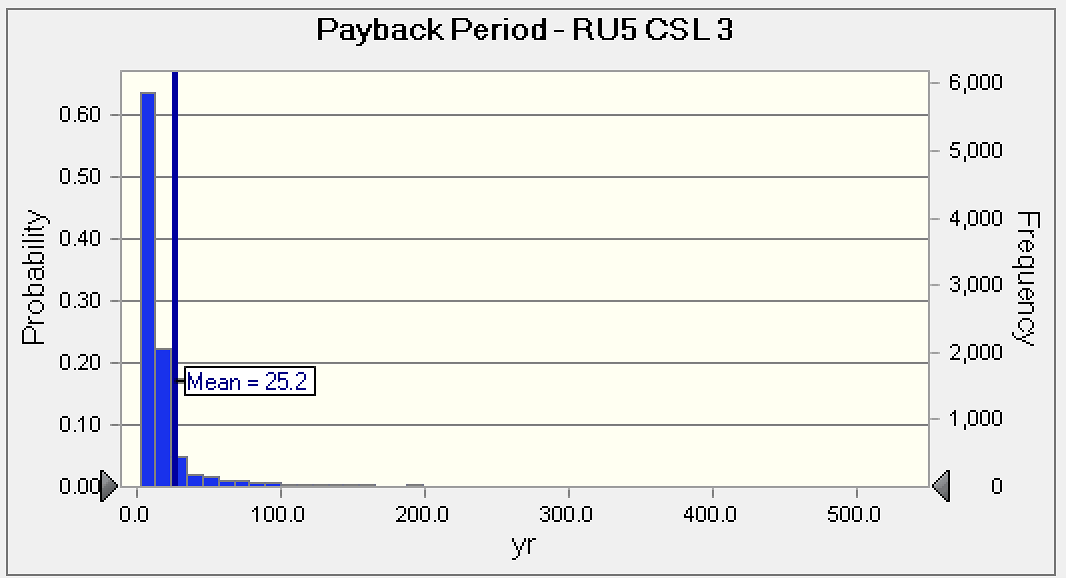

Figure 8B.2.21 Representative Unit 5: Distribution of Payback Periods for CSL 3

8B.2.6 Representative Unit 7, Fire Pump, 30 hp, 4 Poles, Enclosed

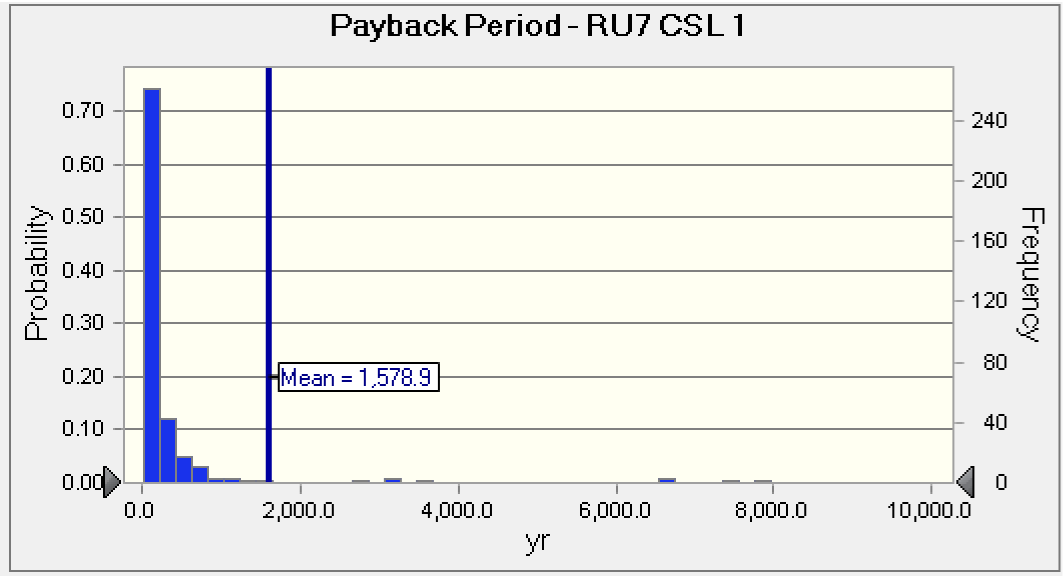

Figure 8B.2.22 Representative Unit 7: Distribution of Payback Periods for CSL 1

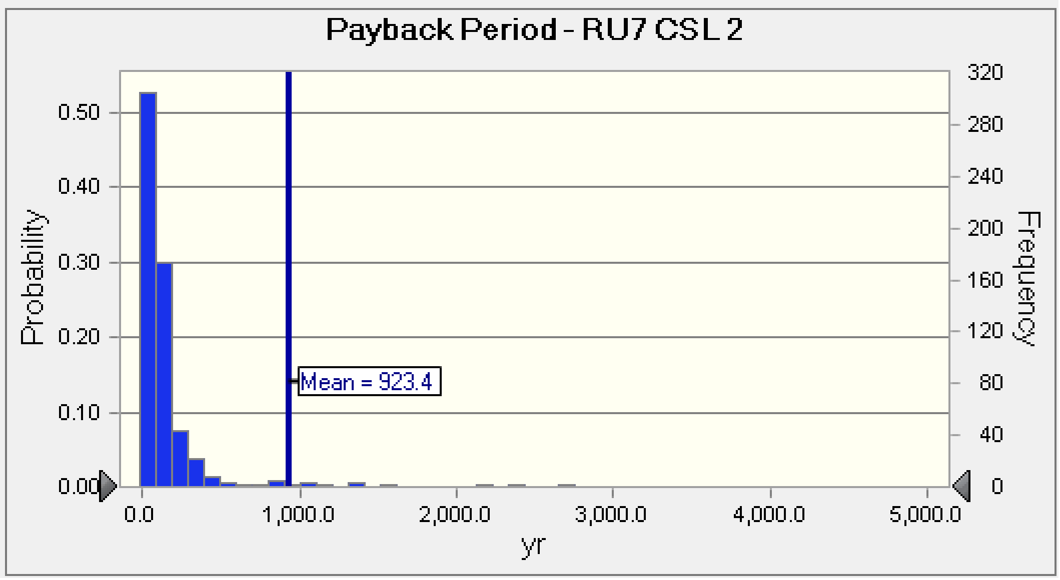

Figure 8B.2.23 **Representative Unit 7: Distribution of Payback Periods for CSL 2**

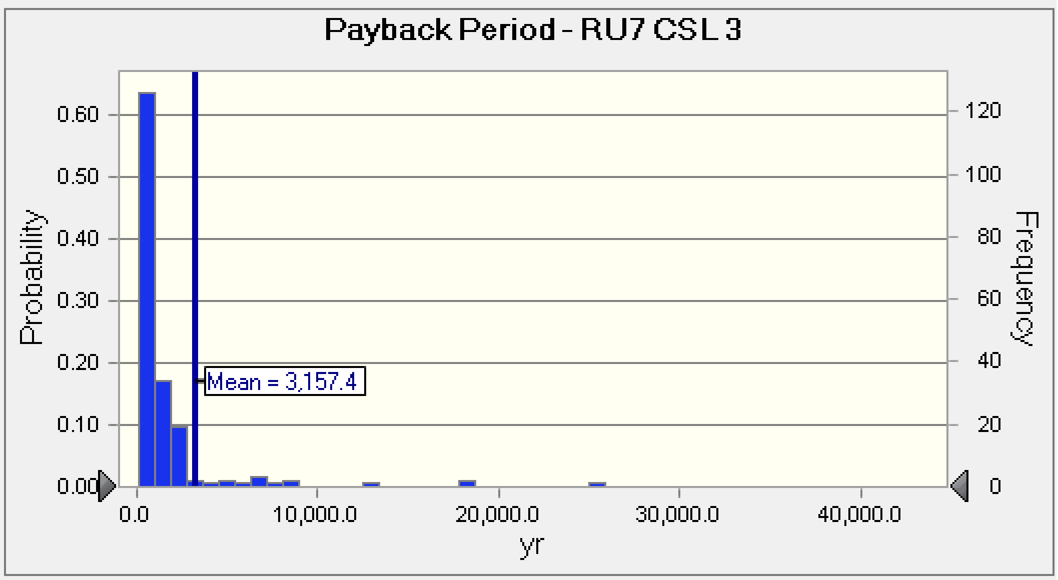

Figure 8B.2.24 **Representative Unit 7: Distribution of Payback Periods for CSL 3**

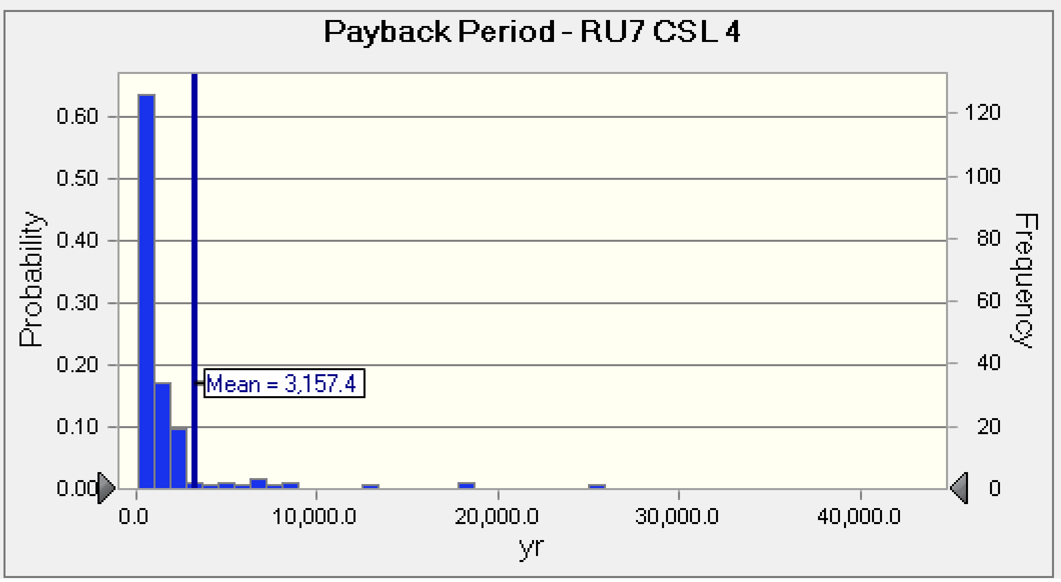

Figure 8B.2.25 **Representative Unit 7: Distribution of Payback Periods for CSL 4**

8B.2.7 Representative Unit 8, Fire Pump, 75 hp, 4 Poles, Enclosed

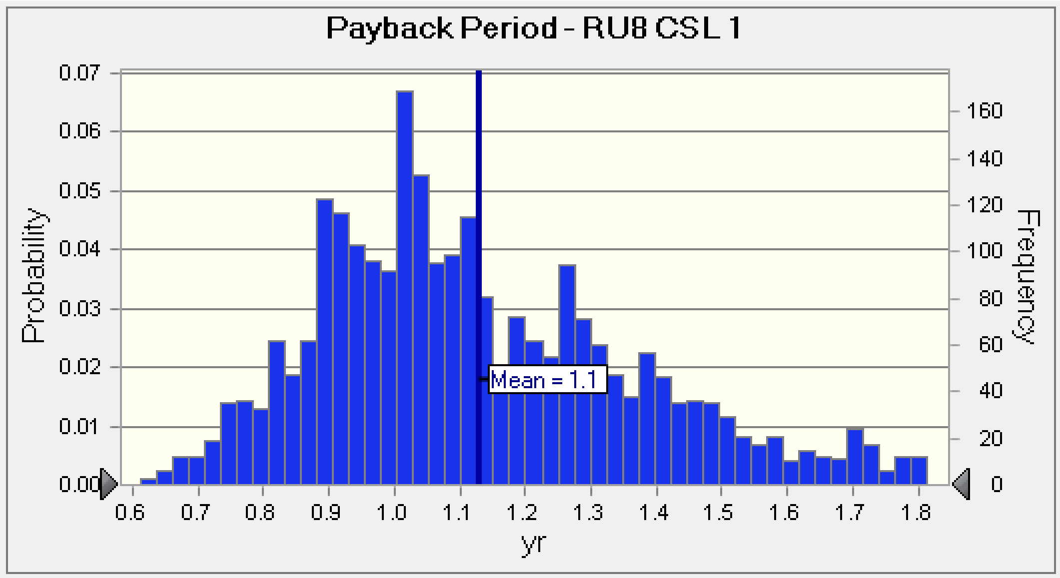

Figure 8B.2.26 **Representative Unit 8: Distribution of Payback Periods for CSL 1**

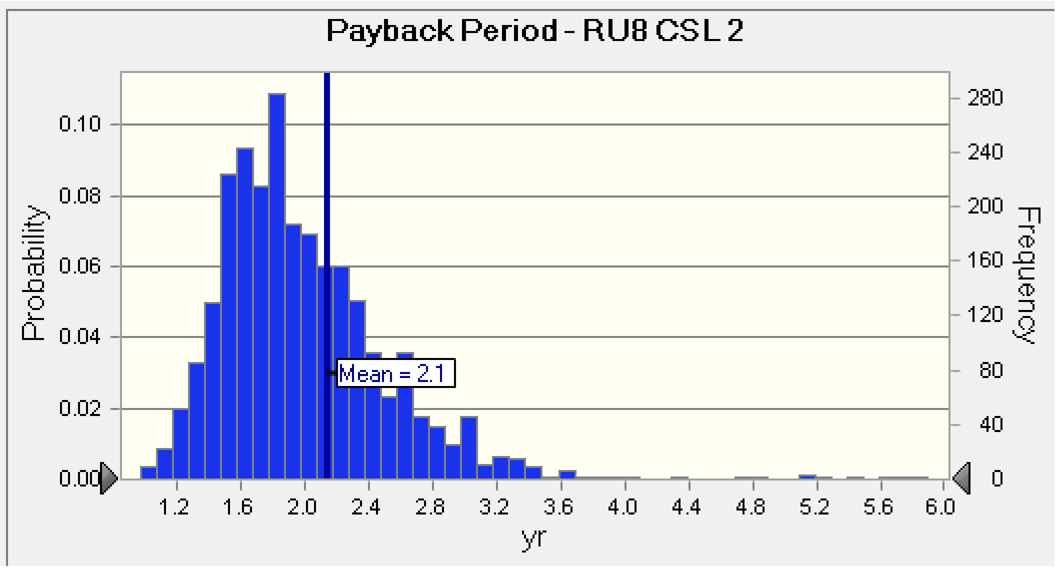

Figure 8B.2.27 **Representative Unit 8: Distribution of Payback Periods for CSL 2**

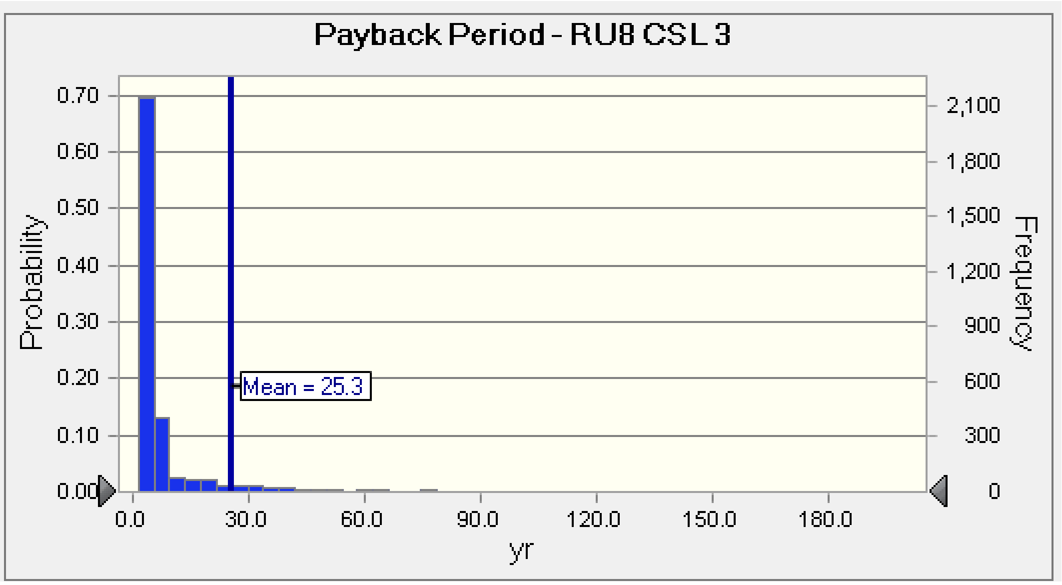

Figure 8B.2.28 **Representative Unit 8: Distribution of Payback Periods for CSL 3**

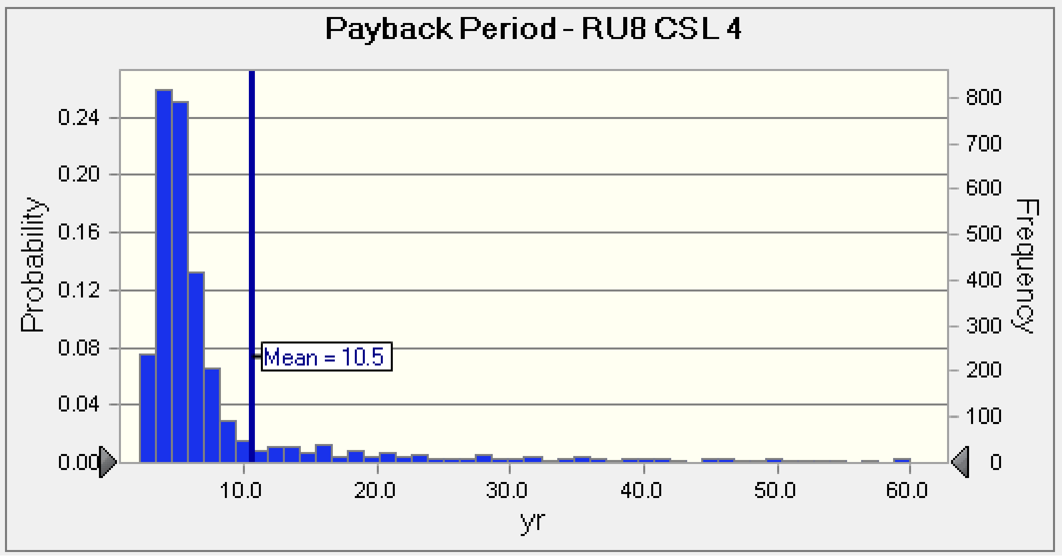

Figure 8B.2.29 Representative Unit 8: Distribution of Payback Periods for CSL 4

APPENDIX 8C. LIFE-CYCLE COST SENSITIVITY ANALYSIS

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APPENDIX 8C. LIFE-CYCLE COST SENSITIVITY ANALYSIS

8C.1 REPRESENTATIVE UNIT 1, NEMA DESIGN B, 5 HORSEPOWER, 4 POLES, ENCLOSED

Table 8C.1.1 Representative Unit 1: Reference Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	82.5	584	10,448	1,006	5,926					
1	87.5	588	9,869	969	5,649	16	0.1	5.8	0.4	0.1
2	89.5	651	9,691	963	5,631	25	18.9	26.4	33.7	5.1
3	90.2	665	9,616	960	5,608	45	20.5	67.8	59.0	4.7
4	91.0	909	9,567	960	5,831	-169	89.3	6.5	361.4	28.2
5	91.7	998	9,487	958	5,883	-220	93.3	5.4	162.7	26.9

Table 8C.1.2 Representative Unit 1: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	82.5	584	10,448	1,022	6,072					
1	87.5	588	9,869	983	5,787	17	0.1	5.8	0.6	0.1
2	89.5	651	9,691	977	5,766	27	18.6	26.7	40.8	5.1
3	90.2	665	9,616	974	5,742	47	19.6	68.7	21.2	4.6
4	91.0	909	9,567	974	5,965	-165	88.8	7.0	215.1	28.1
5	91.7	998	9,487	972	6,016	-216	92.9	5.8	200.9	26.5

Table 8C.1.3 Representative Unit 1: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	82.5	584	10,448	990	5,795					
1	87.5	588	9,869	953	5,525	16	0.1	5.8	0.6	0.1
2	89.5	651	9,691	947	5,509	24	19.2	26.1	54.5	5.2
3	90.2	665	9,616	945	5,487	43	21.3	67.0	56.1	4.7
4	91.0	909	9,567	945	5,711	-171	89.7	6.0	127.3	28.6
5	91.7	998	9,487	943	5,764	-224	93.7	5.0	202.3	27.2

Table 8C.1.4 Representative Unit 1: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	82.5	426	10,448	1,006	5,768					
1	87.5	429	9,869	969	5,490	16	0.1	5.8	0.3	0.1
2	89.5	477	9,691	963	5,457	32	15.5	29.8	25.9	4.0
3	90.2	486	9,616	960	5,429	56	13.9	74.3	41.3	3.2
4	91.0	662	9,567	960	5,584	-92	83.0	12.8	261.2	20.3
5	91.7	725	9,487	958	5,610	-118	86.0	12.7	116.8	19.4

Table 8C.1.5 Representative Unit 1: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	82.5	320	10,448	1,006	5,663					
1	87.5	322	9,869	969	5,383	17	0.1	5.8	0.2	0.1
2	89.5	361	9,691	963	5,341	36	12.3	33.0	20.8	3.2
3	90.2	367	9,616	960	5,310	63	9.8	78.5	29.5	2.2
4	91.0	497	9,567	960	5,418	-40	74.8	20.9	194.5	15.1
5	91.7	543	9,487	958	5,428	-50	75.4	23.4	86.2	14.3

Table 8C.1.6 Representative Unit 1: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	82.5	215	10,448	1,006	5,557					
1	87.5	216	9,869	969	5,277	17	0.1	5.8	0.1	0.0
2	89.5	246	9,691	963	5,225	40	9.2	36.1	15.6	2.4
3	90.2	248	9,616	960	5,191	71	6.9	81.4	17.8	1.1
4	91.0	332	9,567	960	5,253	11	59.9	35.9	127.7	9.7
5	91.7	361	9,487	958	5,246	18	55.0	43.7	55.7	9.2

8C.2 REPRESENTATIVE UNIT 2, NEMA DESIGN B, 30 HORSEPOWER, 4 POLES, ENCLOSED

Table 8C.2.1 Representative Unit 2: Reference Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	89.5	1,570	57,642	5,489	44,182					
1	92.4	1,986	55,912	5,358	43,376	45	0.6	4.9	11.6	3.5
2	93.6	2,277	55,021	5,295	43,035	177	5.7	32.9	14.6	5.3
3	94.1	2,288	54,492	5,255	42,666	511	4.0	86.6	6.0	0.7
4	94.5	3,468	54,326	5,249	43,735	-558	87.1	12.9	107.6	23.8
5	94.5	3,468	54,326	5,249	43,735	-558	87.1	12.9	107.6	23.8

Table 8C.2.2 Representative Unit 2: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	89.5	1,570	57,642	5,575	45,496					
1	92.4	1,986	55,912	5,442	44,651	47	0.6	4.9	8.0	3.5
2	93.6	2,277	55,021	5,377	44,290	187	5.4	33.2	13.2	5.2
3	94.1	2,288	54,492	5,337	43,909	532	3.8	86.8	6.0	0.7
4	94.5	3,468	54,326	5,330	44,974	-533	86.1	13.9	87.0	23.4
5	94.5	3,468	54,326	5,330	44,974	-533	86.1	13.9	87.0	23.4

Table 8C.2.3 Representative Unit 2: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	89.5	1,570	57,642	5,397	43,033					
1	92.4	1,986	55,912	5,269	42,261	43	0.6	4.9	8.2	3.6
2	93.6	2,277	55,021	5,207	41,938	168	6.0	32.6	11.4	5.4
3	94.1	2,288	54,492	5,168	41,580	492	4.1	86.5	4.2	0.7
4	94.5	3,468	54,326	5,162	42,652	-580	88.1	11.9	320.4	24.3
5	94.5	3,468	54,326	5,162	42,652	-580	88.1	11.9	320.4	24.3

Table 8C.2.4 Representative Unit 2: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	89.5	1,166	57,642	5,489	43,778					
1	92.4	1,476	55,912	5,358	42,866	51	0.4	5.1	8.7	2.6
2	93.6	1,700	55,021	5,295	42,459	209	4.2	34.4	11.2	4.0
3	94.1	1,706	54,492	5,255	42,085	547	2.9	87.6	4.4	0.4
4	94.5	2,557	54,326	5,249	42,825	-193	74.3	25.7	77.7	17.3
5	94.5	2,557	54,326	5,249	42,825	-193	74.3	25.7	77.7	17.3

Table 8C.2.5 Representative Unit 2: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	89.5	897	57,642	5,489	43,509					
1	92.4	1,136	55,912	5,358	42,526	55	0.4	5.1	6.7	2.0
2	93.6	1,315	55,021	5,295	42,074	230	3.3	35.3	9.0	3.2
3	94.1	1,319	54,492	5,255	41,697	571	2.3	88.3	3.3	0.2
4	94.5	1,950	54,326	5,249	42,217	51	58.7	41.3	57.8	12.9
5	94.5	1,950	54,326	5,249	42,217	51	58.7	41.3	57.8	12.9

Table 8C.2.6 Representative Unit 2: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	89.5	627	57,642	5,489	43,240					
1	92.4	796	55,912	5,358	42,186	59	0.2	5.3	4.7	1.4
2	93.6	931	55,021	5,295	41,689	251	2.4	36.2	6.7	2.4
3	94.1	931	54,492	5,255	41,309	595	1.6	89.0	2.2	0.0
4	94.5	1,343	54,326	5,249	41,610	294	37.1	62.9	37.9	8.5
5	94.5	1,343	54,326	5,249	41,610	294	37.1	62.9	37.9	8.5

8C.3 REPRESENTATIVE UNIT 3, NEMA DESIGN B, 75 HORSEPOWER, 4 POLES, ENCLOSED

Table 8C.3.1 Representative Unit 3: Reference Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Average	Median
0	93.0	3,463	204,834	17,168	124,170					
1	94.1	3,831	202,540	17,033	123,348	40	0.8	4.5	24.3	2.9
2	95.4	4,296	198,496	16,733	121,510	663	1.4	32.9	6.6	1.5
3	95.8	4,776	197,697	16,687	121,590	597	35.1	47.5	38.3	6.5
4	96.2	6,044	197,194	16,661	122,598	-340	66.9	25.9	162.7	15.5
5	96.5	6,640	196,604	16,631	122,905	-639	73.6	23.7	136.2	16.0

Table 8C.3.2 Representative Unit 3: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	3,463	204,834	17,457	127,748					
1	94.1	3,831	202,540	17,318	126,885	42	0.7	4.6	18.7	2.9
2	95.4	4,296	198,496	17,013	124,975	689	1.3	32.9	11.3	1.5
3	95.8	4,776	197,697	16,966	125,042	634	34.1	48.5	26.7	6.3
4	96.2	6,044	197,194	16,939	126,041	-294	66.1	26.8	82.6	15.2
5	96.5	6,640	196,604	16,908	126,338	-583	72.6	24.8	109.2	15.7

Table 8C.3.3 Representative Unit 3: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	3,463	204,834	16,850	120,893					
1	94.1	3,831	202,540	16,718	120,107	38	0.8	4.5	31.7	3.0
2	95.4	4,296	198,496	16,424	118,336	638	1.4	32.8	6.0	1.5
3	95.8	4,776	197,697	16,380	118,428	562	36.1	46.5	80.1	6.6
4	96.2	6,044	197,194	16,355	119,444	-382	67.6	25.2	105.1	15.8
5	96.5	6,640	196,604	16,325	119,761	-691	74.9	22.5	207.4	16.3

Table 8C.3.4 Representative Unit 3: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	2,568	204,834	17,168	123,275					
1	94.1	2,857	202,540	17,033	122,374	44	0.5	4.8	19.2	2.3
2	95.4	3,198	198,496	16,733	120,412	709	1.0	33.2	4.9	1.1
3	95.8	3,539	197,697	16,687	120,352	759	24.1	58.5	27.2	4.6
4	96.2	4,460	197,194	16,661	121,014	144	58.4	34.4	117.6	11.2
5	96.5	4,894	196,604	16,631	121,159	2	62.7	34.7	98.6	11.6

Table 8C.3.5 Representative Unit 3: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	1,971	204,834	17,168	122,679					
1	94.1	2,208	202,540	17,033	121,725	47	0.4	4.9	15.8	1.9
2	95.4	2,466	198,496	16,733	119,681	740	0.9	33.3	3.8	0.8
3	95.8	2,713	197,697	16,687	119,527	867	16.0	66.6	19.8	3.4
4	96.2	3,403	197,194	16,661	119,957	467	49.6	43.2	87.5	8.4
5	96.5	3,730	196,604	16,631	119,995	430	51.6	45.8	73.6	8.6

Table 8C.3.6 Representative Unit 3: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	1,375	204,834	17,168	122,082					
1	94.1	1,559	202,540	17,033	121,076	50	0.3	5.0	12.4	1.5
2	95.4	1,734	198,496	16,733	118,949	772	0.8	33.5	2.7	0.6
3	95.8	1,888	197,697	16,687	118,702	975	8.4	74.2	12.4	2.1
4	96.2	2,347	197,194	16,661	118,901	789	37.4	55.4	57.4	5.5
5	96.5	2,566	196,604	16,631	118,831	857	37.1	60.3	48.6	5.7

8C.4 REPRESENTATIVE UNIT 4, NEMA DESIGN C, 5 HORSEPOWER, 4 POLES, ENCLOSED

Table 8C.4.1 Representative Unit 4: Reference Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	583	9,987	984	5,807					
1	89.5	627	9,808	974	5,771	34	32.3	59.9	29.7	4.6
2	90.2	903	9,738	971	6,007	-203	97.8	2.2	95.6	25.0
3	91.0	961	9,630	966	6,011	-207	95.6	4.4	122.7	20.2

Table 8C.4.2 Representative Unit 4: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	583	9,987	999	5,951					
1	89.5	627	9,808	988	5,912	36	31.4	60.7	32.6	4.5
2	90.2	903	9,738	985	6,148	-200	97.4	2.7	185.1	24.5
3	91.0	961	9,630	980	6,150	-202	94.9	5.1	192.2	19.9

Table 8C.4.3 Representative Unit 4: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	583	9,987	968	5,678					
1	89.5	627	9,808	958	5,644	32	33.2	59.0	37.1	4.6
2	90.2	903	9,738	956	5,881	-206	98.1	1.9	226.9	25.7
3	91.0	961	9,630	950	5,887	-211	96.1	3.9	148.3	20.6

Table 8C.4.4 Representative Unit 4: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency %	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	424	9,987	984	5,648					
1	89.5	458	9,808	974	5,601	44	22.7	69.4	22.6	3.5
2	90.2	656	9,738	971	5,760	-115	89.4	10.6	69.0	18.1
3	91.0	697	9,630	966	5,747	-102	82.7	17.3	88.4	14.6

Table 8C.4.5 Representative Unit 4: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	319	9,987	984	5,543					
1	89.5	346	9,808	974	5,489	50	16.9	75.2	17.9	2.8
2	90.2	491	9,738	971	5,595	-57	76.1	23.9	51.2	13.5
3	91.0	521	9,630	966	5,571	-32	66.3	33.7	65.6	10.8

Table 8C.4.6 Representative Unit 4: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	213	9,987	984	5,437					
1	89.5	233	9,808	974	5,376	57	12.6	79.5	13.1	2.0
2	90.2	326	9,738	971	5,431	2	57.7	42.3	33.5	8.8
3	91.0	346	9,630	966	5,395	37	41.1	58.9	42.7	7.1

8C.5 REPRESENTATIVE UNIT 5, NEMA DESIGN C, 50 HORSEPOWER, 4 POLES, ENCLOSED

Table 8C.5.1 Representative Unit 5: Reference Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	2,786	89,523	8,459	69,419					
1	94.1	3,173	88,507	8,383	69,098	236	18.3	55.6	38.8	5.9
2	94.5	3,673	88,119	8,360	69,329	5	59.6	40.4	53.3	12.7
3	95.0	3,950	87,444	8,309	69,104	229	42.3	57.8	25.2	9.8

Table 8C.5.2 Representative Unit 5: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	2,786	89,523	8,593	71,508					
1	94.1	3,173	88,507	8,515	71,163	253	17.5	56.4	40.7	5.8
2	94.5	3,673	88,119	8,492	71,385	31	57.8	42.2	51.1	12.5
3	95.0	3,950	87,444	8,440	71,144	272	40.3	59.7	30.0	9.6

Table 8C.5.3 Representative Unit 5: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	2,786	89,523	8,317	67,586					
1	94.1	3,173	88,507	8,242	67,284	221	19.0	54.8	22.4	6.0
2	94.5	3,673	88,119	8,220	67,524	-18	61.1	38.9	45.2	12.9
3	95.0	3,950	87,444	8,170	67,314	192	43.7	56.3	33.1	10.0

Table 8C.5.4 Representative Unit 5: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	2,077	89,523	8,459	68,710					
1	94.1	2,369	88,507	8,383	68,293	307	13.0	60.9	29.2	4.5
2	94.5	2,721	88,119	8,360	68,377	223	42.6	57.4	38.3	9.1
3	95.0	2,920	87,444	8,309	68,074	526	25.5	74.5	18.1	7.0

Table 8C.5.5 Representative Unit 5: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	1,604	89,523	8,459	68,237					
1	94.1	1,833	88,507	8,383	67,757	354	9.6	64.3	22.8	3.5
2	94.5	2,086	88,119	8,360	67,742	368	29.4	70.6	28.2	6.8
3	95.0	2,232	87,444	8,309	67,386	724	17.1	82.9	13.4	5.2

Table 8C.5.6 Representative Unit 5: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	93.0	1,132	89,523	8,459	67,764					
1	94.1	1,296	88,507	8,383	67,220	401	6.7	67.1	16.4	2.5
2	94.5	1,451	88,119	8,360	67,107	513	16.4	83.6	18.2	4.4
3	95.0	1,545	87,444	8,309	66,699	922	9.8	90.3	8.7	3.4

8C.6 REPRESENTATIVE UNIT 6, FIRE PUMP, 5 HORSEPOWER, 4 POLES, ENCLOSED

Table 8C.6.1 Representative Unit 6: Reference Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	87.5	588	19.6	106	632					
1	89.5	651	19.2	115	697	-62	95.1	0.0	NA	NA
2	90.2	666	19.1	119	706	-70	99.9	0.1	NA	NA
3	91.0	909	19.0	124	949	-314	100.0	0.0	NA	NA
4	91.7	998	18.8	128	1,038	-403	100.0	0.0	NA	NA

Table 8C.6.2 Representative Unit 6: High Energy Price Trend Scenario

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	87.5	588	19.6	106	634					
1	89.5	651	19.2	115	699	-62	95.1	0.0	NA	NA
2	90.2	665	19.1	119	707	-70	99.9	0.2	NA	NA
3	91.0	909	19.0	124	951	-314	100.0	0.0	NA	NA
4	91.7	998	18.8	128	1,040	-403	100.0	0.0	NA	NA

Table 8C.6.3 Representative Unit 6: Low Energy Price Trend Scenario

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	87.5	588	19.6	106	630					
1	89.5	651	19.2	115	695	-61	95.1	0.0	NA	NA
2	90.2	665	19.1	119	704	-70	99.9	0.1	NA	NA
3	91.0	909	19.0	124	948	-314	100.0	0.0	NA	NA
4	91.7	998	18.8	128	1,037	-403	100.0	0.0	NA	NA

Table 8C.6.4 Representative Unit 6: Low Retail Price Discount Scenario

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	87.5	429	19.6	106	473					
1	89.5	477	19.2	115	523	-48	95.1	0.0	NA	NA
2	90.2	486	19.1	119	527	-52	99.3	0.7	NA	NA
3	91.0	662	19.0	124	702	-227	100.0	0.0	NA	NA
4	91.7	725	18.8	128	765	-290	100.0	0.0	NA	NA

Table 8C.6.5 Representative Unit 6: Medium Retail Price Discount Scenario

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	87.5	322	19.6	106	367					
1	89.5	361	19.2	115	407	-39	95.1	0.0	NA	NA
2	90.2	367	19.1	119	408	-39	97.6	2.4	NA	NA
3	91.0	497	19.0	124	537	-168	100.0	0.0	NA	NA
4	91.7	543	18.8	128	584	-215	100.0	0.0	NA	NA

Table 8C.6.6 Representative Unit 6: High Retail Price Discount Scenario

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	87.5	216	19.6	106	260					
1	89.5	246	19.2	115	292	-30	95.1	0.0	NA	NA
2	90.2	248	19.1	119	288	-27	95.6	4.4	NA	NA
3	91.0	332	19.0	124	372	-110	100.0	0.0	NA	NA
4	91.7	361	18.8	128	402	-140	100.0	0.0	NA	NA

8C.7 REPRESENTATIVE UNIT 7, FIRE PUMP, 30 HORSEPOWER, 4 POLES, ENCLOSED

Table 8C.7.1 Representative Unit 7: Reference Scenario

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	92.4	1,986	1,601	347	3,869					
1	93.6	2,277	1,577	363	4,131	-213	78.8	2.5	1,578.9	104.9
2	94.1	2,288	1,562	371	4,124	-207	78.7	8.1	923.4	79.2
3	94.5	3,468	1,558	380	5,295	-1,378	100.0	0.0	3,157.4	433.6
4	94.5	3,468	1,558	380	5,295	-1,378	100.0	0.0	3,157.4	433.6

Table 8C.7.2 Representative Unit 7: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	92.4	1,986	1,601	349	3,953					
1	93.6	2,277	1,577	365	4,214	-212	78.4	2.9	390.3	112.1
2	94.1	2,288	1,562	373	4,206	-205	78.4	8.3	130.7	69.7
3	94.5	3,468	1,558	382	5,377	-1,376	100.0	0.0	2,354.3	492.7
4	94.5	3,468	1,558	382	5,377	-1,376	100.0	0.0	2,354.3	492.7

Table 8C.7.3 Representative Unit 7: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	92.4	1,986	1,601	344	3,789					
1	93.6	2,277	1,577	360	4,052	-214	79.4	1.9	463.7	113.1
2	94.1	2,288	1,562	368	4,046	-209	79.0	7.7	204.1	92.9
3	94.5	3,468	1,558	377	5,217	-1,380	100.0	0.0	3,198.6	443.4
4	94.5	3,468	1,558	377	5,217	-1,380	100.0	0.0	3,198.6	443.4

Table 8C.7.4 Representative Unit 7: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	92.4	1,476	1,601	347	3,359					
1	93.6	1,700	1,577	363	3,554	-159	76.0	5.3	1,217.3	81.2
2	94.1	1,706	1,562	371	3,542	-149	77.4	9.3	697.8	60.3
3	94.5	2,557	1,558	380	4,384	-990	100.0	0.0	2,310.5	317.3
4	94.5	2,557	1,558	380	4,384	-990	100.0	0.0	2,310.5	317.3

Table 8C.7.5 Representative Unit 7: Medium Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	92.4	1,136	1,601	347	3,019					
1	93.6	1,315	1,577	363	3,169	-122	74.0	7.3	976.2	65.4
2	94.1	1,319	1,562	371	3,154	-109	76.4	10.3	547.4	47.8
3	94.5	1,950	1,558	380	3,777	-732	99.9	0.1	1,745.9	239.7
4	94.5	1,950	1,558	380	3,777	-732	99.9	0.1	1,745.9	239.7

Table 8C.7.6 Representative Unit 7: High Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	92.4	796	1,601	347	2,679					
1	93.6	931	1,577	363	2,785	-86	73.5	7.8	735.1	49.9
2	94.1	931	1,562	371	2,766	-70	74.6	12.1	397.0	35.3
3	94.5	1,343	1,558	380	3,169	-473	98.2	1.8	1,181.3	162.2
4	94.5	1,343	1,558	380	3,169	-473	98.2	1.8	1,181.3	162.2

8C.8 REPRESENTATIVE UNIT 8, FIRE PUMP, 75 HORSEPOWER, 4 POLES, ENCLOSED

Table 8C.8.1 Representative Unit 8: Reference Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	94.1	3,831	97,791	8,050	110,032					
1	95.4	4,296	95,934	7,937	108,445	1,274	55.4	25.3	1.1	1.1
2	95.8	4,776	95,554	7,927	108,544	1,193	56.7	26.0	2.1	1.9
3	96.2	6,044	95,313	7,924	109,522	215	73.0	27.0	25.3	4.5
4	96.5	6,640	95,033	7,920	109,826	-89	72.0	28.0	10.5	5.3

Table 8C.8.2 Representative Unit 8: High Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	94.1	3,831	97,791	8,184	114,838					
1	95.4	4,296	95,934	8,069	113,159	1,349	55.4	25.3	1.1	1.1
2	95.8	4,776	95,554	8,059	113,240	1,282	56.7	26.0	2.1	1.9
3	96.2	6,044	95,313	8,055	114,205	317	72.9	27.1	22.1	4.4
4	96.5	6,640	95,033	8,051	114,495	26	71.8	28.2	10.2	5.2

Table 8C.8.3 Representative Unit 8: Low Energy Price Trend Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	94.1	3,831	97,791	7,899	105,523					
1	95.4	4,296	95,934	7,790	104,023	1,204	55.4	25.3	1.2	1.1
2	95.8	4,776	95,554	7,780	104,138	1,109	56.7	26.0	2.2	2.0
3	96.2	6,044	95,313	7,777	105,129	119	73.2	26.8	55.3	4.6
4	96.5	6,640	95,033	7,774	105,445	-197	72.2	27.8	10.9	5.4

Table 8C.8.4 Representative Unit 8: Low Retail Price Discount Scenario

Energy Efficiency Level	Efficiency *%*	Life-Cycle Cost				Life-Cycle Cost Savings			Payback Period *years*	
		Average Installed Price *$*	Average Energy Use *kWh/yr*	Average Annual Operating Cost *$*	Average Life-Cycle Cost *$*	Average Savings *$*	Customers with			
							Net Cost *%*	Net Benefit *%*	Average	Median
0	94.1	2,857	97,791	8,050	109,058					
1	95.4	3,198	95,934	7,937	107,347	1,374	55.4	25.3	0.8	0.8
2	95.8	3,539	95,554	7,927	107,306	1,408	56.7	26.0	1.5	1.4
3	96.2	4,460	95,313	7,924	107,938	777	72.0	28.0	18.4	3.2
4	96.5	4,894	95,033	7,920	108,080	635	70.7	29.3	7.6	3.8

Table 8C.8.5 Representative Unit 8: Medium Retail Price Discount Scenario

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	94.1	2,208	97,791	8,050	108,409					
1	95.4	2,466	95,934	7,937	106,616	1,441	55.4	25.3	0.6	0.6
2	95.8	2,713	95,554	7,927	106,481	1,552	56.7	26.0	1.1	1.0
3	96.2	3,403	95,313	7,924	106,881	1,151	71.2	28.8	13.7	2.4
4	96.5	3,730	95,033	7,920	106,915	1,117	69.8	30.2	5.7	2.9

Table 8C.8.6 Representative Unit 8: High Retail Price Discount Scenario

Energy Efficiency Level	**Efficiency** *%*	**Life-Cycle Cost**				**Life-Cycle Cost Savings**			**Payback Period** *years*	
		Average Installed Price *$*	**Average Energy Use** *kWh/yr*	**Average Annual Operating Cost** *$*	**Average Life-Cycle Cost** *$*	**Average Savings** *$*	**Customers with**			
							Net Cost *%*	**Net Benefit** *%*	**Average**	**Median**
0	94.1	1,559	97,791	8,050	107,760					
1	95.4	1,734	95,934	7,937	105,884	1,507	55.3	25.3	0.4	0.4
2	95.8	1,888	95,554	7,927	105,656	1,695	56.7	26.0	0.7	0.7
3	96.2	2,347	95,313	7,924	105,825	1,526	70.3	29.7	9.1	1.6
4	96.5	2,566	95,033	7,920	105,751	1,600	68.6	31.4	3.8	1.9

APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NATIONAL IMPACT ANALYSIS SPREADSHEET MODELS

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APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NATONAL IMPACT ANALYSIS SPREADSHEET MODEL

10-A.1 USER INSTRUCTIONS

The results obtained in 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's (DOE)'s website at: http://www1.eere.energy.gov/buildings/appliance_standards/commercial/electric_motors.html.

The shipments model is in the spreadsheet called "MEM_Prelim_Shipments_Model.xls," and the NIA in the spreadsheets "MEM_Prelim_NIA_Summary.xlsm," "MEM_Prelim_NIA_DesignAB.xlsx," "MEM_Prelim_NIA_DesignC.xlsx" and "MEM_Prelim_NIA_FirePump.xlsx." These spreadsheets implement the calculations described in Chapters 9 and 10. Further, the NIA spreadsheets enable the user to simulate national impacts under different parameters and scenarios. To run the spreadsheets the user needs to have Microsoft Excel 2007 or a later version.

10-A.1.1 Shipments Model Spreadsheet Description

The shipments model spreadsheet performs calculations to forecast the shipments of motors covered by the rulemaking. The methodology for developing the shipments model is described in Chapter 9. The shipments model spreadsheet, or workbook, consists of the following worksheets:

(a) Shipments: Calculates and provides a summary of the shipment forecasts for the entire analysis period (2015-2044) and beyond.

(b) Invest. vs. Ship.: Presents how DOE developed a relationship between shipments and private fixed investment in selected equipment and structure.

(c) Invest. vs. Tol. Invest.: Calculates projections for private fixed investment in equipment and structure for selected sectors.

(d) Tot. Invest. vs. GDP: Calculates projections for total private fixed investment.

(e) Census: Presents the Census data used to develop the historical shipments index

10-A.1.2 National Impact Analysis Spreadsheets Description

The NIA spreadsheets perform calculations to forecast the changes in national energy savings (NES) and net present value (NPV) due to an energy efficiency standard. For a standard set at a given candidate standard level (CSL), the energy consumption and the costs associated with each equipment class, as well as the corresponding NES and NPV results rely on the shipments estimated in the shipments spreadsheet and on calculation performed by three *accountability spreadsheets*, each dedicated to a specific equipment category. A fourth, *summary spreadsheet* provides the accountability spreadsheets with general parameters and tables, and summarizes their results. Figure 10-A.1.1 presents the general organization and interactions between the spreadsheets comprising the NIA model. The following subsections describe, respectively, the worksheets comprising the summary and the accountability spreadsheets, and provide instructions to operate the NIA model.

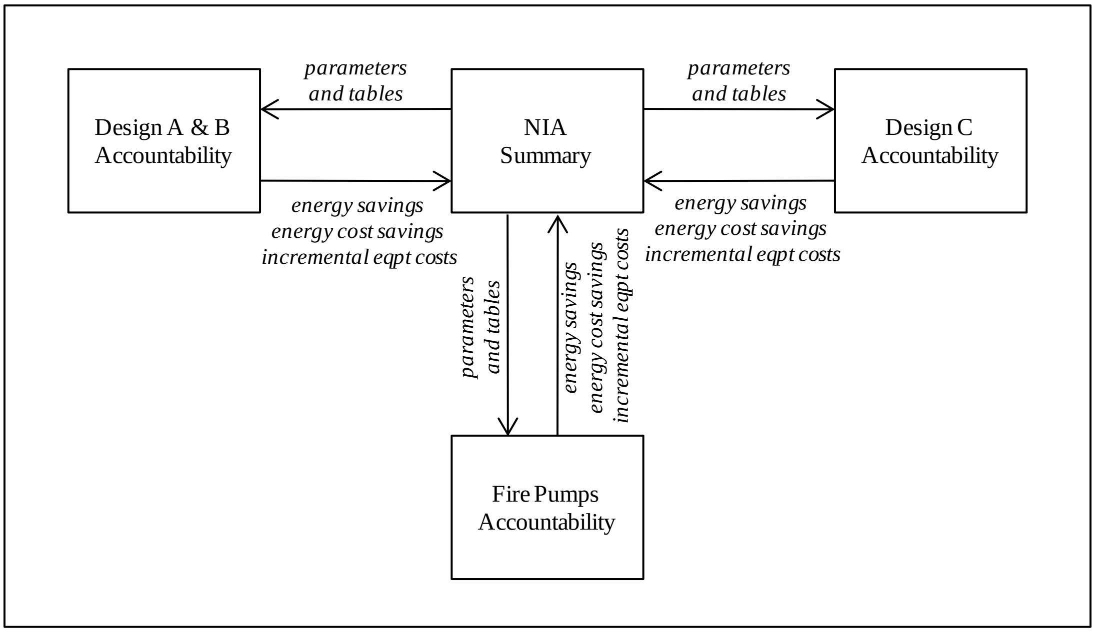

Figure 10-A.1.1 National lmpact Analysis Spreadsheets Architecture

10-A.1.2.1 Summary Spreadsheet Organization

The summary spreadsheet consists of the following six worksheets which support the accountability spreadsheets and summarize their results.

(a) Lifetime: Presents, for each equipment category, motor survival probabilities by sector and horsepower (HP) range.

(b) Efficiency Tables: Presents, for each equipment category, the efficiency levels by CSL and equipment class.

(c) General Tables & Parameters: Presents all tables and single-value parameters used by the accountability spreadsheets.

(d) Shipments: Presents total historical and forecast shipments, as well as shipment distributions across equipment class groups, and motor HP and configuration.

(e) Summary: Enables the user to select CSLs, scenarios and sensitivity levels to be simulated by the accountability spreadsheets, and summarize their results.

(f) Scenario Results: Automatically simulates pre-determined combinations of scenarios and sensitivity levels, and summarize results in a pivot-table.

10-A.1.2.2 Accountability Spreadsheets Organization

The accountability spreadsheets consist of the following 11 worksheets which calculate the national energy savings, the national energy cost savings, and the national (non-energy) incremental equipment costs for all equipment classes of each equipment category.

(a) Shipments: Presents the base case shipments forecast by sector for all equipment classes, and estimates shipments for the standards case scenario (in this version, equal to the base case).

(b) Efficiency Distribution: Presents the base case energy efficiency distribution by motor HP, and calculates the corresponding distributions to the standards case according to the CSL selected in the Summary spreadsheet.

(c) Unit Energy Consumption: Calculates, for all equipment classes and efficiency levels, the lifetime source energy consumption of a unit shipped in each year of the analysis period, according to the sector to which it is shipped and the application for which it is used.

(d) Natl Energy Consumption: Calculates, for all equipment classes, the base case and the standards case national lifetime energy consumption and losses from units shipped in each year of the analysis period. The calculation is disaggregated by sector and application.

(e) Natl Energy Savings: Calculates, for all equipment classes, the national energy savings by sector.

(f) Unit Energy Cost: Calculates, for all equipment classes and efficiency levels, the lifetime energy cost of a unit shipped in each year of the analysis period, according to the sector to which it is shipped and the application for which it is used.

(g) Natl Energy Cost: Calculates, for all equipment classes, the base case and the standards case national lifetime energy costs from units shipped in each year of the analysis period. The calculation is disaggregated by sector and application.

(h) Natl Energy Cost Savings: Calculates, for all equipment classes, the present-value of the national energy cost savings by sector.

(i) Unit Eqpt Costs: Calculates, for all equipment classes and efficiency levels, the lifetime non-energy equipment costs of a unit shipped in each year of the analysis period, according to the sector to which it is shipped.

(j) Natl Eqpt Costs: Calculates, for all equipment classes, the base case and the standards case national lifetime non-energy equipment costs from units shipped in each year of the analysis period. The calculation is disaggregated by sector and application.

(k) Natl Eqpt Incr Costs: Calculates, for all equipment classes, the present-value of the national (non-energy) incremental equipment costs by sector.

10-A.1.2.3 National Impact Analysis Spreadsheet Operating Instructions

Basic instructions for operating the NIA spreadsheet are as follows:

1. After downloading the NIA set of spreadsheet files from DOE's website, open the Summary file using Excel. Once loaded, this spreadsheet will ask if the user wants to open the additional files. If you intend only to see the existing results, the answer maybe "No." However, if you plan to do your own simulations you must answer with "Yes," in which case Excel will automatically open the three additional accountability spreadsheet files and activate back the Summary spreadsheet.

2. If you intend only to see the existing results, click on the tab for the worksheet "Scenario Results." To select results for specific combinations of parameters and scenarios one can either use: (a) the filtering feature in the column headers, or (b) the pivot-table located at the right side of the results listing.[a]

3. If you intend to run your own simulations, there are two options: (a) running the model for a specific combination of parameters and scenarios, and (b) running the model for pre-determined combinations of parameters and scenarios. The two options can be operated as follows:

   (a) For a specific combination of parameters and scenarios:

   Click on the tab for the worksheet "Summary." This worksheet serves as the user interface for running the model for a particular combination of parameters and scenarios. To provide flexibility, the spreadsheet permits some user modifications to the model. The user may select a particular:

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[a] To learn more on how to use Excel pivot-tables refer to "PivotTable I: Get started with PivotTable reports in Excel 2007" in <http://office.microsoft.com/en-us/excel-help/pivottable-i-get-started-with-pivottable-reports-in-excel-2007-RZ010205886.aspx>.

- *Discount rate*, which enables the user to set a discount rate (in percentage) and affects the present-values of energy savings and incremental equipment (non-energy) costs;
- *Economic growth* which enables the user to select an annual economic outlook (AEO) macroeconomic forecast and determines the electricity prices to be used by the model;
- *Product price trend*, which enables the user to select a scenario of motor price trends and affects motor manufacturer selling prices (MSPs) over the analysis period;
- *Energy Savings*, which enables the user to select whether the energy savings are to be reported as source energy savings or as full-fuel-cycle energy savings;
- *CSLs*, which enables the user to select a CSL as the standard level for each equipment category, and affects the standards case efficiency distribution; and
- *Sensitivity*, which enables the user to change (with a direct multiplier) all motors MSP, repair cost and operating hours values, and affects energy consumption and costs, as well as equipment non-energy costs.

Once the desired parameters are set, the user should start the spreadsheet calculation. This can be done either by pressing F9 or navigating through the Excel menu as follows: Formulas >> Calculate Now.

(b) For pre-determined combinations of parameters and scenarios:

Click on the tab for the worksheet "Scenario Results." This worksheet can automatically calculate results for all equipment class groups, CSLs, and discount rates considering all Reference scenarios. It can further extend these calculations to selected alternative scenarios (including scenarios for sensitivity analysis). To enable the automatic calculation one must answer "Yes" to the "Recalculate all?" question, or otherwise the worksheet will just show the results from the earlier run (see item 2 above on how to examine results from a model run). After answering with a "Yes" to the "Recalculate all?" message, the following alternatives will be posted to the user:

- "Only Reference scenarios?"
  Yes: simulate only the Reference economic growth and the Constant product price trend scenarios
  No: enables the selection of additional scenarios to be simulated (see the next item).

- "Select scenarios to simulate:"
  "E=Economic growth,"
  "F=Source/FFC savings,"
  "P=Prod price trend,"
  "*=All"

E: simulates the Low- and High AEO economic growth scenarios, in addition to the Reference one
F: calculates both source and full-fuel-cycle energy savings
P: simulates the Decreasing and Increasing product price trend scenarios, in addition to the Constant one
*: simulates all economic growth and product price trend scenarios.

- "Include sensitivity analysis?"
  Yes: enables the user to setup the sensitivity level to be simulated (see the next item)
  No: only the reference values for hours of operation, MSP and repair cost will be simulated.

- "Enter percentage:"
  Enables the user to type the percentage corresponding to the desired sensitivity level to be simulated (for example, to simulate hours of operation, MSP and repair cost values 10 percent lower and higher than the former values just enter the number 10).

- "Run:"
  "<…> scenarios,"
  "<yes/no> sensitivity analysis."
  This message summarizes what it will be simulated. To start the simulation process, click Ok; otherwise, click Cancel.

During the simulation process, messages in the left side of the lower message bar will report the process progress and an estimate of the remaining time. Once the simulation is over, the user can then examine the results (see item 2 above on how to examine results from a model run).

APPENDIX 10-B. NATIONAL IMPACT ANALYSIS SENSITIVITY ANALYSIS FOR ALTERNATIVE PRODUCT PRICE TREND SCENARIOS

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APPENDIX 10-B. NATIONAL IMPACT ANALYSIS SENSITIVITY ANALYSIS FOR ALTERNATIVE PRODUCT PRICE TREND SCENARIOS

10-B.1 INTRODUCTION

The U.S. Department of Energy (DOE) used a constant price assumption for the default forecast in the National Impact Analysis (NIA) described in Chapter 10. In order to investigate the impact of different equipment price forecasts (or product price forecasts) on the consumer net present value (NPV) for the considered candidate standard levels (CSLs) for electric motors, DOE also considered two alternative price trends for a sensitivity analysis. This appendix describes the alternative price trends and compares NPV results for these scenarios with the default forecast.

10-B.2 ALTERNATIVE MOTOR PRICE TREND SCENARIOS

DOE considered two alternative price trends for a sensitivity analysis. One of these used an exponential fit on the deflated Producer Price Index (PPI) for electric motors, and the other is based on the “chained price index—industrial equipment” that was forecasted for EIA’s *Annual Energy Outlook 2011* (*AEO2011*).

10-B.2.1 Exponential Fit Approach (High Price Scenario)

For this scenario, DOE used an inflation-adjusted integral horsepower motor and generator manufacturing Producer Price Index (PPI) from 1969-2011 to fit an exponential model with *year* as the explanatory variable. DOE obtained historical PPI data for integral horsepower motors and generators manufacturing spanning the time period 1969-2011 from the Bureau of Labor Statistics’ (BLS).[a] The PPI data reflect nominal prices, adjusted for product quality changes. An inflation-adjusted (deflated) price index for integral horsepower motors and generators manufacturing was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index. In this case, the exponential function takes the form of:

$$Y = a \cdot e^{bX}$$

where Y is the motor price index, X is the time variable, *a* is the constant and *b* is the slope parameter of the time variable.

To estimate these exponential parameters, a least-square fit was performed on the inflation-adjusted motor price index versus *year* from 1969 to 2011. See Figure 10-B.2.1.

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[a] Series ID PCU3353123353123; http://www.bls.gov/ppi/

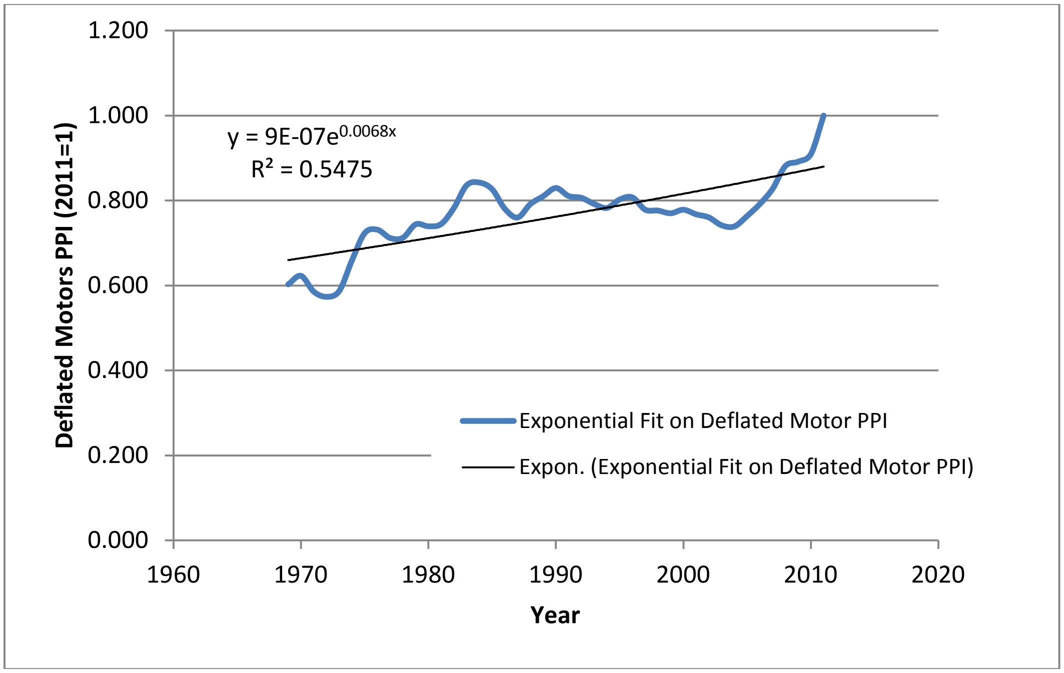

Figure 10-B.2.1 Relative Price of Electric Motors versus Year, with Exponential Fit

The regression performed as an exponential trend line fit results in an R-square of 0.55, which indicates a moderate fit to the data. The final estimated exponential function is:

$$Y = 9.21 \times 10^{(-7)} \cdot e^{0.0068X}$$

DOE then derived a price factor index for this scenario, with 2011 equal to 1, to forecast prices in each future year in the analysis period considered in the NIA. The index value in a given year is a function of the exponential parameter and *year*.

10-B.2.2 Annual Energy Outlook 2011 Price Forecast (Low Price Scenario)

DOE also examined a forecast based on the "chained price index—industrial equipment" that was forecasted for *AEO2011* out to 2035. This index is the most disaggregated category that includes electric motors. To develop an inflation-adjusted index, DOE normalized the above index with the "chained price index—gross domestic product" forecasted for *AEO2011*. To extend the price index beyond 2035, DOE used the average annual price growth rate in 2026 to 2035.

10-B.2.3 Summary

Table 10-B.2.1 shows the summary of the average annual rates of changes for the product price index in each scenario. Figure 10-B.2.2 shows the resulting price trends.

Table 10-B.2.1 Price Trend Sensitivities

Sensitivity	**Price Trend**	**Average Annual rate of change**
Medium (Default)	Constant Price Projection	0.0%
Low Price Scenario	AEO2011-- "chained price index—industrial equipment"	-1.0%
High Price Scenario	Exponential Fit using data from 1969 to 2011	0.7%

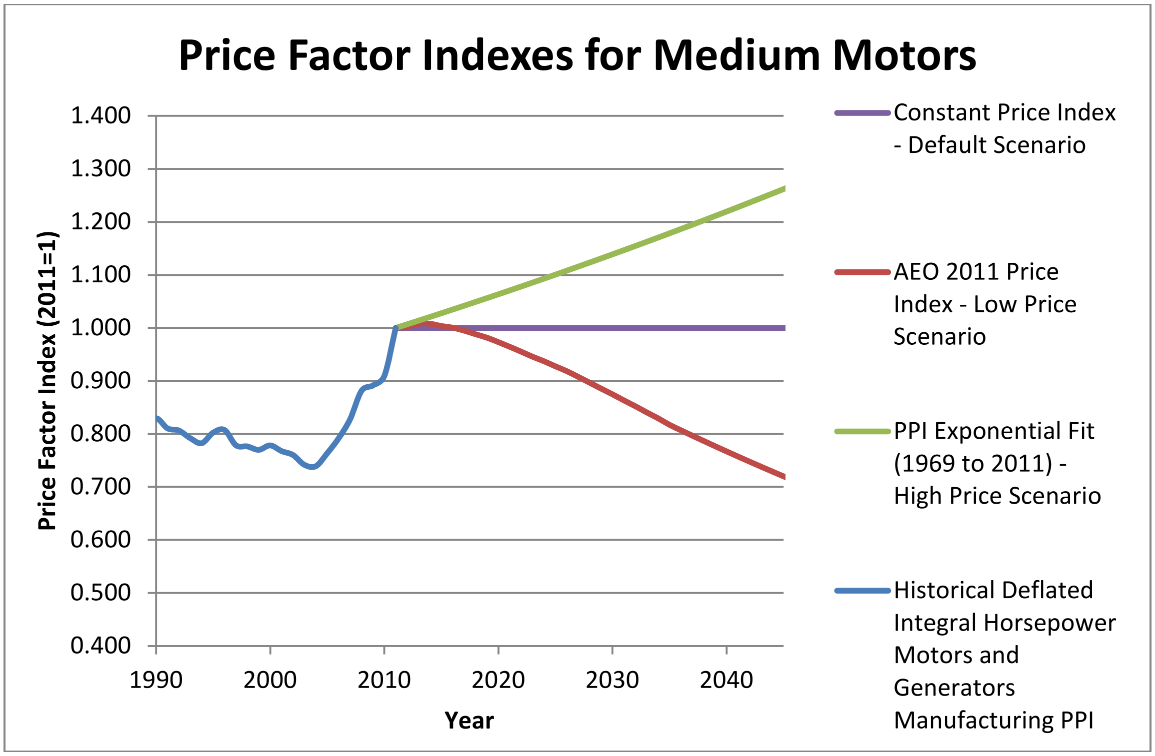

Figure 10-B.2.2 Electric Motor Price Forecast Indexes

10-B.3 NET PRESENT VALUE RESULTS BY PRICE TREND SCENARIO

Table 10-B.3.1 through Table 10-B.3.3 present, for each equipment class group and CSL, equipment incremental non-energy costs and energy cost savings, with their corresponding NPV results, across discount rates and the three product price trend scenarios.

Table 10-B.3.1 Detailed Net Present Value Results for NEMA Designs A and B Motors (billion 2011$)

	7% discount rate			*3% discount rate*		
	Low	**Default**	**High**	**Low**	**Default**	**High**
CSL 1						
Incr Non-Energy Costs	0.473	0.501	0.533	0.986	1.052	1.124
Energy Cost Savings	2.819	2.819	2.819	6.578	6.578	6.578
NPV	2.345	2.318	2.285	5.592	5.526	5.454
CSL 2						
Incr Non-Energy Costs	5.137	5.502	5.933	10.213	11.084	12.036
Energy Cost Savings	12.572	12.572	12.572	29.504	29.504	29.504
NPV	7.435	7.070	6.638	19.291	18.420	17.467
CSL 3						
Incr Non-Energy Costs	9.199	9.925	10.782	18.245	19.976	21.870
Energy Cost Savings	21.348	21.348	21.348	50.163	50.163	50.163
NPV	12.149	11.423	10.565	31.918	30.186	28.293
CSL 4						
Incr Non-Energy Costs	37.546	41.084	45.267	70.376	78.818	88.052
Energy Cost Savings	30.716	30.716	30.716	72.184	72.184	72.184
NPV	-6.829	-10.368	-14.550	1.808	-6.634	-15.868
CSL 5						
Incr Non-Energy Costs	45.168	49.403	54.408	84.808	94.912	105.962
Energy Cost Savings	36.693	36.693	36.693	86.277	86.277	86.277
NPV	-8.475	-12.710	-17.715	1.469	-8.634	-19.684

Table 10-B.3.2 Detailed Net Present Value Results for NEMA Design C Motors (billion 2011$)

	7% discount rate			*3% discount rate*		
	Low	**Default**	**High**	**Low**	**Default**	**High**
CSL 1						
Incr Non-Energy Costs	0.013	0.014	0.015	0.025	0.027	0.030
Energy Cost Savings	0.035	0.035	0.035	0.081	0.081	0.081
NPV	0.022	0.021	0.019	0.056	0.054	0.051
CSL 2						
Incr Non-Energy Costs	0.054	0.059	0.065	0.101	0.113	0.127
Energy Cost Savings	0.052	0.052	0.052	0.123	0.123	0.123
NPV	-0.002	-0.007	-0.013	0.022	0.009	-0.004
CSL 3						
Incr Non-Energy Costs	0.069	0.075	0.083	0.129	0.144	0.161
Energy Cost Savings	0.070	0.070	0.070	0.164	0.164	0.164
NPV	0.001	-0.005	-0.013	0.035	0.020	0.003

Table 10-B.3.3 Detailed Net Present Value Results for Fire Pump Motors (billion 2011$)

	7% discount rate			*3% discount rate*		
	Low	**Default**	**High**	**Low**	**Default**	**High**
CSL 1						
Incr Non-Energy Costs	0.015	0.016	0.017	0.032	0.035	0.037
Energy Cost Savings	0.006	0.006	0.006	0.016	0.016	0.016
NPV	-0.009	-0.010	-0.011	-0.016	-0.018	-0.021
CSL 2						
Incr Non-Energy Costs	0.021	0.023	0.024	0.048	0.051	0.055
Energy Cost Savings	0.009	0.009	0.009	0.025	0.025	0.025
NPV	-0.013	-0.014	-0.016	-0.023	-0.026	-0.030
CSL 3						
Incr Non-Energy Costs	0.059	0.064	0.070	0.119	0.131	0.144
Energy Cost Savings	0.012	0.012	0.012	0.033	0.033	0.033
NPV	-0.047	-0.052	-0.058	-0.086	-0.098	-0.111
CSL 4						
Incr Non-Energy Costs	0.069	0.075	0.082	0.140	0.154	0.169
Energy Cost Savings	0.015	0.015	0.015	0.040	0.040	0.040
NPV	-0.055	-0.061	-0.068	-0.100	-0.114	-0.129

APPENDIX 10-C. FULL FUEL CYCLE MULTIPLIERS

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APPENDIX 10-C. FULL FUEL CYCLE MULTIPLIERS

10-C.1 METHODOLOGY

To provide one unit of energy to the final consumer, for example, in buildings, vehicles or industrial processes, a variety of fuels are used in upstream activities. Thus, if the point-of-use (site) energy demand is reduced by one unit, the economy-wide demand for energy will be reduced by an additional amount corresponding to this upstream fuel use. The sum of site energy and upstream energy is called the full-fuel cycle (FFC) energy. This appendix provides a brief description of the methodology used to calculate FFC savings from the site energy savings that result from a candidate standard level. The mathematical approach is discussed in Coughlin (2012)[1], and details on the fuel production chain analysis are presented in[2] This appendix outlines the steps involved in the calculation, defines the data that are taken from the AEO and used in the calculation, and presents the results of the calculations for electricity, natural gas and fuel oil.

When all quantities are normalized to the same units, the FFC energy can be represented as the product of the site energy and an *FFC multiplier*. The multiplier is defined mathematically as a function of a set of parameters representing the energy intensity and material losses at each production stage. These parameters depend only on physical data, i.e. the calculations do not require any assumptions about prices or other economic data. Most generally, these parameter values may vary by geographic region, time, *etc*. For the calculations used in this analysis, the parameters represent national averages.

Schematically, the steps in the calculation of FFC energy associated with electricity savings are:

1. Assume the site energy savings, denoted S_0 (mWh), are known.
2. Site electricity savings are converted to electricity savings at the power plant, taking into account the transmission and distribution loss factors. The power plant electricity savings are given by $S_1 = tdloss*S_0$, where
    - S_1 is the power plant electricity savings (mWh)
    - *tdloss* is the transmission & distribution loss factor[a]
3. Power plant electricity savings are converted to fuel savings. This conversion depends on a set of parameters a_x where
    - x is an index used to indicate fuel type, with x=c for coal, x=g for natural gas, and x=p for petroleum fuels
    - a_x is the amount of fuel x consumed per MWh of electricity produced at the power plant
    - The fuel savings are $S_{2x} = a_x S_1$, for each fuel type x

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[a] The values for *tdloss* are taken from NEMS. The value depends on region and changes slightly over the forecast period. The range of *tdloss* is 1.07 to 1.09.

The value of a_x over the analysis period is calculated from NEMS output. It depends on the capacity mix by fuel type, and on individual power plant efficiencies or heat rates, and so varies with region and with time. The higher the penetration of renewables, the lower the value of a_x.

4. For each fuel type x, an analysis of the fuel production chain determines the amount of energy required to produce one unit of fuel for site consumption. This analysis accounts for all energy sources, including electricity, that are used in fuel production. The consumption of fuel y required to provide one unit of fuel x for site consumption is denoted by the matrix element V_{xy}.
5. The matrix elements V_{xy}, which represent the incremental use of fuel y in the production chain for fuel x, are converted to the matrix elements M_{xy}, which represent the economy wide reduction in demand for fuel y resulting from a one unit reduction in demand for fuel x.
6. The equation $S_{3y} = \sum_x M_{xy} S_{2x}$ gives the full fuel cycle savings of fuel y.
7. The fuel savings are converted to energy units by multiplying S_{3y} by the heat content of fuel y, denoted q_y. The total FFC energy savings are given by the sum over the index y, so the total is equal to $\sum_x q_y S_{3y}$.

In addition to electricity, natural gas and petroleum-based fuels (primarily fuel oil) are used in buildings. The steps required to calculate the full fuel cycle energy use associated with production of gas or fuel oil are essentially identical to the scheme outlined above. The only difference is that the analysis begins at step 3, with the site fuel savings substituted for S_{2x}.

For simplicity in applications, the FFC energy use is summarized as a *multiplier* μ (mu). This is a dimensionless number that can be applied to the site energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (1-μ).

This methodology is completely general and is based on the mathematical definition of the quantity the FFC energy is meant to represent. The supporting numerical calculations of the parameters can be implemented in a variety of ways. As the data required are incomplete, some simplifying assumptions or approximations need to be made (these are explained in detail in[2]). These will generally have a limited quantitative impact, but may lead to small differences in the fuel cycle energy use parameters calculated by different authors. The GREET model developed by Argonne National Laboratory[3] is one example of a spreadsheet tool that calculates full fuel cycle energy use, with a focus on vehicle-fuel systems. For the Department's appliance standards energy savings estimates, the implementation of the FFC calculations has been designed specifically to make use of energy forecast data published in the AEO. These data include time series of:

1. Domestic production of natural gas by source type, imports of natural gas, and natural gas use by the oil and gas industry
2. Domestic production and imports of petroleum fuels by source type; total refinery inputs, outputs and refinery fuel use
3. Electric generating capacity by fuel type and fuel consumption for power generation
4. Coal use for power generation, by source type and coal quality

5. Fuel heat content for each fuel type

These quantities vary with each year in the AEO forecast period, leading to a corresponding variation in estimates of the full fuel cycle energy multipliers. Multipliers are presented in Table 1 for the AEO forecast years 2012 to 2035. To extend the analysis period beyond 2035, the years 2020 to 2035 are used to define a linear trend, which is then extrapolated to the final year of the analysis period.

For electricity, the site-to-source conversion factors are not included in the multiplier shown in Table 10-C.1.1. Hence, this multiplier is applied to the source energy savings. Site-to-source conversion factors are given in chapter 10.

Table 10-C.1.1 Full Fuel Cycle Multipliers for the AEO2011 Forecast Period

Forecast year	Source Energy Savings For Electricity	Site Fuel Oil Savings	Site Natural Gas Savings
2008	1.056	1.123	1.135
2009	1.058	1.120	1.129
2010	1.061	1.120	1.139
2011	1.060	1.118	1.139
2012	1.060	1.131	1.136
2013	1.059	1.130	1.133
2014	1.059	1.130	1.131
2015	1.059	1.129	1.129
2016	1.058	1.129	1.128
2017	1.058	1.130	1.127
2018	1.057	1.129	1.126
2019	1.057	1.128	1.125
2020	1.056	1.127	1.126
2021	1.055	1.127	1.125
2022	1.055	1.127	1.125
2023	1.055	1.127	1.125
2024	1.054	1.127	1.124
2025	1.054	1.127	1.123
2026	1.053	1.127	1.123
2027	1.053	1.127	1.122
2028	1.054	1.128	1.122
2029	1.054	1.128	1.121
2030	1.055	1.130	1.121
2031	1.055	1.131	1.120
2032	1.055	1.131	1.120
2033	1.055	1.131	1.120
2034	1.055	1.132	1.121
2035 on	1.055	1.132	1.121

REFERENCES

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[1] Coughlin, Katie. (2012a) "A Mathematical Analysis of Full Fuel Cycle Energy Use." *Energy* 37(1), pp. 698–708. http://www.sciencedirect.com/science/article/pii/S0360544211006803.

[2] Coughlin, Katie. (2012b) "Calculation of Full Fuel Cycle Multipliers for Energy Use in Buildings". Lawrence Berkeley National Laboratory, July 2012.

[3] Argonne National Laboratory. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. http://greet.es.anl.gov/

APPENDIX 16-A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 16-A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the

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[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).

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

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[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

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[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.

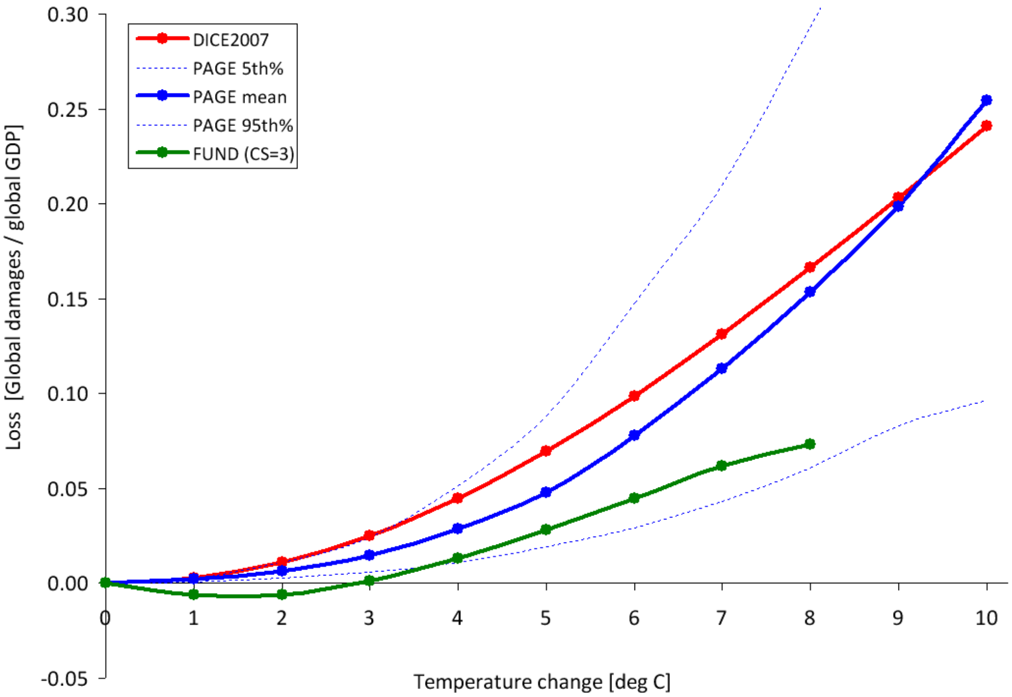

Figure 16-A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models[e]

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[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.

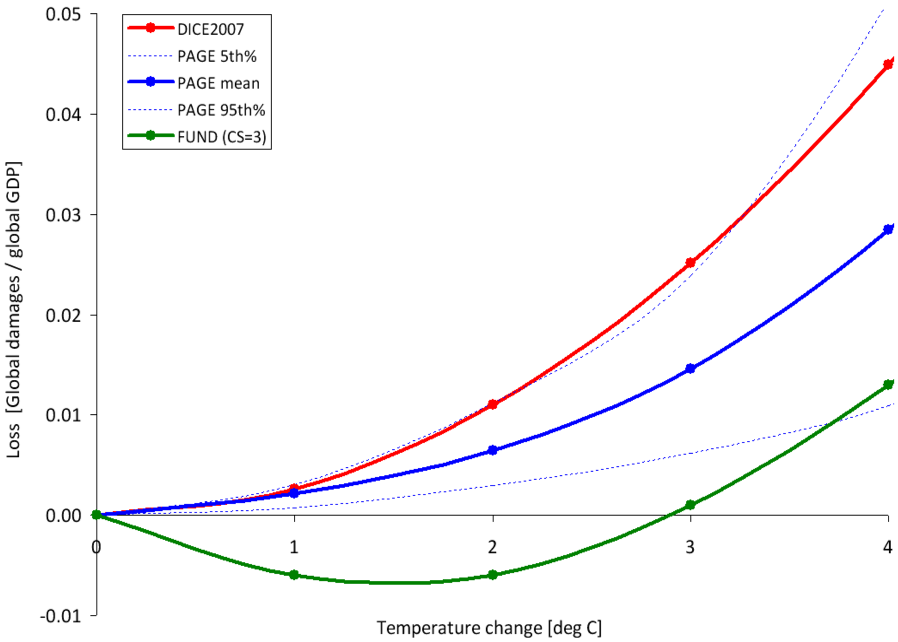

Figure 16-A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

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

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[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.

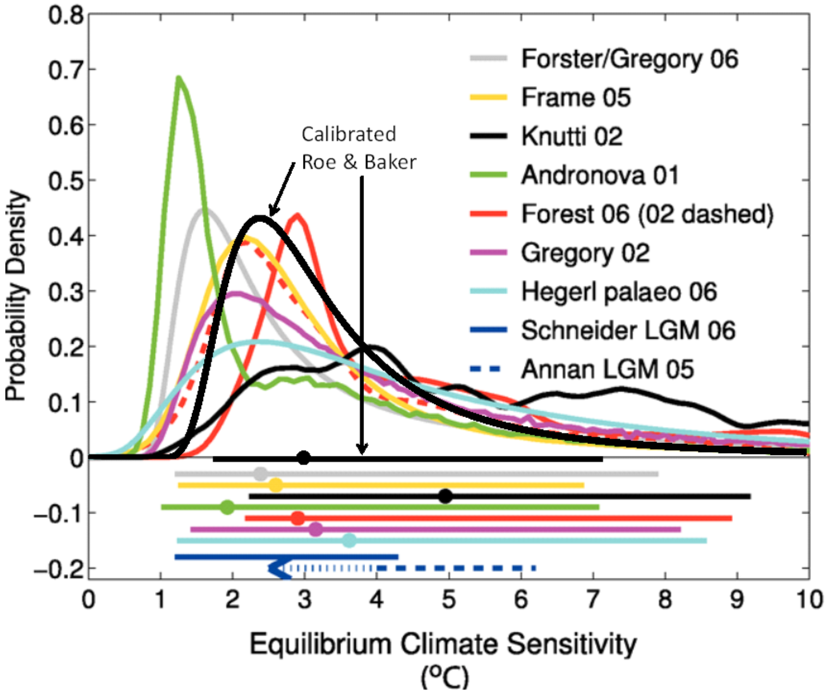

Figure 16-A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

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]

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[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.

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[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

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[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," $\rho + \eta \cdot g$, 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

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[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

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[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 95th 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.

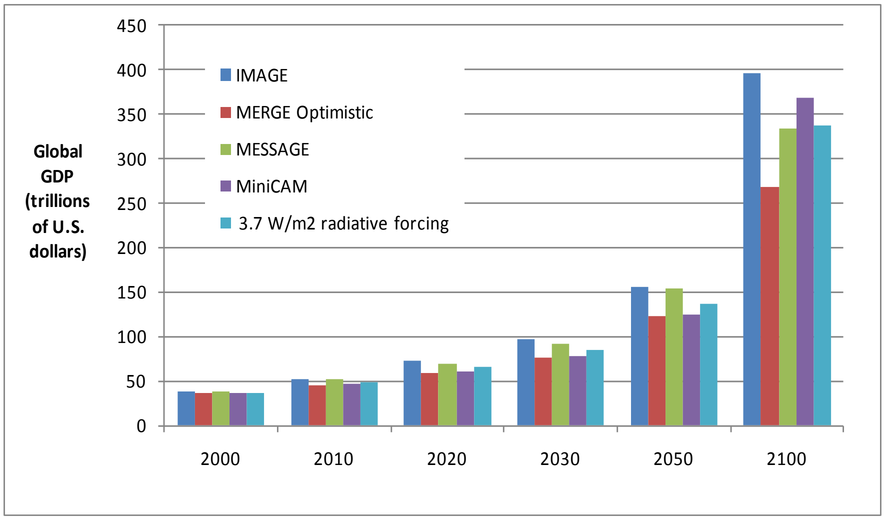

Figure 16-A.5.1 Level of Global GDP across EMF Scenarios

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.

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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-

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[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.

REFERENCES

Andronova, N., and M. Schlesinger. 2001. "Objective estimation of the probability density function for climate sensitivity." *J. Geophys. Res.*, 106(D19), 22605–22611.

Annan, J., et al., 2005. "Efficiently constraining climate sensitivity with paleoclimate simulations." *Scientific Online Letters on the Atmosphere,* 1, 181–184.

Anthoff D, C. Hepburn, and R. Tol. 2009a. "Equity Weighting and the Marginal Damage Costs of Climate Change." *Ecological Economics* 68:836-849.

Anthoff, D., R. Tol, and G. Yohe. 2009b. "Risk aversion, time preference, and the social cost of carbon." *Environmental Research Letters* 4: 024002 (7pp).

Arrow, K. 2007. "Global climate change: a challenge to policy." *Economist's Voice* 4(3):Article 2.

Arrow, K. 2000. "A Comment on Cooper." *The World Bank Research Observer*. vol 15, no. 2.

Arrow, K., et al. 1996. *Benefit-Cost Analysis in Environmental, Health, and Safety Regulation: A Statement of Principles*. Washington, D.C., AEI Press. pp. 13-14.

Arrow, K.J., et al. 1996. "Intertemporal equity, discounting and economic efficiency," in Climate Change 1995: Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the *Second Assessment Report of the Intergovernmental Panel on Climate Change*.

Campbell, J., P. Diamond, and J. Shoven. 2001. "Estimating the Real Rate of Return on Stocks Over the Long Term." Presented to the Social Security Advisory Board. August.

Campbell, K. et al. 2007. *The age of consequences: The foreign policy and national security implications of global climate change*. Center for Strategic & International Studies, 119 pp.

Castles, I. and D. Henderson. 2003. "The IPCC Emission Scenarios: An Economic-Statistical Critique." *Energy and Environment* 14(2-3): 159-185.

Chetty, R. 2006. "A New Method of Estimating Risk Aversion." *American Economic Review* 96(5): 1821–1834.

Dasgupta P. 2006. "Comments on the Stern Review's economics of climate change." University of Cambridge working paper.

Dasgupta P. 2008. "Discounting climate change." *Journal of Risk and Uncertainty* 37:141-169.

Easterling, W., et al. 2007. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Intergovernmental Panel on Climate Change, 976 pp.

Evans D., and H. Sezer. 2005. “Social discount rates for member countries of the European Union.” *J. Econ. Stud*. 32 47–59.

Forest, C., et al. 2002. “Quantifying uncertainties in climate system properties with the use of recent observations.” *Science* 295, 113.

Forest, D., P. Stone, and A. Sokolov. 2006. “Estimated PDFs of climate system properties including natural and anthropogenic forcings.” *Geophys. Res. Lett*., 33, L01705.

Forster, P., and J. Gregory. 2006. “The climate sensitivity and its components diagnosed from Earth radiation budget data.” *J. Clim*., 19, 39–52.

Frame, D., et al. 2005. “Constraining climate forecasts: The role of prior assumptions.” *Geophys. Res. Lett*., 32, L09702.

Gingerich, P. 2006. “Environment and evolution through the Paleocene-Eocene thermal maximum.” *Trends Ecol. Evol.* 21: 246-253.

Gollier, C. 2008. “Discounting with fat-tailed economic growth.” *Journal of Risk and Uncertainty* 37:171-186.

Gollier, C. and M. Weitzman (2009). "How Should the Distant Future be Discounted When Discount Rates are Uncertain?" Harvard University, mimeo, Nov 2009.

Gregory, J., et al. 2002a. “An observationally based estimate of the climate sensitivity.” *J. Clim*., 15(22), 3117–3121.

Groom, B., Koundouri, P., Panipoulou, E., Pantelidis, T. 2006. “An econometric approach to estimating long-run discount rates.” *Journal of Applied Econometrics.*

Hall R, and C. Jones . 2007. “The value of life and the rise in health spending.” Quarterly *Journal of Economics* 122(1):39-72.

Hansen, J.,M. Sato, P. Kharecha, G. Russell, D. W. Lea and M. Siddall. 2007. “Climate change and trace gases.” *Phil. Trans. Roy. Soc. A* 365: 1925-1954.

Hegerl G, et al. 2007. “Understanding and attributing climate change.” in Solomon S, et al. (eds) *Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Hegerl, G., T. Crowley, W. Hyde, and D. Frame. 2006. “Constraints on climate sensitivity from temperature reconstructions of the past seven centuries.” *Nature* 440.

Holtsmark, B., and K. Alfsen. 2005. “PPP Correction of the IPCC Emission Scenarios – Does it Matter?” *Climatic Change* 68(1-2): 11-19.

Hope C. 2006. “The marginal impact of CO2 from PAGE2002: an integrated assessment model incorporating the IPCC’s five reasons for concern.” *The Integrated Assessment Journal* 6(1):19-56.

Hope C. 2008. “Optimal carbon emissions and the social cost of carbon under uncertainty.” *The Integrated Assessment Journal* 8(1):107-122.

Intergovernmental Panel on Climate Change (2007). “Summary for Policymakers.” In *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Just, R., D. Hueth, and A. Schmitz. 2004. *The Welfare Economics of Public Policy*. Glos UK: Edward Elgar Publishing Limited.

Knutti, R., T. Stocker, F. Joos, and G. Plattner. 2002. “Constraints on radiative forcing and future climate change from observations and climate model ensembles.” *Nature*, 416, 719–723.

Kriegler, E. et al. 2009. “Imprecise probability assessment of tipping points in the climate system.” *Proc. Natl. Acad. Sci.* 106: 5041-5046.

Kotlikoff, L. and D. Rapson. 2006. “Does It Pay, at the Margin, to Work and Save? – Measuring Effective Marginal Taxes on Americans’ Labor Supply and Saving.” National Bureau of Economic Research, Working Paper, No. 12533.

Le Treut H., et al. 2007. “Historical Overview of Climate Change.” in Solomon et al., *Climate Change 2007.*

Lenton, T., et al. 2008. “Tipping elements in the Earth’s climate system.” *Proc. Natl. Acad. Sci.* 105: 1786-1793.

Levy, M., et al. 2005. “Ecosystem conditions and human well-being.” In: *Ecosystems and Human Well-being: Current State and Trends, Volume 1*. [R. Hassan, R. Scholes, and N. Ash, eds.] Washington: Island Press. pp. 123-164.

Lind, R. 1990. “Reassessing the Government’s Discount Rate Policy in Light of New Theory and Data in a World Economy with a High Degree of Capital Mobility.” *Journal of Environmental Economics and Management* 18, S-8-S-28.

Mastrandre, M. 2009. “Calculating the benefits of climate policy: Examining the assumptions of Integrated Assessment Models.” Pew Center on Global Climate Change Working Paper, 60 pp.

Meehl, G, et al. 2007. “Global Climate Projections.” in Solomon et al., *Climate Change 2007.*

National Research Council (2009). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academies Press.

Newbold S, Daigneault A. 2009. "Climate response uncertainty and the benefits of greenhouse gas emissions reductions." *Environmental and Resource Economics* 44:351-377.

Newell, R., and W. Pizer. 2003. Discounting the distant future: how much do uncertain rates increase valuations? *Journal of Environmental Economics and Management* 46: 52-71.

Nordhaus, W. 1994. "Expert Opinion on Climate Change." *American Scientist* 82: 45-51.

Nordhaus, W. 2007a. *Accompanying notes and documentation on development of DICE-2007 model: notes on DICE-2007.delta.v8 as of September 21, 2007.*

Nordhaus, W. 2007b. "Alternative measures of output in global economic-environmental models: Purchasing power parity or market exchange rates?" *Energy Economics* 29: 349-372.

Nordhaus W. 2008. *A Question of Balance: Weighing the Options on Global Warming Policies*. New Haven, CT: Yale University Press.

Nordhaus, W. 2009. "An Analysis of the Dismal Theorem. Cowles Foundation Discussion Paper. No. 1686. January.

Nordhaus W., and Boyer J. 2000. *Warming the World: Economic Models of Global Warming*. Cambridge, MA: MIT Press.

Pindyck, R. 2009. "Uncertain Outcomes and Climate Change Policy." NBER Working Paper, No. 15259. August.

Ramsey, F. 1928. "A Mathematical Theory of Saving." *The Economic Journal* 38(152): 543-559.

Roe, G. 2008. "Feedbacks, timescales, and seeing red." *Annual Review of Earth and Planetary Sciences* 37:5.1-5.23.

Roe, G., and M. Baker. 2007. "Why is climate sensitivity so unpredictable?" *Science* 318:629-632.

Schneider von Deimling, T., H. Held, A. Ganopolski, and S. Rahmstorf. 2006. "Climate sensitivity estimated from ensemble simulations of glacial climate." *Clim. Dyn.*, 27, 149–163.

Smith, J. et al. 2009. "Transient dwarfism of soil fauna during the Paleocene-Eocene Thermal Maximum." *Proc. Natl. Acad. Sci.* 106: 17665-17660.

Stern, N., et al. (2006), *Stern Review: The Economics of Climate Change*, HM Treasury, London.

Stern N. 2008. "The economics of climate change." *American Economic Review* 98(2):1-37.

Sterner, T., and U. Persson. 2008. An even Sterner review: Introducing relative prices into the discounting debate. *Rev. Env. Econ. Pol.* 2: 61-76.

Summers, L., and R. Zeckhauser. 2008. "Policymaking for Prosperity." Journal of Risk and Uncertainty 37: 115-140.

Szpiro, G. 1986. "Measuring Risk Aversion: An Alternative Approach." *The Review of Economics and Statistics* 68(1): 156-9.

Tol, R. 2002a. "Estimates of the damage costs of climate change. Part I: benchmark estimates." *Environmental and Resource Economics* 21:47-73.

Tol, R. 2002b. "Estimates of the damage costs of climate change. Part II: dynamic estimates." *Environmental and Resource Economics* 21:135-160.

Tol, R. 2006. "Exchange Rates and Climate Change: An Application of FUND." *Climatic Change* 75(1-2): 59-80.

Tol, R. 2009. "An analysis of mitigation as a response to climate change." Copenhagen Consensus on Climate. Discussion Paper.

U.S. Department of Defense. 2010. Quadrennial Defense Review Report. February.

Warren, R., et al. 2006. "Spotlight Impact Functions in Integrated Assessment." Tyndall Center for Climate Change Research, Working Paper 91.

Weitzman, M. 2009. "On modeling and interpreting the economics of catastrophic climate change." *Review of Economics and Statistics* 91:1-19.

Weitzman, M. 2007. "A review of The Stern Review of the Economics of Climate Change." *Journal of Economic Literature* 45:703-724.

Weitzman, M. 1999. In Portney P.R. and Weyant J.P. (eds.), *Discounting and Intergenerational Equity*, Resources for the Future, Washington, D.C.

Weitzman, M. 1998. "Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate." *Journal of Environmental Economics and Management* 36 (3): 201-208.

Wing, S. et al. 2005. "Transient floral change and rapid global warming at the Paleocene-Eocene boundary." *Science* 310: 993-996.

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.

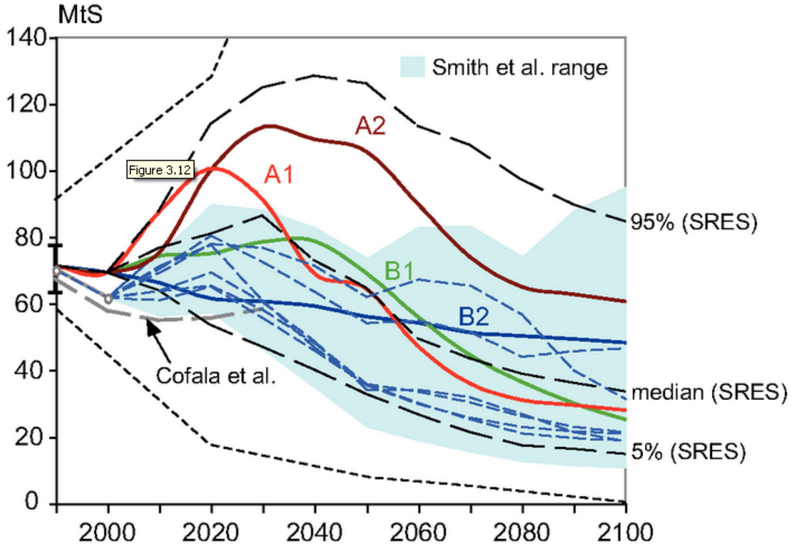

Figure 16-A.9.1 Sulphur Dioxide Emission Scenarios

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.

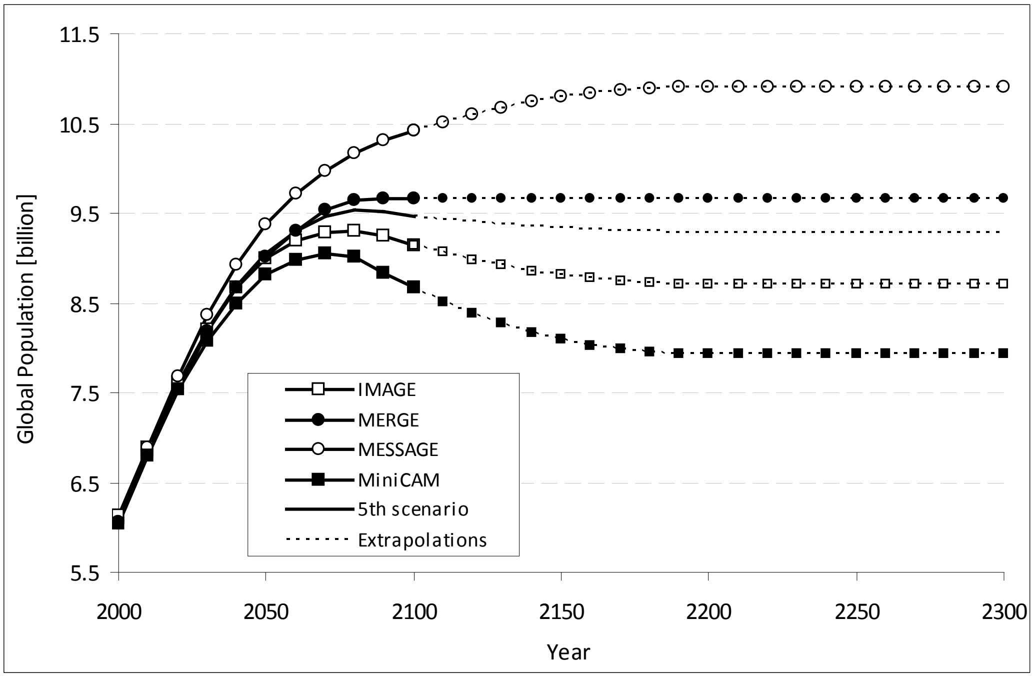

Figure 16-A.9.2 Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200.)

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.

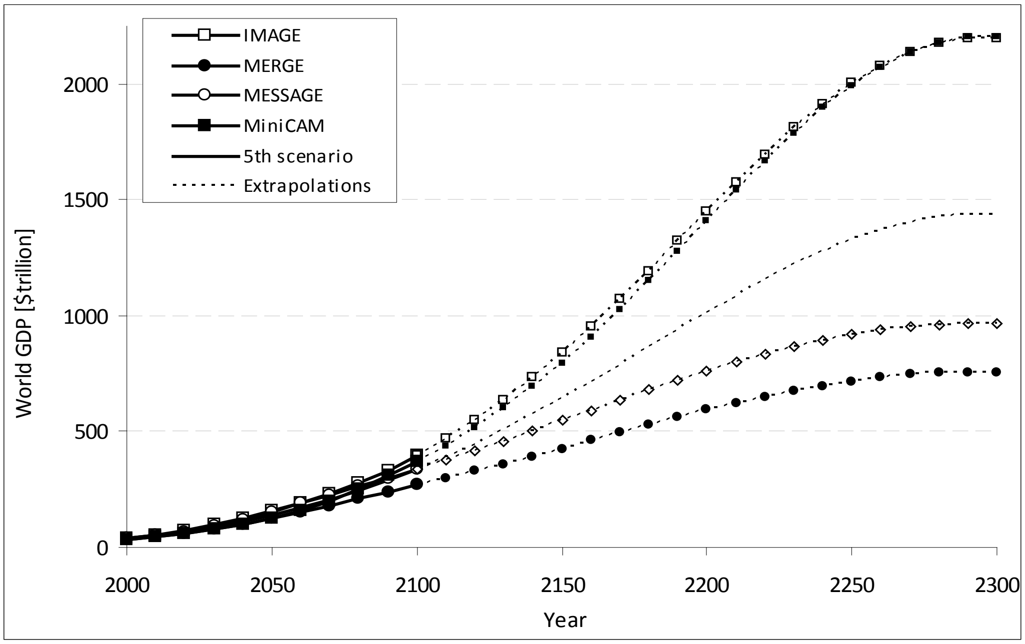

Figure 16-A.9.3 **World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)**

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.

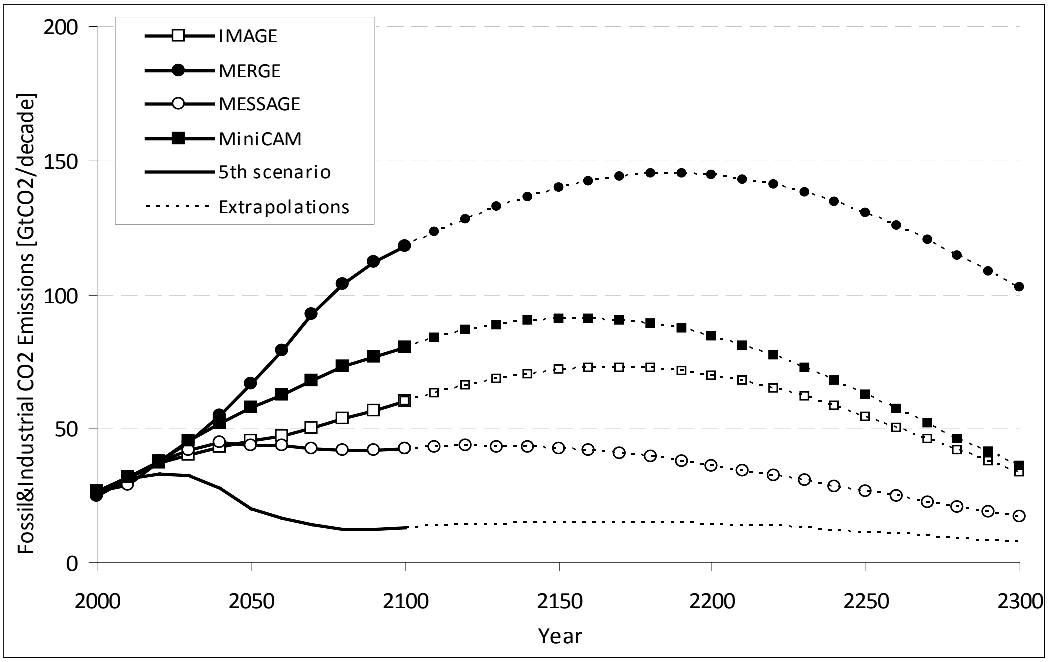

Figure 16-A.9.4 Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300.)

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.

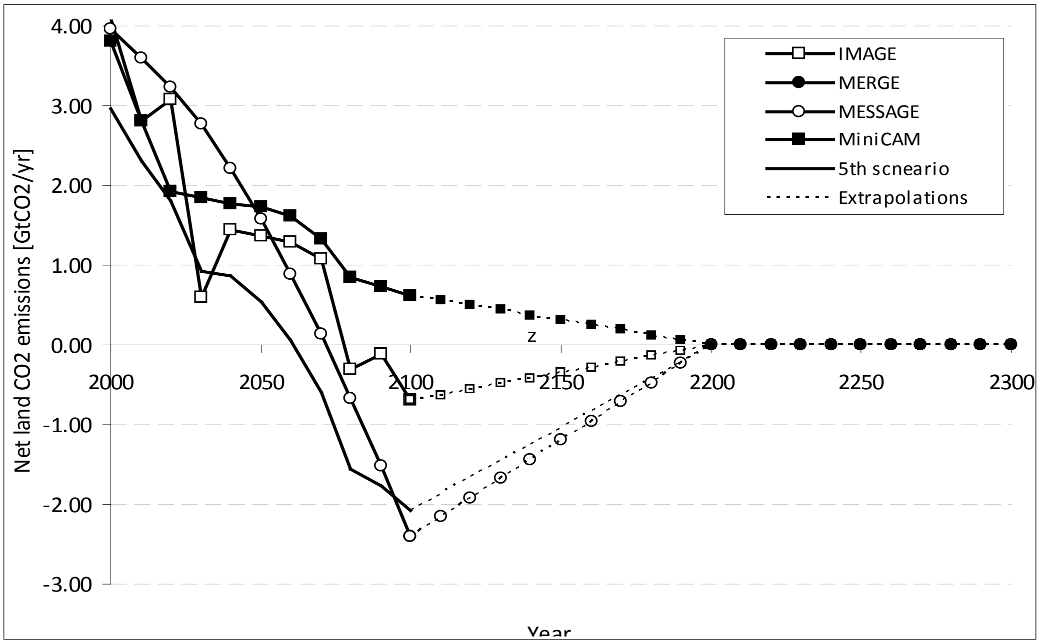

Figure 16-A.9.5 Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[jj]

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).

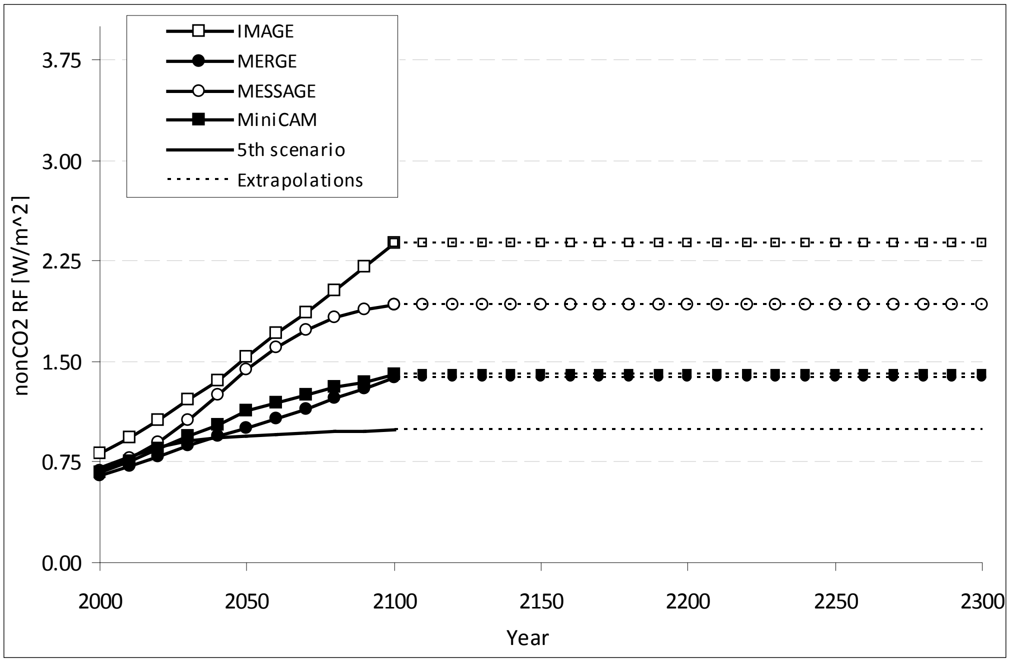

Figure 16-A.9.6 **Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100)**

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.

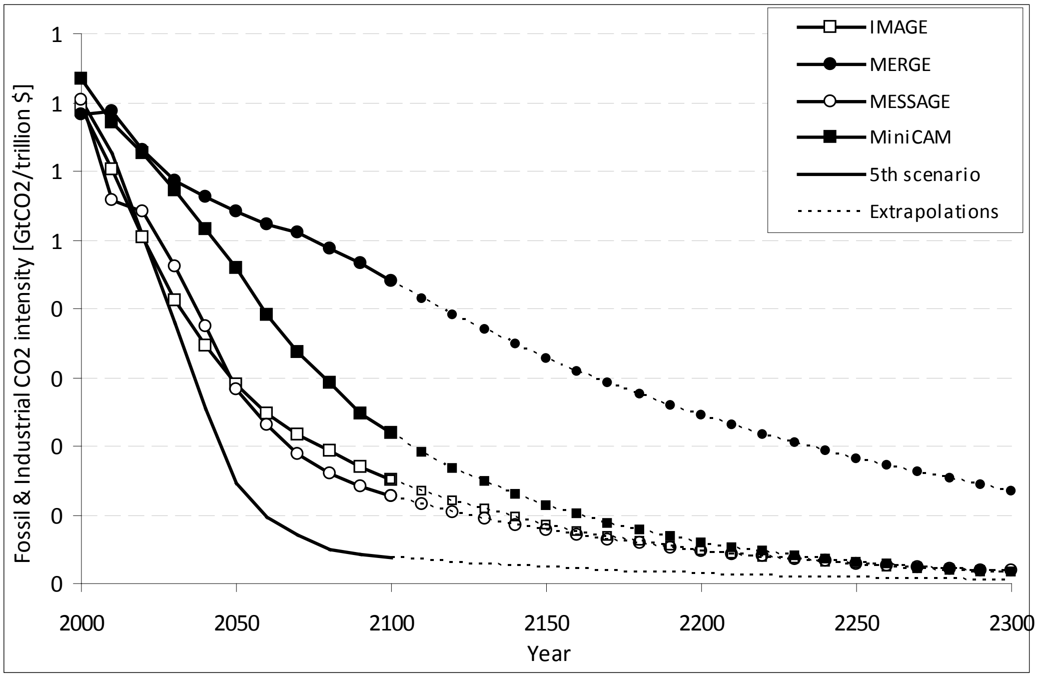

Figure 16-A.9.7 Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300)

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

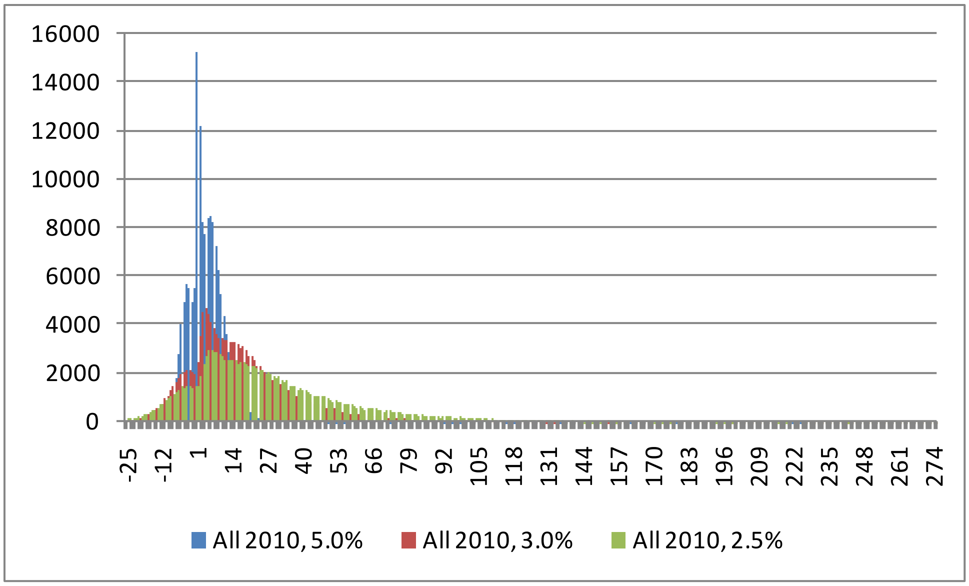

Figure 16-A.9.8 Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by discount rate

* 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

PRELIMINARY TECHNICAL SUPPORT DOCUMENT EXECUTIVE SUMMARY

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ES.1 OVERVIEW OF CURRENT ACTIVITIES

The Energy Policy and Conservation Act (EPCA), 42 U.S.C. § 6311, *et seq.*, as amended by the Energy Policy Act of 1992 (EPACT) established energy conservation standards and test procedures for certain commercial and industrial electric motors manufactured (alone or as a component of another piece of equipment) after October 24, 1997. Then, in December 2007, Congress passed into law the Energy Independence and Security Act of 2007 (EISA 2007) (Pub. L. No. 110–140). Section 313(b)(1) of EISA 2007 updated the energy conservation standards for those electric motors already covered by EPCA and established energy conservation standards for a larger scope of motors not previously covered. (42 U.S.C. 6313(b)(2))

EPCA also directs the Secretary of Energy to publish a final rule no later than 24 months after the effective date of the previous final rule to determine whether to amend the standards in effect for such product. Any such amendment shall apply to electric motors manufactured after a date which is five years after –

(i) the effective date of the previous amendment; or
(ii) if the previous final rule did not amend the standards, the earliest date by which a previous amendment could have been effective. (42 U.S.C. 6313(b)(4)(B))

EISA 2007, which went into effect on December 19, 2010, constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. DOE will determine whether to promulgate amended energy conservation standards for electric motors and, if so, what level the new standards should be set at based on an in-depth consideration of the technological feasibility, economic justification, and energy savings of candidate standards levels as required by section 325 of EPCA. (42 U.S.C. 6295(o)-(p), 6316(a)) Any such amended standards that DOE establishes would take effect December 19, 2015.

This executive summary describes current activities and key results from the preliminary analyses that DOE conducted in its review of potential amendments to the energy conservation standards for electric motors. Furthermore, the executive summary identifies issues about which DOE seeks comments from interested parties. These issues are addressed in more detail in chapter 2 of the preliminary technical support document (preliminary TSD) and will be discussed in a future public meeting.

To evaluate and consider impacts under the seven EPCA factors for economic justification (42 U.S.C. 6295(o)(2)(B)(i), 6316(a)), DOE conducts a detailed analysis of regulatory impacts on a product and presents them in a technical support document (preliminary TSD). Figure ES.1.1 summarizes the analytical components of this regulatory analysis methodology. The focus of this figure is the center column, identified as "Analyses." The columns labeled "Key Inputs" and "Key Outputs" show how the analyses fit into the rulemaking process, and how the analyses relate to each other. Key inputs are the types of data and other information that the analyses require. Some key inputs exist in public databases; DOE collects other inputs from interested parties or persons with special knowledge and expertise. 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.

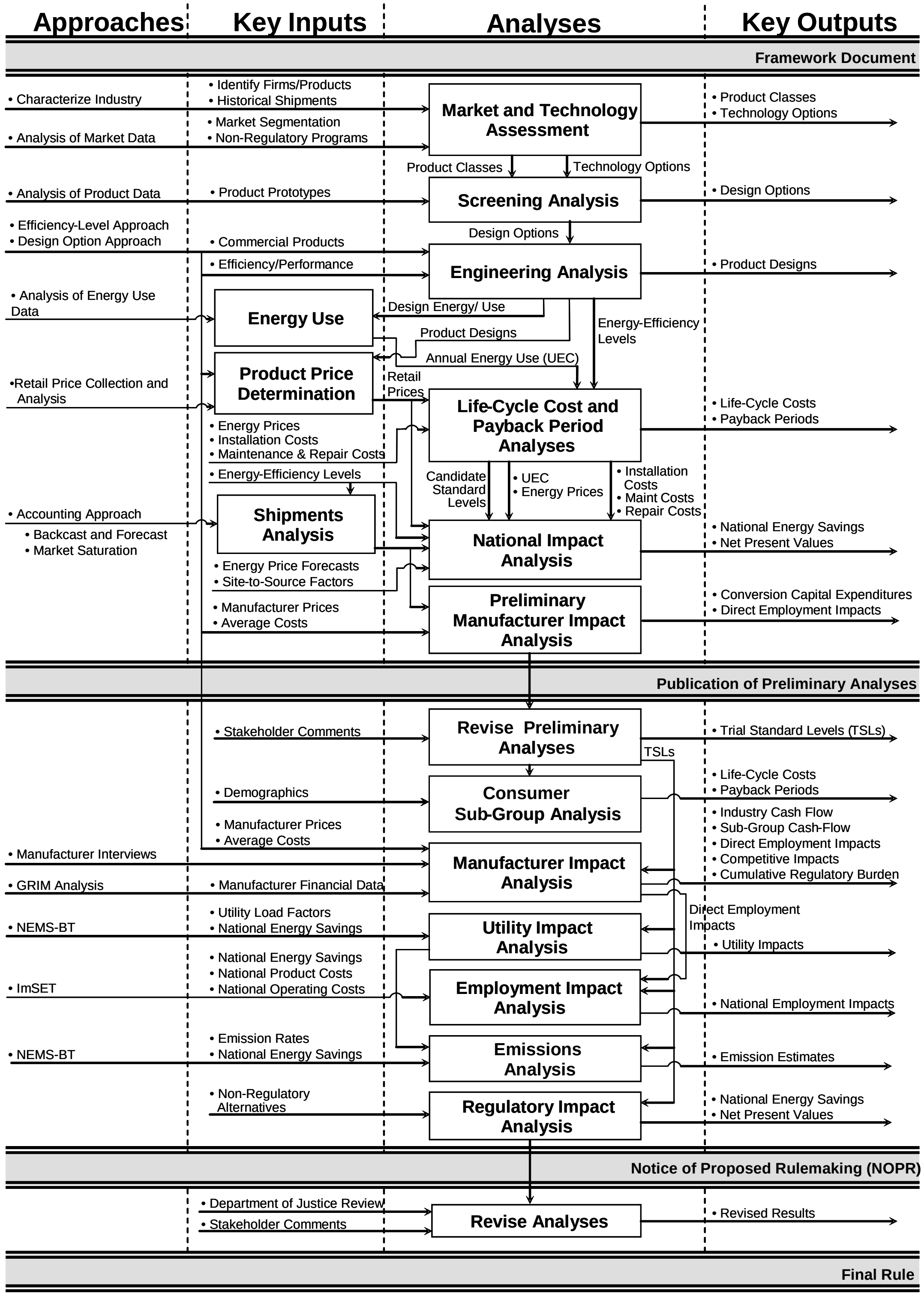

Figure ES.1.1 Flow Diagram of Electric Motor Rulemaking Analyses

ES.2 OVERVIEW OF THE PRELIMINARY ANALYSES AND THE PRELIMINARY TECHNICAL SUPPORT DOCUMENT

DOE is publishing a notice of public meeting (NOPM) in the Federal Register, which announces the availability of the preliminary TSD, the date of the public meeting, and information pertaining to the public meeting. In addition, the NOPM highlights the major preliminary analyses DOE has developed at this stage of the rulemaking.

The preliminary TSD describes each analysis in detail, providing detailed descriptions of inputs, sources, methodologies, and results. Chapter 2 of the preliminary TSD provides an overview of each preliminary analysis, the comments DOE received in response to the framework document, and DOE's responses to those comments. The remaining chapters of the preliminary TSD, which are described later, address the preliminary analyses performed:

Chapter 3: A market and technology assessment that characterizes the relevant product markets and technology options, including prototype designs.

Chapter 4: A screening analysis that reviews each technology option to determine whether it (1) is technologically feasible, (2) is practicable to manufacture, install, and service, (3) would adversely affect product utility or product availability, or (4) would have adverse impacts on health and safety.

Chapter 5: An engineering analysis that develops cost-efficiency relationships estimating the manufacturer's cost of achieving increased efficiency. DOE determines the increased cost to the consumer through an analysis of engineering markups, which convert manufacturer production cost to manufacturer selling price (MSP).

Chapter 6: A markups analysis that converts the estimated MSPs derived from the engineering analysis to installed prices.

Chapter 7: An energy use analysis that determines the annual energy use of the considered products.

Chapter 8: Life-cycle cost (LCC) and payback period (PBP) analyses that calculate, at the consumer level, the discounted savings in operating costs (less maintenance and repair costs) throughout the estimated average life of the covered products, compared to any increase in the installed cost for the products likely to result directly from the imposition of a given standard.

Chapter 9: A shipments analysis that projects product shipments, which are then used to calculate the national impacts of standards on energy, net present value (NPV), and future manufacturer cash flows.

Chapter 10: An assessment of the aggregate impacts at the national level of potential energy conservation standards for the considered products, as measured by the NPV of total consumer economic impacts and the national energy savings (NES).

Chapter 11: A customer subgroup analysis that evaluates the impacts of standards on identifiable groups of customers, such as customers of different business types, which may be disproportionately affected by an energy conservation standard.

Chapter 12: A preliminary manufacturer impact analysis (MIA) that assesses the potential impacts of energy conservation standards on manufacturers, such as effects on expenditures for capital conversion, marketing costs, shipments, and research and development costs.

Chapter 13: An employment impact analysis that examines the effects of energy conservation standards on national employment.

Chapter 14: A utility impact analysis that examines impacts of energy conservation standards on the generation capacity of electric utilities.

Chapter 15: An emissions analysis that evaluates the reduced power plant emissions resulting from reduced consumption of electricity.

Chapter 16: A monetization of emission reduction benefits resulting from reduced emissions associated with potential amended standards.

Chapter 17: A regulatory impact analysis that: (1) identifies and seeks to mitigate overlapping effects of regulations on manufacturers and (2) addresses the potential for non-regulatory approaches to supplant or augment energy conservation standards.

ES.3 KEY RESULTS FROM THE ANALYSES

The following sections describe in detail the key analyses DOE performed in support of the preliminary TSD.

ES.3.1 Market and Technology Assessment

When initiating an energy conservation 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. For the equipment in the preliminary analyses, DOE addressed the following: (1) manufacturer market share and characteristics, (2) existing regulatory and non-regulatory initiatives to improve the efficiency of the equipment, and (3) trends in the equipment's characteristics and retail markets. This information serves as resource material throughout the rulemaking.

DOE reviewed literature and interviewed manufacturers to get an overall understanding of the electric motors industry in the United States. Industry publications, trade journals, government agencies, and trade organizations provided the bulk of the information obtained regarding: (1) manufacturers and their market shares, (2) shipments by equipment class, (3) equipment information, and (4) industry trends. The appropriate sections of preliminary TSD chapters 2 and 3 describe the analyses and resulting information.

DOE typically uses information about existing and past technology options and prototype designs to determine which technologies and combinations of 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 of those options that might for improve equipment efficiency. DOE developed its list of technology options for electric motors from its examination of technical documents and through consultation with manufacturers and industry experts.

ES.3.2 Screening Analysis

The screening analysis (chapter 4) 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; or (4) have adverse impacts on health and safety. DOE develops an initial list of efficiency-enhancement options (i.e., technology options) from those identified as “technologically feasible” in the technology assessment. In consultation with interested parties, DOE then reviews the list to determine if these technologies are practicable to manufacture, install, and service; would adversely affect product utility or availability; or would have adverse impacts on health and safety. DOE removes from the list those technology options for which no energy consumption information is available and technology options whose energy consumption could not be adequately measured by the existing DOE test procedure. After DOE examines all of the technology options and pares them down in the screening analysis, it uses the remaining design options as inputs to estimate the characteristics and the cost of higher efficiency equipment in the engineering analysis.

ES.3.3 Engineering Analysis

The engineering analysis (chapter 5) establishes the relationship between the MSP and product efficiency. This relationship serves as the basis for cost/benefit calculations in terms of individual consumers, manufacturers, and the Nation. This chapter discusses the equipment classes DOE analyzed, the representative baseline units, the incremental efficiency levels, the methodology DOE used to develop the MSP, the cost-efficiency curves for equipment classes analyzed, and the methodology DOE used to scale those results to other equipment classes of electric motors that were not analyzed.

ES.3.3.1 Equipment Classes Analyzed

Because of the large number of electric motor equipment classes, DOE did not analyze each one in the engineering analysis. Instead, DOE analyzed five representative equipment classes: three from equipment class group 1 (NEMA Design A and B motors) and two from equipment class group 2 (NEMA Design C motors). The equipment class group 3 (fire pump motors) analysis will be based on the data from equipment class group 1 representative units because of the similarities between fire pump electric motors and NEMA Design B motors. When selecting these groups, DOE used catalog data, discussions with industry experts, and the Framework Document. After analyzing this information, DOE reached the tentative conclusion that the selected motor groups were representative of the commercial and industrial electric motor market which made them reasonable selections for the purposes of conducting the engineering analysis. The motors presented in Table ES.3.1 are the five representative units DOE analyzed. The left three columns provide the three characteristics of an electric motor that define its equipment class – namely, motor category, horsepower and number of poles. The fourth column denotes the frame series of the analyzed motor.

Table ES.3.1 Design Characteristics of the Five Representative Units Analyzed

Motor Category	Horsepower	Number of Poles	Frame Series
NEMA Design B	5	4	184T
NEMA Design B	30	4	286T
NEMA Design B	75	4	365T
NEMA Design C	5	4	184T
NEMA Design C	50	4	326T

DOE requests comment on its selection of representative units for equipment class group 1, Design A and B motors from 1-500 horsepower, and equipment class group 2, Design C motors from 1-200 horsepower. DOE also requests comment on basing its analysis of equipment class group 3, fire pump electric motors, on the analysis of equipment class group 1 representative units.

ES.3.3.2 Engineering Analysis Results

For each NEMA Design B representative unit, DOE purchased four electric motors at four increasing efficiency levels[a]. The purchased motors included a baseline design at the minimum efficiency commercially available, while considering the expanded scope of coverage, a design at the EPACT 1992 level, a design at the NEMA Premium level, and a design at the maximum efficiency commercially available for that motor rating. DOE then used software modeling to create a fifth and sixth motor design for each of the three NEMA Design B electric motors. These additional designs had efficiencies corresponding to an incremental efficiency level and a maximum technologically feasible ("max tech") efficiency level. DOE assigned each of these efficiency levels a candidate standard level (CSL) number from 0-5 with the baseline motor being assigned CSL 0 and the max-tech software modeled motor being assigned CSL 5. See Table ES.3.2 for a layout of the CSLs and their efficiency representations.

Table ES.3.2 NEMA Design B Motor Candidate Standard Levels

Motor Designation	Efficiency Level
CSL 0	Minimum Commercially Available
CSL 1	EPACT 1992
CSL 2	NEMA Premium
CSL 3	Maximum Commercially Available

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[a] For the 30 horsepower representative unit, DOE purchased three electric motors at different efficiency levels, and used software modeling to simulate motors at the remaining efficiency levels.

CSL 4	Incremental
CSL 5	Maximum Technology

For the NEMA Design C representative units, DOE purchased one baseline motor and used software to model three additional designs with higher efficiencies than the efficiency of the baseline motor. DOE used this approach because NEMA Design C motors constitute a small portion of the electric motor market with limited product selection and DOE was unable to locate any commercially available units with increased efficiency levels. The NEMA Design C motors were assigned CSL numbers from 0-3 with CSL 0 representing EPACT 1992 efficiency levels and CSL 3 representing the max-tech efficiency level. See Table ES.3.3 and Table ES.3.4 for a layout of the CSLs and their efficiency representations.

Table ES.3.3 Design C 5 Horsepower Motor Candidate Standard Levels

Motor Designation	Efficiency Level
CSL 0	EPACT 1992
CSL 1	NEMA Premium
CSL 2	Incremental
CSL 3	Maximum Technology

Table ES.3.4 NEMA Design C 50 Horsepower Motor Candidate Standard Levels

Motor Designation	Efficiency Level
CSL 0	EPACT 1992
CSL 1	Incremental
CSL 2	NEMA Premium
CSL 3	Maximum Technology

DOE used a consistent methodology and pricing scheme including material, labor costs and manufacturer markups to develop MSPs for the baseline and incrementally more efficient electric motor designs. This methodology included tearing down the motors, weighing components, and estimating the material costs based on material pricing. DOE used this bottoms-up derived and manufacturer marked-up selling prices throughout this section. The engineering analysis results are a series of MSP-versus-efficiency curves that represent the five motor types analyzed from the representative equipment classes. The five graphs shown in Figure ES.3.1 through Figure ES.3.5 provide the MSP-versus-efficiency curves and Table ES.3.6 through Table ES.3.14 present the tabulated results.

In determining the relationship between MSP and energy efficiency for electric motors, DOE estimated the increase in MSP associated with technological changes that increase the efficiency of the baseline models. DOE developed cost estimates for the engineering analysis from information received from subject matter experts with many years experience in the field, manufacturers' suggestions, and input from other industry-related experts, including material suppliers.

NEMA Design B, 5 Horsepower, 4-Pole, Enclosed Frame Motor

Figure ES.3.1 presents the relationship between the MSP and full-load efficiency for the 5 horsepower, Design B, 4-pole enclosed polyphase motor analyzed. Using tear-down results for CSLs 0-3, DOE determined that the manufacturer of those motors used various combinations of stack length increases, electrical material such as copper or electrical steel, and rotor cage design changes to increase the electric motor's efficiency level. The max-tech software modeled CSL 5 and utilized a die-cast copper conductor in the rotor. Also, DOE assumed a hand-wound labor hour amount for the two software modeled CSLs (CSL 4 and 5). The increased labor hour amounts account for the larger than usual increase in the MSPs for the higher CSLs as illustrated in Figure ES.3.1.

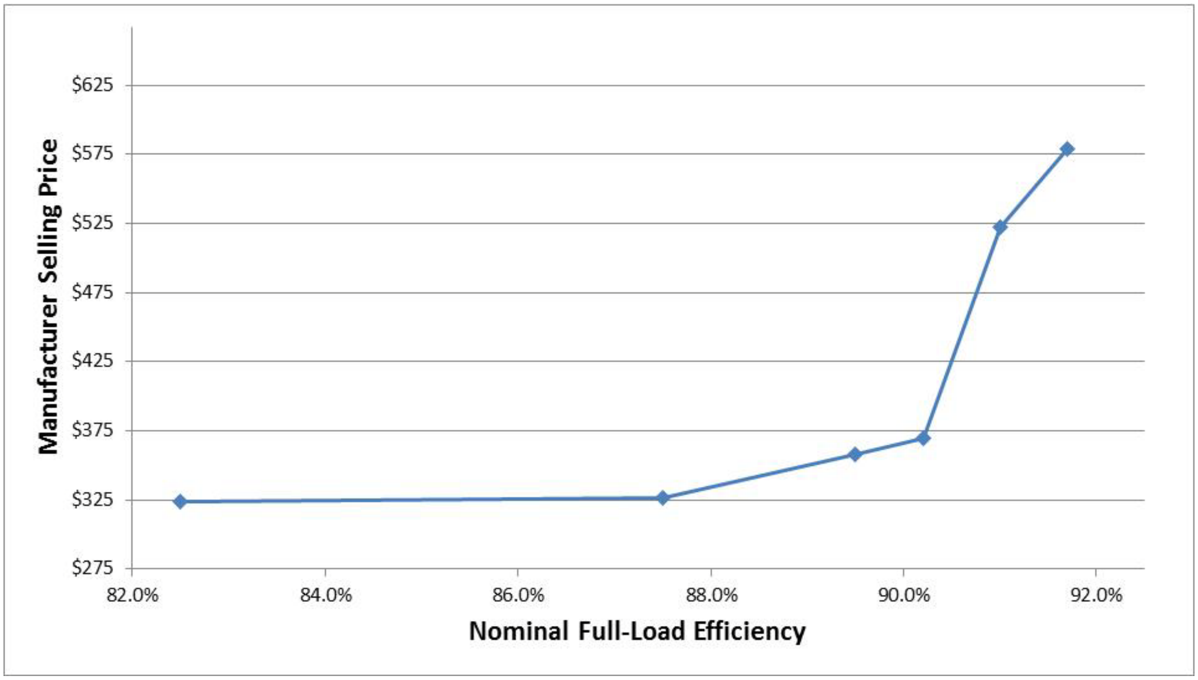

Figure ES.3.1 NEMA Design B, 5 Horsepower, 4-Pole, Enclosed Frame Motor Engineering Analysis Curve

Table ES.3.5 presents the same engineering analysis results in tabular form, including the nominal full-load efficiency values and the MSPs. From CSL 0 to 3, DOE found that the full-load efficiency would increase 7.7 nominal percentage points over the baseline, CSL 0, which represents a 49 percent reduction in motor losses. When moving from CSL 3 to 4 and from CSL 4 to 5, MSP increases by 41 percent and 11 percent, respectively, for consecutive loss reductions of roughly 10 percent. Again, the large price increases when getting to CSLs 4 and 5 are a result of the use of hand-wound labor hour assumptions and the use of low-loss electrical steels.

Table ES.3.5 Efficiency and Manufacturer Selling Price Data for the NEMA Design B 5 Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	82.5	324
1	87.5	326
2	89.5	358
3	90.2	370
4	91.0	523
5	91.7	579

Table ES.3.6 presents some of the design and performance specifications associated with the six 5-horsepower NEMA Design B motors presented in Table ES.3.5 including stator copper weight, rotor conductor weight, and electrical steel weight.

Table ES.3.6 NEMA Design B 5 Horsepower, 4-Pole, Enclosed Frame Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
Efficiency	**%**	82.5	87.5	89.5	90.2	91.0	91.7
Line Voltage	**V**	460	460	460	460	460	460
Full Load Speed	**RPM**	1,745	1,745	1,760	1,755	1,773	1,776
Full Load Torque	**Nm**	20.3	20.4	20.3	20.4	20.1	20.1
Current	**A**	6.9	6.5	6.3	6.2	6.3	6.0
Steel	**-**	M56	M47	M47	M47	M36	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	43.5%	57.2%	70.0%	68.6%	82.4%	85.2%
Stator Wire Gauge	**AWG**	19	19	19	20	20	20
Stator Copper Weight	**lbs**	8.4	10.1	10.1	12.2	14.4	14.4
Rotor Conductor Weight	**lbs**	2.63	2.87	2.6	3.42	2.7	9.1
Stack Length	**In**	2.8	3.47	5.14	4.65	5.32	5.32
Housing Weight	**lbs**	8	9	22	12	14	14

NEMA Design B, 30 Horsepower, 4-Pole, Enclosed Frame Motor

Figure ES.3.2 presents the relationship between the MSP and full-load efficiency for the 30 horsepower, Design B, 4-pole enclosed polyphase motor analyzed. Using tear-down results for CSLs 0 through 3, DOE determined that the manufacturer of these motors used a combination of material grade, material quantities, and design changes to increase the electric motor's efficiency.

DOE used software modeling to develop CSL 4. For this design, DOE used a copper rotor and low-loss electrical steel to achieve efficiencies higher than the most efficient purchased motor, CSL 3. DOE was unable to increase the efficiency a full NEMA band greater than CSL 4 and therefore the 30 horsepower Design B representative equipment class does not have a CSL 5.

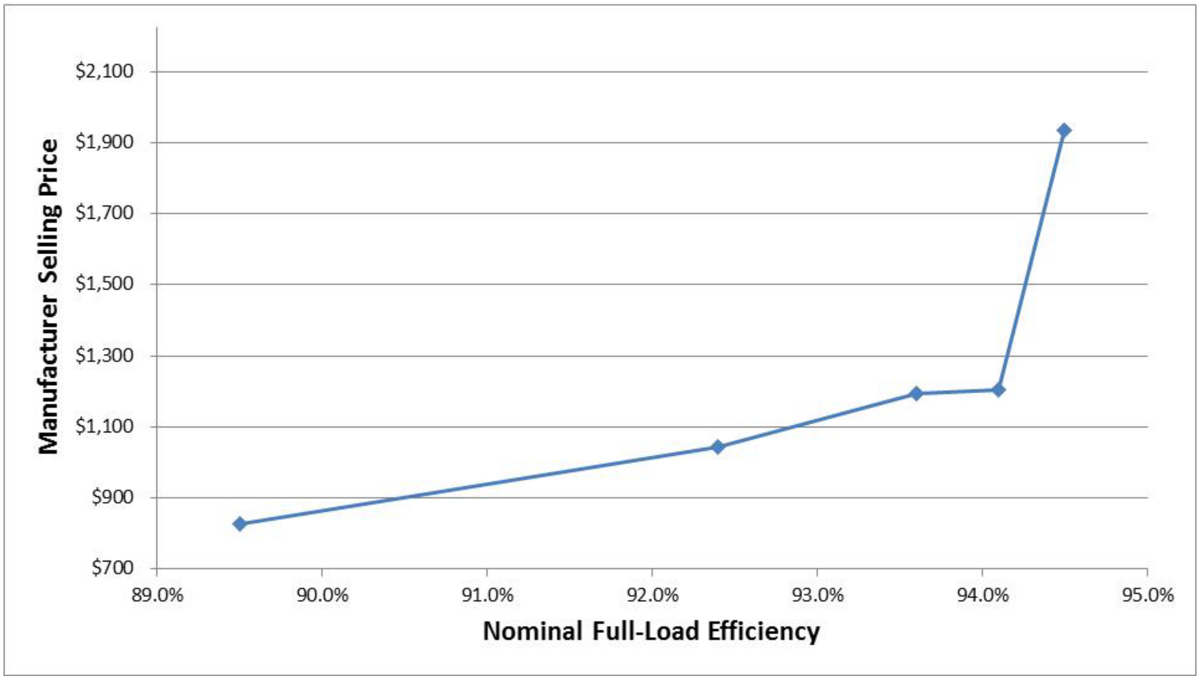

Figure ES.3.2 NEMA Design B, 30 Horsepower, 4-Pole, Enclosed Frame Motor Engineering Analysis Curve

Table ES.3.7 presents the same engineering analysis results in a tabular form, including the full-load efficiency values and the MSPs. From CSL 0 through 3, DOE found that the full-load efficiency would increase 4.6 nominal percentage points over the baseline, CSL 0, which represents about a 47 percent reduction in motor losses. The increase in MSP to move from CSL 0 to CSL 3 is $377, or about a 46 percent increase in MSP over CSL 0. Moving from CSL 3 to CSL 4 provides a 7 percent reduction in motor losses for a MSP increase of $732 or about a 61 percent MSP increase over CSL 3.

Table ES.3.7 Efficiency and Manufacturer Selling Price Data for the NEMA Design B 30 Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	89.5	827
1	92.4	1,044
2	93.6	1,193
3	94.1	1,204
4	94.5	1,936

Table ES.3.8 presents some of the design and performance specifications associated with the four 30 horsepower designs presented in Table ES.3.7.

Table ES.3.8 NEMA Design B 30 Horsepower, 4-Pole, Enclosed Frame Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4
Efficiency	**%**	89.5	92.4	93.6	94.1	94.5
Line Voltage	**V**	230	460	460	460	460
Full Load Speed	**RPM**	1,755	1,765	1,768	1,770	1,784
Full Load Torque	**Nm**	121.6	121.4	120.8	120.6	119.6
Current	**A**	37	37	36	36	37
Steel	**-**	M56	M56/M47	M47	M47	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	48.4	84.0	70.0	70.0	83.2
Stator Wire Gauge	**AWG**	18	17	16	18	18
Stator Copper Weight	**lbs**	20.2	43.5	45.2	47.7	74.5
Rotor Conductor Weight	**lbs**	8.25	9.5	7.5	13.66	42.6
Stack Length	**In**	7.88	5.53	6.00	6.74	7.00
Housing Weight	**lbs**	21	130	131	147	79

NEMA Design B, 75 Horsepower, 4-Pole, Enclosed Frame Motor

Figure ES.3.3 presents the relationship between the MSP and full-load efficiency for the 75 horsepower, Design B, 4-pole enclosed polyphase motor analyzed.

Using tear-down results for CSLs 0 through 3, DOE determined that the manufacturer of these electric motors increased the stack length and other material amounts to increase the electric motor’s efficiency levels from 93.0 percent to 95.8 percent. The torn-down electric motor representing CSL 3 used increased rotor aluminum and stator copper as well as an increased stack length to achieve 95.8 percent efficiency. To develop CSL 4 and 5, DOE used die-cast copper conductors in the rotors and increased the stack lengths for each CSL 4 and 5. The use of die-cast copper rotors and change from machine winding to hand winding labor hours account for the larger-than-typical price increases for CSL 4 and 5 when compared to lower CSLS for the 75 horsepower Design B representative units.

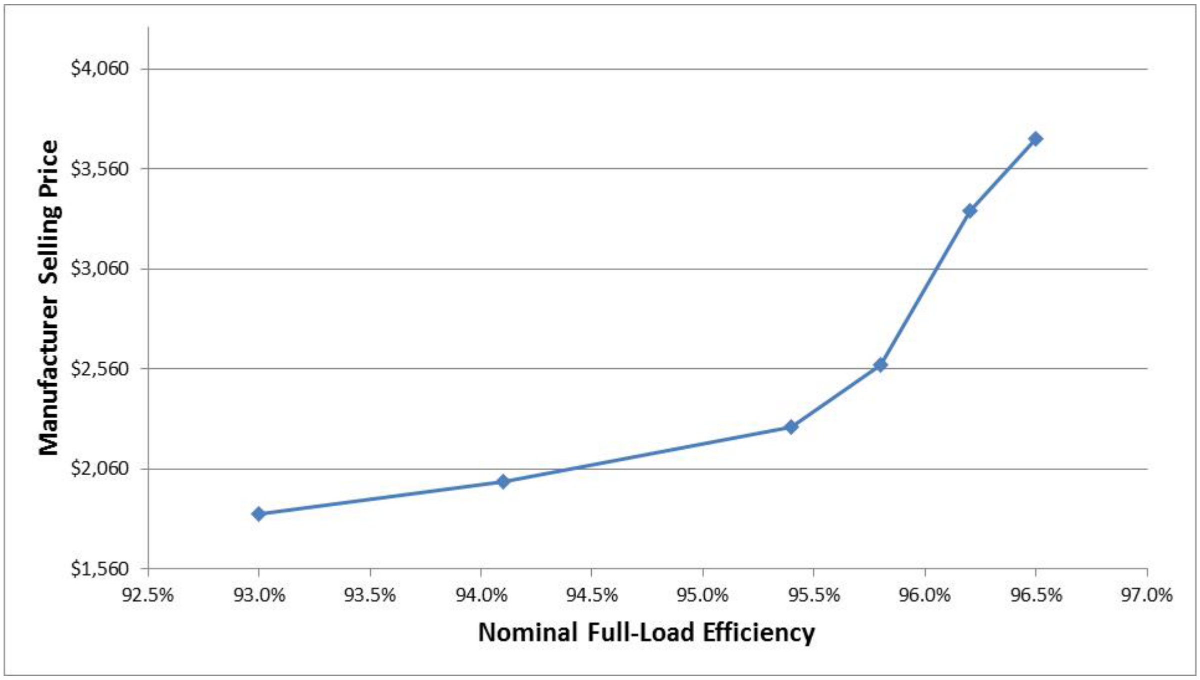

Figure ES.3.3 NEMA Design B, 75 Horsepower, 4-Pole, Enclosed Frame Motor Engineering Analysis Curve

Table ES.3.9 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from CSL 0 to CSL 3, DOE found that the full-load efficiency would increase 2.8 nominal percentage points over the baseline, CSL 0, which represents about a 42 percent reduction in motor losses. The increase in MSP to move from CSL 0 to CSL 3 is about $748 or about a 41 percent increase in MSP over CSL 0. Moving from CSL 3 to CSL 4 provides a 10 percent reduction in motor losses for a MSP increase of $772 or about a 30 percent MSP increase over the CSL 3 electric motor, and to increase the efficiency from CSL 4 to the max-tech efficiency of CSL 5 there is a 10 percent reduction in motor losses for a 11 percent increase in MSP of $359.

Table ES.3.9 Efficiency and Manufacturer Selling Price Data for the NEMA Design B 75 Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	93.0	1,833
1	94.1	1,994
2	95.4	2,270
3	95.8	2,581
4	96.2	3,353
5	96.5	3,712

Table ES.3.10 presents some of the design and performance specifications associated with the six 75-horsepower designs presented in Table ES.3.9.

Table ES.3.10 NEMA Design B 75 Horsepower, 4-Pole, Enclosed Frame Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
Efficiency	**%**	93.0	94.1	95.4	95.8	96.2	96.5
Line Voltage	**V**	460	460	460	460	460	460
Full Load Speed	**RPM**	1,775	1,785	1,781	1,785	1,788	1,789
Full Load Torque	**Nm**	299.8	299.8	302.3	300.8	299.6	299.6
Current	**A**	88	91.8	89.4	88.6	89.8	91.9
Steel	**-**	M56	M47	M47	M47	M36	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Aluminum	Copper	Copper
Approximate Slot Fill	**%**	48.0	44.5	70.0	70.0	85.1	83.4
Stator Wire Gauge	**AWG**	17	12	12	15	14	14
Stator Copper Weight	**lbs**	77.8	71	82	136	127	160
Rotor Conductor Weight	**lbs**	31.0	20.7	27.3	38.5	79	84.3
Stack Length	**In**	8.15	10.23	10.58	11.37	12.00	13.00
Housing Weight	**lbs**	130	79	168	180	190	206

NEMA Design C, 5 Horsepower, 4-Pole, Enclosed Frame Motor

Figure ES.3.3 presents the relationship between the MSP and full-load efficiency for the 5 horsepower, NEMA Design C, 4-pole enclosed polyphase motor analyzed. DOE purchased one NEMA Design C electric motor for a tear-down analysis. The remaining three CSLs were based on software modeled motors. To achieve higher efficiency levels, the software modeling expert used various combinations of higher grade electrical steel, increased slot fill, increased stack length, changed from aluminum to copper die-cast conductors in the rotors. Figure ES.3.4 shows the efficiency versus MSP curve for the 5 horsepower NEMA Design C electric motor CSLs.

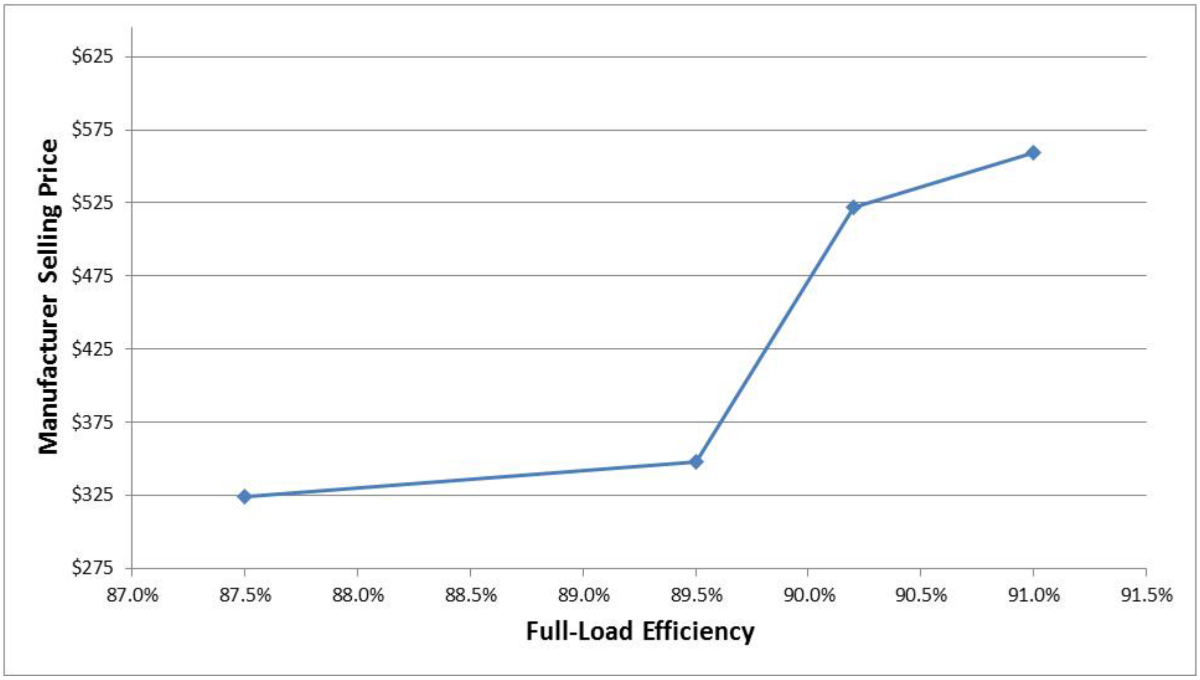

Figure ES.3.4 NEMA Design C, 5 Horsepower, 4-Pole, Enclosed Frame Motor Engineering Analysis Curve

Table ES.3.11 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from CSL 0 to CSL 2, DOE found that the nominal full-load efficiency would increase 2.7 percentage points over the baseline CSL 0 which represents a 24 percent reduction in motor losses. The increase in MSP to move from CSL 0 to CSL 2 is $198, or about a 61 percent increase in MSP over CSL 0. To increase from CSL 2 to CSL 3 would result in a 10 percent reduction in motor losses and a 7 percent increase in MSP.

Table ES.3.11 Efficiency and Manufacturer Selling Price Data for the NEMA Design C 5 Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	87.5	324
1	89.5	348
2	90.2	522
3	91.0	559

Table ES.3.12 presents some of the design and performance specifications associated with the four Design C 5 horsepower motors presented in Table ES.3.11.

Table ES.3.12 NEMA Design C 5 Horsepower, 4-Pole, Enclosed Frame Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3
Efficiency	**%**	87.5	89.5	90.2	91.0
Line Voltage	**V**	460	460	460	460
Full Load Speed	**RPM**	1,750	1,762	1,767	1,776
Full Load Torque	**lb-ft**	15	14.9	14.9	14.8
Current	**A**	7.1	8.4	7.1	6.5
Steel	**-**	M47	M36	M36	M36
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	67.9	79.9	83.9	82.9
Stator Wire Gauge	**AWG**	18	18	18	18
Stator Copper Weight	**lbs**	10	9.9	15	12.8
Rotor Conductor Weight	**lbs**	2.2	2.0	2.4	7.8
Stack Length	**in**	4.75	4.25	5.32	5.32
Frame Weight	**lbs**	12	11	14	14

NEMA Design C, 50 Horsepower, 4-Pole, Enclosed Frame Motor

Figure ES.3.5 presents the relationship between the MSP and full-load efficiency for the 5 horsepower, NEMA Design C, 4-pole enclosed polyphase motor analyzed. DOE purchased only one NEMA Design C electric motor for tear-down analysis. The remaining three CSLs were based on software modeled motors. To achieve higher efficiency levels, the software modeling expert used various combinations of higher grade electrical steel, increased slot fill, increased stack length, and copper rotors. Figure ES.3.5 shows the efficiency versus MSP curve for the 50 horsepower NEMA Design C electric motor CSLs.

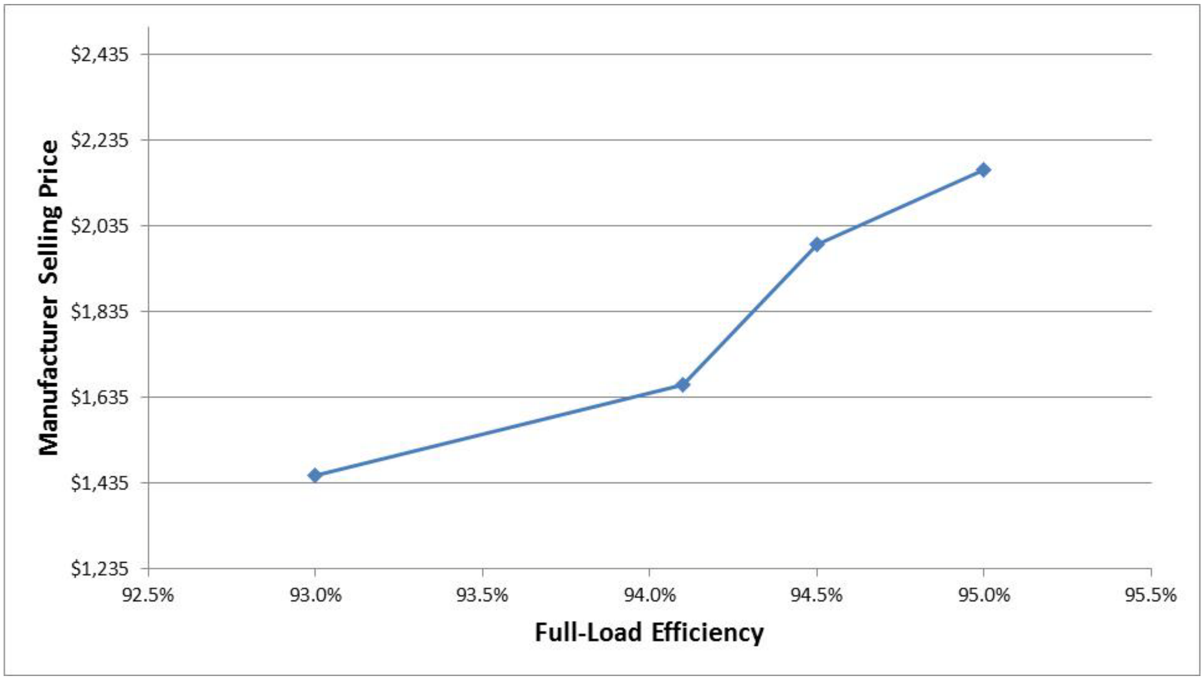

Figure ES.3.5 NEMA Design C, 50 Horsepower, 4-Pole, Enclosed Frame Motor Engineering Analysis Curve

Table ES.3.13 presents the same engineering analysis results in a tabular form, including the nominal full-load efficiency values and the MSPs. Moving from CSL 0 to CSL 2, DOE found that the nominal full-load efficiency would increase 1.5 nominal percentage points over the baseline, CSL 0, which represents about a 23 percent reduction in motor losses. The increase in MSP to move from CSL 0 to CSL 2 is $540, or about a 37 percent increase in MSP over CSL 0. To increase from CSL 2 to CSL 3, a 10 percent reduction in motor losses, results in an 8.8 percent increase in MSP.

Table ES.3.13 Efficiency and Manufacturer Selling Price Data for the NEMA Design C 50 Horsepower Motor

CSL	Nominal Full-Load Efficiency (%)	MSP ($)
0	93.0	1,452
1	94.1	1,664
2	94.5	1,992
3	95.0	2,168

Table ES.3.14 presents some of the design and performance specifications associated with the four 50 horsepower electric motor designs presented in Table ES.3.13.

Table ES.3.14 NEMA Design C 50 Horsepower, 4-Pole, Enclosed Frame Motor Characteristics

Parameter	Units	CSL 0	CSL 1	CSL 2	CSL 3
Efficiency	**%**	93.0	94.1	94.5	95.0
Line Voltage	**V**	460	460	460	460
Full Load Speed	**RPM**	1,770	1,775	1,775	1,782
Full Load Torque	**lb-ft**	148	148	148	147.3
Current	**A**	59.4	63.9	63.7	61.3
Steel	**-**	M47	M36	M36	M19
Rotor Conductor Material	**-**	Aluminum	Aluminum	Aluminum	Copper
Approximate Slot Fill	**%**	79.6	74.8	85.3	81.3
Stator Wire Gauge	**AWG**	17	17	17	17
Stator Copper Weight	**lbs**	66	78	90	85
Rotor Conductor Weight	**lbs**	16.5	11	11	36.6
Stack Length	**In**	8.67	9.55	9.55	9.55
Frame Weight	**lbs**	125	138	138	138

ES.3.4 Markups Analysis

The markups analysis (chapter 6 of the preliminary TSD) develops appropriate markups in the distribution chain to convert the estimates of manufacturer cost derived in the engineering analysis to installed prices for medium electric motors. The engineering analysis (chapter 5 of the preliminary TSD) identifies eight representative units and develops the MSP for each. The eight representative units are evaluated in the LCC analysis (chapter 8 of the preliminary TSD). DOE derived a set of prices for each representative unit by applying markups to the MSP. Those markups represent all the costs associated with bringing a manufactured motor into service as an installed piece of electrical equipment at a customer's site.

For medium electric motors (those built in a three-digit frame number series), DOE defined six distribution channels and estimated their respective shares of shipments. The six channels are:

(1) from manufacturers to original equipment manufacturers (OEMs) and then to end-users (50 percent of shipments);
(2) from manufacturers to distributors and then to end-users (24 percent of shipments);
(3) from manufacturers to distributors to OEMs and then to end-users (23 percent of shipments);
(4) from manufacturers to end-users through contractors (less than 1 percent of shipments);
(5) from manufacturers to distributors to contractors and then to end-users (less than 1 percent of shipments); and
(6) directly to end-users (less than 2 percent of shipments).

Table ES.3.15 summarizes the markups at each stage in the distribution channel and the overall baseline and incremental markups, as well as sales taxes, for each of the primary channels (see items 1 through 3 above).

Table ES.3.15 Summary of Markups for the Three Primary Distribution Channels for Medium Electric Motors

Markup	OEM to End-User (50%)		Distributor to End-User (24%)		Distributor to OEM to End-User (23 %)	
	Baseline	**Incremental**	**Baseline**	**Incremental**	**Baseline**	**Incremental**
Distributor	-	-	1.35	1.20	1.35	1.20
OEM	1.44	1.39	-	-	1.44	1.39
Contractor/Installer	-	-	-	-	-	-
Sales Tax	1.0712	1.0712	1.0712	1.0712	1.0712	1.0712
Overall	1.54	1.49	1.45	1.29	2.08	1.79

Weighting the markups in all six channels by each channel's share of shipments yields an average overall baseline markup of 1.63 and an overall incremental markup of 1.50. DOE used those markups for each equipment class. Applying the markups, DOE generated end-user motor prices for each efficiency level it considered, assuming that each level represents a new minimum efficiency standard.

ES.3.5 Energy Use Characterization

The energy use characterization (chapter 7 of the preliminary TSD) produces energy use estimates for electric motors. Those estimates enable DOE to evaluate the energy savings from the operation of electric motors at the efficiency levels associated with amended efficiency standards. The energy use characterization provides the basis for developing the energy savings used in the LCC and subsequent analyses.

The energy use by electric motors equals the end-use load plus any energy losses associated with motor operation. Energy use is derived from three components: useful mechanical shaft power, motor losses, and reactive power.[b] Motor losses consist of I^2R (resistance heat) losses, core losses, stray-load losses, and friction and windage losses. For a motor having a given nominal efficiency, the annual energy consumption depends on the motor's annual operating hours and loading, which are determined by the motor's sector (industry, agriculture, and commercial) and application (compressor, fans, pumps, material handling and processing, fire pumps, and others).

DOE developed estimates of motor losses and reactive power at full load and part-load for various nominal efficiency levels based on estimates of the specific motor designs that it

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[b] In an alternating current power system, the reactive power is the root mean square (RMS) voltage multiplied by the RMS current, multiplied by the sine of the phase difference between the voltage and the current. Reactive power occurs when the inductance or capacitance of the load shifts the phase of the voltage relative to the phase of the current. Although reactive power does not itself consume energy, it can increase losses and costs for the electricity distribution system. Motors tend to create reactive power because the windings in the motor coils have high inductance.

developed in the engineering analysis. DOE then characterized the energy use of motors within horsepower ranges according to the end-use sector and application. Motor distribution across sectors varied depending on a motor's horsepower range. Motor distribution across applications varied depending on the motor's horsepower range and equipment class group.

Table ES.3.16 shows the results of the energy use analysis for the eight representative units at each considered energy efficiency level. Results are given for baseline units (CSL 0) and the additional candidate standard levels (CSLs) being considered. Chapter 7 provides greater detail regarding the methods, data, and assumptions used for the energy use analysis.

Table ES.3.16 Average Annual Energy Consumption by Efficiency Level for Representative Units

Representative Unit	Description	*kilowatt-hours per year*					
		CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5
1	Design B, T-frame, 5 hp, 4 poles, enclosed	10,448	9,869	9,691	9,616	9,567	9,487
2	Design B, T-frame, 30 hp, 4 poles, enclosed	57,642	55,912	55,021	54,492	54,326	-
3	Design B, T-frame, 75 hp, 4 poles, enclosed	204,834	202,540	198,496	197,697	197,194	196,604
4	Design C, T-frame, 5 hp, 4 poles, enclosed	9,987	9,808	9,738	9,630	-	-
5	Design C, T-frame, 50 hp, 4 poles, enclosed	89,523	88,507	88,119	87,444	-	-
6	Fire pump, 5 hp, 4 poles, enclosed	19.6	19.2	19.1	19.0	18.8	-
7	Fire pump, 30 hp, 4 poles, enclosed	1,601	1,577	1,562	1,558	-	-
8	Fire pump, 75 hp, 4 poles, enclosed	97,791	95,934	95,554	95,313	95,033	-

ES.3.6 Life-Cycle Cost and Payback Period Analysis

New and amended equipment standards result in changes in customer operating expenses (usually a decrease) and changes in initial customer price (usually an increase). DOE performed the LCC analysis to evaluate the net effect of new and amended standards on customers based on the cost-efficiency relationship derived from the engineering analysis, as well as the energy costs derived from the energy use characterization. Inputs to the LCC calculation include the installed cost to the customer (purchase price plus installation cost), operating costs (primarily energy expenses), expected lifetime of the equipment, and discount rate.

Because the installed cost of equipment typically increases while operating costs typically decrease in response to new or amended standards, there is a period when the net operating-cost benefit (in dollars) since the time of purchase of the more efficient equipment equals the incremental first cost of purchasing the higher efficiency unit. The length of time required for equipment to reach this cost-equivalence point is known as the PBP.

DOE conducted the LCC and PBP analysis using Monte Carlo simulation methods and probability distributions to model both the uncertainty and variability in the inputs. Inputs to the LCC and PBP analysis are:

- motor application and sector
- annual energy use,
- electricity prices and price trends,
- operating hours,
- motor lifetime,
- motor efficiency, and
- a discount rate.

These variables, and the interactions among them, are discussed in the following paragraphs.

DOE characterized a set of end-use applications for electric motors that determine motor use profiles. In each Monte Carlo simulation, one application is identified by sampling a distribution of applications for each equipment class. The selected application determines the number of operating hours per year as well as the motor loading (i.e. output power as a percentage of rated power). DOE used the operating hours and the motor loading for each application to estimate motor energy use.

For electricity prices, DOE derived sector-specific average electricity prices for four census regions (Northeast, Midwest, South, and West) using data from the Energy Information Administration (EIA Form 861). For each sector, DOE assigned electricity prices using a Monte Carlo approach that incorporated weightings based on the estimated number of motors in each region. The regional quantities were derived based on indicators specific to each sector (e.g., for industry, the value of shipments by census region from the Manufacturing Energy Consumption Survey). To estimate future trends in energy prices, DOE used projections from the EIA's *Annual Energy Outlook 2011* (*AEO 2011*).

Because of the wide range of applications and motor use characteristics considered in the LCC and PBP analysis, the range of annual energy use is quite broad. Although the annual energy use and/or energy pricing are generally known for a given application, the variability across all applications contributes to the range of LCCs and PBPs calculated for any particular CSL. There is also an energy use and/or energy pricing distribution between the sectors (industry, agriculture, and commercial) associated with each application. The sector to which an application belongs determines the energy price and discount rate DOE used in each simulation performed for calculating the LCC.

DOE estimated the mechanical lifetime of motors in hours (i.e., the total number of hours a motor operates throughout its lifetime, including repairs) depending on its horsepower (hp) size. DOE then developed Weibull distributions of mechanical lifetimes. (Weibull distributions are statistical models used to predict the likelihood of failure over time.) The lifetime in years for a sampled motor was calculated by dividing the sampled mechanical lifetime by the sampled annual operating hours of the motor. This model produces a negative correlation between annual hours of operation and motor lifetime: motors operated many hours per year are likely to be retired sooner than motors that are used for only a few hundred hours per year. DOE considered that motors of less than 75 hp are most likely to be embedded in another piece of equipment (i.e., an application). For such applications DOE developed Weibull distributions of application lifetimes expressed in years, then compared the sampled mechanical lifetime (in years) with the sampled application lifetime. DOE assumed that the motor would be retired at the younger of the two ages.

DOE made several assumptions regarding motor repair based on stakeholder inputs and on information found in the literature. First, DOE assumed that NEMA Design A, B and C medium electric motors are repaired on average after 32,000 hours of operation[c],and that repair costs vary depending on motor size, configuration, and efficiency. Second, DOE assumed that one-third of repairs are performed competently and according to recommended practice as defined by the Electrical Apparatus Service Association[d] and therefore do not adversely affect the efficiency of the motor (i.e., there is no degradation of efficiency after repair). Third, DOE assumed that the remaining two-thirds of repairs are not performed in a similar manner and result in a slight decrease in efficiency. Finally, DOE assumed the efficiency drops by 1 percent in the case of motors of less than 40 hp, and by 0.5 percent in the case of larger motors.

For each representative unit, DOE developed a projection of base case (no amended standards) efficiency distribution in 2015. DOE based the projection on the percentage of models at different levels using recent manufacturer catalogs. Applying the base case distribution of equipment efficiencies for each representative unit, DOE randomly assigned an equipment efficiency to each unit based on the market share. If a motor was assigned an equipment efficiency greater than or equal to the efficiency of the CSL under consideration, the LCC calculation would show that the motor unit would not be affected by that standard level.

ES.3.6.1 Results of Life-Cycle Cost and Payback Period Analysis

Table ES.3.17 describes the eight representative units that DOE analyzed. The engineering analysis examined units 1 through 5, but did not directly analyze fire pump electric motors. Instead, the engineering outputs for representative units 1, 2, and 3 were assumed to also be valid to characterize representative units 6, 7, and 8.

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[c] Based on the annual operating hours by sector and application, this corresponds, on average, to a repair frequency of 5, 16, and 15 years in the industrial, commercial and agricultural sectors, respectively.

[d] Good practice in motor repair is defined in the joint EASA AEMT study at http://www.easa.com/sites/default/files/rwstdy1203.pdf

Table ES.3.17 Representative Units for Preliminary Analysis

Representative Unit	Equipment Class Group	Specifications	Horsepower
1	NEMA Designs A & B	Design B, T-frame, enclosed, 4-pole	5
2			30
3			75
4	NEMA Design C	Design C, T-frame, enclosed, 4-pole	5
5			50
6	Fire Pump	Uses same engineering outputs as units 1, 2, and 3	5
7			30
8			75

Table ES.3.18 through Table ES.3.25 present key findings from the LCC and PBP analysis performed for this preliminary TSD. Most of the values in the tables are average or median values, although the tables also show the percentage of end-users expected to experience a net cost (negative LCC savings) or net benefit (positive LCC savings) at each CSL. The average LCC savings are calculated relative to a base case efficiency distribution. Chapter 8 of the preliminary TSD presents distributions of LCC and PBP results for each representative unit analyzed.

For representative unit 1 (Table ES.3.18), the highest CSL that provides positive average LCC savings is CSL 3. DOE estimates that 67.8 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL and that the increase in average total installed cost (relative to the base case) would be $81, or a 13.9 percent increase, while operating costs decrease by $46, or a 4.6 percent decrease.

Table ES.3.18 Life-Cycle Cost and Payback Period Results for Representative Unit 1: NEMA Design B, T-Frame, 5 Horsepower, 4-Pole, Enclosed Motor

Candidate Standard Level	Efficiency *%*	Life-Cycle Cost			Life-Cycle Cost Savings			Payback Period *years*
		Average Installed Price *$*	Average Annual Operating Cost *$*	Average LCC *$*	Average Savings *$*	Customers with		Median
						Net Cost *%*	Net Benefit *%*	
0	82.5	584	1,006	5,926				
1	87.5	588	969	5,649	16	0.1	5.8	0.1
2	89.5	651	963	5,631	25	18.9	26.4	5.1
3	90.2	665	960	5,608	45	20.5	67.8	4.7
4	91.0	909	960	5,831	-169	89.3	6.5	28.2
5	91.7	998	958	5,883	-220	93.3	5.4	26.9

For representative unit 2 (Table ES.3.19), the highest CSL that provides positive average LCC savings is CSL 3. DOE estimates that 86.6 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL and that the increase in average total installed cost (relative to the base case) is $718, or a 45.7 percent increase, while operating costs decrease by $234, or a 4.3 percent decrease.

Table ES.3.19 Life-Cycle Cost and Payback Period Results for Representative Unit 2: NEMA Design B, T-Frame, 30 Horsepower, 4-Pole, Enclosed Motor

		Life-Cycle Cost			**Life-Cycle Cost Savings**			**Payback Period** *years*
						Customers with		
Candidate Standard Level	**Efficiency** *%*	**Average Installed Price** *$*	**Average Annual Operating Cost** *$*	**Average LCC** *$*	**Average Savings** *$*	**Net Cost** *%*	**Net Benefit** *%*	**Median**
0	89.5	1,570	5,489	44,182				
1	92.4	1,986	5,358	43,376	45	0.6	4.9	3.5
2	93.6	2,277	5,295	43,035	177	5.7	32.9	5.3
3	94.1	2,288	5,255	42,666	511	4.0	86.6	0.7
4	94.5	3,468	5,249	43,735	-558	87.1	12.9	23.8

For representative unit 3 (Table ES.3.20), the highest CSL that provides positive average LCC savings is CSL 3. DOE estimates that 47.5 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL and that the increase in average total installed cost (relative to the base case) is $1,313, or a 37.9 percent increase, while operating costs decrease by $481, or a 2.8 percent decrease.

Table ES.3.20 Life-Cycle Cost and Payback Period Results for Representative Unit 3: NEMA Design B, T-Frame, 75 Horsepower, 4-Pole, Enclosed Motor

		Life-Cycle Cost			**Life-Cycle Cost Savings**			**Payback Period** *years*
						Customers with		
Candidate Standard Level	**Efficiency** *%*	**Average Installed Price** *$*	**Average Annual Operating Cost** *$*	**Average LCC** *$*	**Average Savings** *$*	**Net Cost** *%*	**Net Benefit** *%*	**Median**
0	93.0	3,463	17,168	124,170				
1	94.1	3,831	17,033	123,348	40	0.8	4.5	2.9
2	95.4	4,296	16,733	121,510	663	1.4	32.9	1.5
3	95.8	4,776	16,687	121,590	597	35.1	47.5	6.5
4	96.2	6,044	16,661	122,598	-340	66.9	25.9	15.5
5	96.5	6,640	16,631	122,905	-639	73.6	23.7	16.0

For representative unit 4 (Table ES.3.21), the highest CSL that provides positive average LCC savings is CSL 1. DOE estimates that 59.9 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL and that the increase in average total installed cost (relative to the base case) is $44, or a 7.5 percent increase, while operating costs decrease by $10, or a 1.0 percent decrease.

Table ES.3.21 Life-Cycle Cost and Payback Period Results for Representative Unit 4: NEMA Design C, T-Frame, 5 Horsepower, 4-Pole, Enclosed Motor

		Life-Cycle Cost			**Life-Cycle Cost Savings**			**Payback Period** *years*
						Customers with		
Candidate Standard Level	**Efficiency** *%*	**Average Installed Price** *$*	**Average Annual Operating Cost** *$*	**Average LCC** *$*	**Average Savings** *$*	**Net Cost** *%*	**Net Benefit** *%*	**Median**
0	87.5	583	984	5,807				
1	89.5	627	974	5,771	34	32.3	59.9	4.6
2	90.2	903	971	6,007	-203	97.8	2.2	25.0
3	91.0	961	966	6,011	-207	95.6	4.4	20.2

For representative unit 5 (Table ES.3.22), the highest CSL that provides positive average LCC savings is CSL 3. DOE estimates that 57.8 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL and that the increase in average total installed cost (relative to the base case) is $1164, or a 41.8 percent increase, while operating costs decrease by $150, or a 1.8 percent decrease.

Table ES.3.22 Life-Cycle Cost and Payback Period Results for Representative Unit 5: NEMA Design C, T-Frame, 50 Horsepower, 4-Pole, Enclosed Motor

		Life-Cycle Cost			**Life-Cycle Cost Savings**			**Payback Period** *years*
						Customers with		
Candidate Standard Level	**Efficiency** *%*	**Average Installed Price** *$*	**Average Annual Operating Cost** *$*	**Average LCC** *$*	**Average Savings** *$*	**Net Cost** *%*	**Net Benefit** *%*	**Median**
0	93.0	2,786	8,459	69,419				
1	94.1	3,173	8,383	69,098	236	18.3	55.6	5.9
2	94.5	3,673	8,360	69,329	5	59.6	40.4	12.7
3	95.0	3,950	8,309	69,104	229	42.3	57.8	9.8

For representative unit 6 (Table ES.3.23), all CSLs other than the baseline result in negative average LCC savings.

Table ES.3.23 Life-Cycle Cost and Payback Period Results for Representative Unit 6: Fire Pump, NEMA Design B, T-Frame, 5 Horsepower, 4-Pole, Enclosed Motor

Candidate Standard Level	Efficiency *%*	Life-Cycle Cost			Life-Cycle Cost Savings			Payback Period *years*
		Average Installed Price *$*	Average Annual Operating Cost *$*	Average LCC *$*	Average Savings *$*	Customers with		
						Net Cost *%*	Net Benefit *%*	Median
0	87.5	588	106	632				
1	89.5	651	115	697	-62	95.1	0.0	NA
2	90.2	665	119	706	-70	99.9	0.1	NA
3	91.0	909	124	949	-314	100.0	0.0	NA
4	91.7	998	128	1,038	-403	100.0	0.0	NA

For representative unit 7 (Table ES.3.24), all CSLs other than the baseline result in negative average LCC savings.

Table ES.3.24 Life-Cycle Cost and Payback Period Results for Representative Unit 7: Fire Pump, NEMA Design B, T-Frame, 30 Horsepower, 4-Pole, Enclosed Motor

Candidate Standard Level	Efficiency *%*	Life-Cycle Cost			Life-Cycle Cost Savings			Payback Period *years*
		Average Installed Price *$*	Average Annual Operating Cost *$*	Average LCC *$*	Average Savings *$*	Customers with		
						Net Cost *%*	Net Benefit *%*	Median
0	92.4	1,986	347	3,869				
1	93.6	2,277	363	4,131	-213	78.8	2.5	104.9
2	94.1	2,288	371	4,124	-207	78.7	8.1	79.2
3	94.5	3,468	380	5,295	-1,378	100.0	0.0	433.6

For representative unit 8 (Table ES.3.25), the highest CSL that provides positive average LCC savings is CSL 3. DOE estimates that 27.0 percent of end-users would experience a net benefit (i.e., LCC decrease) at this CSL and that the increase in average total installed cost (relative to the base case) is 2,213, or a 57.8 percent increase, while operating costs decrease by $126, or a 1.6 percent decrease.

Table ES.3.25 Life-Cycle Cost and Payback Period Results for Representative Unit 8: Fire Pump, NEMA Design B, T-Frame, 75 Horsepower, 4-Pole, Enclosed Motor

Candidate Standard Level	Efficiency %	Life-Cycle Cost			Life-Cycle Cost Savings			Payback Period *years*
		Average Installed Price *$*	Average Annual Operating Cost *$*	Average LCC *$*	Average Savings *$*	Customers with Net Cost *%*	Customers with Net Benefit *%*	Median
0	94.1	3,831	8,050	110,032				
1	95.4	4,296	7,937	108,445	1,274	55.4	25.3	1.1
2	95.8	4,776	7,927	108,544	1,193	56.7	26.0	1.9
3	96.2	6,044	7,924	109,522	215	73.0	27.0	4.5
4	96.5	6,640	7,920	109,826	-89	72.0	28.0	5.3

Chapter 8 of the preliminary TSD provides more details on the methods, data, and assumptions used for the LCC and PBP analyses

ES.3.7 Shipments Analysis

An important component of any estimate of future impacts from energy efficiency standards is equipment shipments (chapter 9). DOE uses projections of shipments for the base case and each potential standards case as inputs to the calculation of national energy savings (NES).

DOE used motor shipment data from multiple sources[e] to develop a set of shipment projections for all motors by horsepower covered by the rulemaking. The shipments represent the sum of U.S. production and imports minus exports and include motors imported as part of larger equipment. DOE then used estimates of market distributions to redistribute the shipments across pole configurations and enclosures to provide shipment values for each electric motor equipment class and sector.

DOE's shipments projection assumes that motor sales are driven by machinery production growth for equipment including motors. DOE assumed that growth rates for motor shipments correlate to growth rates in fixed investment in equipment and structures[f] including motors, as provided by the U.S. Bureau of Economic Analysis's (BEA)[g]. This correlation was developed based on historical data on growth rates for motor shipments and fixed investment

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[e] DOE based its shipments estimates on the following sources of data: market research report (IMS Research (February 2012), The World Market for Low Voltage Motors, 2012 Edition, Austin), stakeholder inputs, and responses to the Request for Information (RFI) published in the Federal Register (76 FR 17577 (March 30, 2011)).

[f] Heating, ventilation, and air conditioning (HVAC) equipment which incorporates motors is typically included in "structures" and not in equipment.

[g] Bureau of Economic Analysis (March 01, 2012), Private *Fixed Investment in Equipment and Software and structure by Type*. http://www.bea.gov/iTable/iTable.cfm?ReqID=12&step=1

data. Additional data on “real gross domestic product” (GDP) from *AEO2011* for 2011–2035 was used to project fixed investments in the selected equipment and structures.

Table ES.3.26 presents DOE’s estimate of projected shipments of electric motors following an AEO reference growth case. Additional detail on the shipments analysis, as well as alternate AEO growth cases can be found in chapter 9 of the preliminary TSD.

Table ES.3.26 Annual and Cumulative Shipments Projection for Electric Motors (AEO reference case)

Equipment Class Group	**Annual Shipments *thousands***				
	2015	**2025**	**2035**	**2044**	**Cumulative 2015–2044**
Designs A & B	5,072	7,254	9,958	13,005	256,846
Design C	10	15	20	26	515
Fire Pump	6	9	12	16	309
Total*	5,089	7,278	9,990	13,047	257,671

*Total may not precisely match the sum of all numbers in the column due to rounding.

Chapter 9 of the preliminary TSD provides more details on the methods, data, and assumptions used for the shipments analysis.

ES.3.8 National Impact Analysis

The national impact analysis (NIA) quantifies the following national impacts from CSLs: (1) NES, (2) monetary value of the energy savings attributable to new or amended standards, (3) increased total installed costs of the considered equipment due to new or amended standards, and (4) NPV of energy savings (difference between value of energy savings and increased total installed costs). DOE prepared a spreadsheet model to project energy savings and national customer economic costs and savings resulting from potential new standards.

The cumulative NES and NPV are calculated by equipment class. Results are calculated by sector for each equipment class. These results are then aggregated across sectors using weighted averages. DOE used weighted average operating hours and loading data across motor applications in each sector, and assigned a range in lifetime data by horsepower based on usage data from the energy use characterization (chapter 7).

For each equipment class that was not directly analyzed in the engineering analysis and the LCC, DOE specified CSLs using scaled, full-load, nominal efficiency data from the engineering analysis. Adjustment factors were derived from the engineering analysis to estimate part-load nominal efficiencies. Further, relationships were developed to estimate MSP data for all equipment classes. The relationships were derived from analyzing how listed prices in six manufacturers and distributors catalogs vary depending on horsepower, poles, and enclosures at a given efficiency level. A similar method, based on advertised weights in catalog listings, was used to estimate weights for all equipment classes as a necessary input to shipping costs.

ES.3.8.1 Analysis of National Energy Savings

DOE calculated cumulative NES for motors shipped in the analysis period, 2015-2044 as the difference between the cumulative national energy consumption in the base case (without new or amended energy conservation standards) and under each CSL. In the base case, DOE estimated a distribution of equipment efficiencies for each equipment class and assumed this distribution remained constant throughout the analysis period. In the standards case, DOE used a roll-up scenario to determine the distribution of equipment efficiencies at each CSL.

DOE estimated cumulative energy consumption and savings based on site energy, and then converted those values to primary (source) energy using factors that account for losses in transmission, distribution, and generation of electricity.

DOE estimated energy consumption and savings based on site energy and converted the site energy values to primary (source) energy using factors that account for losses in transmission and distribution and in electricity generation. These site-to-source factors are derived from the National Energy Modeling System (NEMS). DOE also estimated full-fuel-cycle (FFC) energy savings for each CSL. The full-fuel-cycle measure includes the energy consumed in extracting, processing, and transporting primary fuels.

Table ES.3.27 summarizes results of the NES for each of the three equipment class groups by horsepower range. NES results are given in quadrillion British thermal units (quads).

Table ES.3.27 Summary of Cumulative National Energy Savings in Quads (2015-2044)

Motor Size *hp*	All	1-5	6-20	21-50	51-100	101-200	201-500
Designs A & B							
CSL 1	0.972	0.270	0.284	0.161	0.108	0.078	0.071
CSL 2	4.414	0.954	1.211	0.668	0.527	0.410	0.644
CSL 3	7.527	1.509	1.980	1.179	0.937	0.831	1.090
CSL 4	10.836	2.123	2.855	1.704	1.378	1.265	1.511
CSL 5	13.005	2.701	3.201	1.704	1.789	1.680	1.929
Design C							
CSL 1	0.012	0.003	0.004	0.002	0.001	0.001	-
CSL 2	0.018	0.004	0.006	0.003	0.002	0.002	-
CSL 3	0.024	0.006	0.008	0.004	0.003	0.003	-
Fire Pumps							
CSL 1	0.003	0.000	0.000	0.000	0.001	0.001	0.001
CSL 2	0.005	0.000	0.000	0.000	0.002	0.001	0.001
CSL 3	0.006	0.000	0.000	0.000	0.002	0.002	0.002
CSL 4	0.008	0.000	0.000	0.000	0.003	0.002	0.002

ES.3.8.2 Analysis of Consumer Net Present Value

DOE calculated net monetary savings each year as the difference between total savings in operating costs and increases in total equipment costs in the base case and each CSL. DOE calculated savings over the life of the equipment purchased during the analysis period. The NPV is the difference between the present value of operating cost savings and the present value of increased total installed costs. DOE used discount rates of 7 percent and 3 percent to discount future costs and savings to the present.

Table ES.3.28 summarizes NPV results for each of the three equipment class groups by horsepower range.

Table ES.3.28 Net Present Value of Customer Impacts (billion 2011$)

	Discount Rate %	**All *hp***	**1-5 *hp***	**6-21 *hp***	**21-50 *hp***	**51-100 *hp***	**101-200 *hp***	**201-500 *hp***
Designs A & B								
CSL 1	3	5.53	1.67	1.78	0.94	0.54	0.35	0.25
	7	2.32	0.73	0.76	0.38	0.22	0.13	0.09
CSL 2	3	18.42	3.57	5.52	2.98	2.27	1.68	2.41
	7	7.07	1.39	2.15	1.13	0.90	0.63	0.87
CSL 3	3	30.19	5.65	8.50	4.91	3.71	3.25	4.16
	7	11.42	2.24	3.25	1.80	1.43	1.20	1.50
CSL 4	3	-6.63	-6.29	-4.67	-1.32	0.57	1.73	3.34
	7	-10.37	-4.47	-4.37	-1.90	-0.50	0.10	0.77
CSL 5	3	-8.63	-8.81	-5.92	-1.32	0.64	2.38	4.40
	7	-12.71	-6.09	-5.26	-1.90	-0.70	0.19	1.05
Design C								
CSL 1	3	0.05	0.01	0.02	0.01	0.00	0.00	-
	7	0.02	0.01	0.01	0.00	0.00	0.00	-
CSL 2	3	0.01	-0.01	0.00	0.01	0.01	0.01	-
	7	-0.01	-0.01	0.00	0.00	0.00	0.00	-
CSL 3	3	0.02	-0.01	0.00	0.01	0.01	0.01	-
	7	-0.01	-0.01	0.00	0.00	0.00	0.00	-
Fire Pumps								
CSL 1	3	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00
	7	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
CSL 2	3	-0.03	-0.02	-0.01	-0.01	0.00	0.00	0.00
	7	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00
CSL 3	3	-0.10	-0.04	-0.04	-0.02	0.00	0.00	0.00
	7	-0.05	-0.02	-0.02	-0.01	0.00	0.00	0.00
CSL 4	3	-0.11	-0.05	-0.05	-0.02	0.00	0.00	0.00
	7	-0.06	-0.02	-0.02	-0.01	0.00	0.00	0.00

Table ES.3.29 summarizes both NES and NPV results for each of the three equipment class groups.

Table ES.3.29 Cumulative National Energy Savings and Net Present Value Results

Equipment Group and Analysis	Discount Rate %	Candidate Standard Level				
		1	2	3	4	5
Designs A & B						
Cumulative Source Savings 2015–2044 *quads*		0.97	4.41	7.53	10.84	13.00
Net Present Value *billion 2011$*	3	5.53	18.42	30.19	-6.63	-8.63
	7	2.32	7.07	11.42	-10.37	-12.71
Design C						
Cumulative Source Savings 2015–2044 *quads*		0.01	0.02	0.02	-	-
Net Present Value *billion 2011$*	3	0.05	0.01	0.02	-	-
	7	0.02	-0.01	-0.01	-	-
Fire Pumps						
Cumulative Source Savings 2015–2044 *quads*		0.00	0.00	0.01	0.01	-
Net Present Value *billion 2011$*	3	-0.02	-0.03	-0.10	-0.11	-
	7	-0.01	-0.01	-0.05	-0.06	-

Chapter 10 of the preliminary TSD provides more details on the methods, data, and assumptions used for the NIA analyses.

ES.3.9 Preliminary Manufacturer Impact Analysis

The preliminary MIA focuses on manufacturers of electric motors. Potential impacts include financial effects, both quantitative and qualitative, that might result from new energy conservation standards and consequently lead to changes in the manufacturing practices for electric motors. DOE identified these potential impacts through interviews with manufacturers and interested parties, as well as through the gathering of publicly available data on products, methods, and practices used in the electric motors industry.

Next, DOE determined how energy efficiency improvements affect cost, production, and various other manufacturing metrics.

Finally, DOE interviewed manufacturers for feedback. DOE developed a questionnaire and distributed it for use during the interviews. Highlights of the questionnaire and topics of focus include production and product mix, compliance costs, exports, foreign competition and outsourcing, market shares and industry consolidation, and cumulative burden.

Perhaps the most important aspect of the preliminary MIA is the opportunity to identify key manufacturer issues early in the development of new standards. During the series of preliminary interviews with manufacturers, DOE assessed concerns about the potential impact of a regulatory standard for electric motors. In general, manufacturers identified three major issues of concern: (1) capital expenditure to retool in response to the standards, (2) maintaining product availability and consumer-oriented features, and (3) enforcement of the new standards.

ES.3.10 Other Analyses

The remaining chapters of the preliminary TSD address the analyses to be performed for the notice of proposed rulemaking (NOPR).

- The customer subgroup analysis evaluates the effects of potential new or amended energy conservation standards on various subgroups (chapter 11).
- The employment impact analysis examines the effects of potential new or amended energy conservation standards on national employment (chapter 13).
- The utility impact analysis examines impacts of potential new or amended energy conservation standards on the generation capacity of electric utilities (chapter 14).
- The emissions analysis examines the effects of potential new or amended energy conservation standards on various airborne emissions (chapter 15)
- The monetization of emission reduction benefits examines the monetary value of benefits resulting from reduced emissions associated with potential new or amended standards (chapter 16).
- The regulatory impact analysis examines the national impacts of nonregulatory alternatives to mandatory energy conservation standards (chapter 17).

ES.4 ISSUES ON WHICH DOE SEEKS PUBLIC COMMENT

DOE is interested in receiving comments on all aspects of the preliminary analyses described in this TSD. DOE especially invites comments or data to improve DOE's analyses, including information that will respond to the following questions and concerns that were raised during DOE's preliminary interviews with manufacturers and in the preparation of this preliminary TSD.

ES.4.1 Scope of Coverage of Electric Motors

DOE invites comments on the scope of motors covered as part of this analysis. Chapter 2 of this TSD presents a list of general purpose motors without energy conservation standards prescribed under EISA 2007 or DOE regulations. These motors generally bear no electromechanical differences from those general purpose motors that are currently regulated. Because of the close similarity between these two sets of motors, DOE tentatively concludes that these currently unregulated motors can achieve the same standards as equipment class group 1 or equipment class group 2 if manufacturers use similar tooling. Refer to chapter 3 of the preliminary TSD for more information on the motors DOE is considering.

ES.4.2 Screening Analysis

DOE invites comments on the two technology options that were screened out of the analysis: plastic bonded iron powder and amorphous core steels for electric motors. Please refer to section 2.4.1 of chapter 2 of the preliminary TSD.

ES.4.3 Engineering Analysis Methodology

DOE invites comments on the methodology followed for the preliminary TSD, namely use of engineering software to design more efficient versions of the five representative units analyzed. DOE is also interested in comments on the estimated manufacturer markups and labor rates that enable the conversion of input costs to selling prices. Please refer to chapter 5 of the preliminary TSD for more detailed information on material prices and markups used.

ES.4.4 Engineering Analysis Results

DOE invites comments on the findings of the engineering analysis. Specifically, DOE requests comment on the derived MSP for its respective motor rating.

ES.4.5 Motor Distribution Across Sectors

DOE seeks comment on any additional sources of data that could be used to establish the distribution of motors across sectors by horsepower range.

ES.4.6 Motor Distribution Across Applications

DOE seeks comment on any additional sources of data that could be used to establish the sector-specific distribution of motors across applications. In its preliminary analysis, DOE assumed that the share of motors in each application is similar across all sectors and equal to the distribution of motors across applications in the industry sector.

ES.4.7 Data on Operating Hours and Loading

DOE seeks comment on any additional sources of field data on operating hours and loading for motors, that could be used to improve field use characterization in the commercial and agricultural sectors.

ES.4.8 Product Price Determination

DOE derived the product prices cited in this TSD by applying markups to the MSP it determined in the engineering analysis. DOE defined six distribution channels and estimated each one’s share of shipments. DOE calculated an average overall baseline markup and an overall incremental markup by weighting the markups in all six channels by each channel’s share of shipments. DOE requests stakeholder input regarding any viable alternative approach or source of information that could be used to develop product prices.

ES.4.9 Repair Costs

DOE welcomes comment on the current method used to determine motor repair costs.

ES.4.10 Frequency of Repair

DOE seeks comment on any additional sources for determining the frequency of motor repair depending on equipment class, sector, and application.

ES.4.11 Maintenance Costs

DOE seeks comment on any additional sources of data on motor maintenance costs. Specifically, DOE invites comment on how amended efficiency requirements may affect maintenance costs.

ES.4.12 Installation Costs

For the engineering analysis performed for the NOPR, DOE will consider technology options that could affect a motor's mechanical configuration. DOE invites comment on how changes in motor mechanical configurations that may accompany more efficient motors may affect installation costs.

ES.4.13 Motor Lifetimes

DOE seeks comment on any additional sources of data on motor lifetime that could be used to validate DOE's estimates of motor mechanical lifetime and its method of estimating lifetimes.

ES.4.14 Product Energy Efficiency in the Base Case

For the LCC analysis, DOE analyzed CSLs relative to a base case. This analysis requires estimating the distribution of product efficiencies in the base case (i.e., what customers would purchase in 2015 in the absence of new standards). For the preliminary TSD, the distribution of product efficiencies that DOE estimated in the base case was based on nominal efficiency data collected from six major manufacturer catalogs. DOE seeks comment on the estimated base case distribution of product efficiencies and on any additional sources of data.

ES.4.15 Efficiency Trends

DOE seeks further comment on its decision to use constant efficiencies for the analysis period. Specifically, DOE would like comments on additional sources of data on trends in efficiency improvement.

ES.4.16 Estimated Shipments

DOE seeks comment on any additional sources of data on motor shipments that could be used to validate its shipments model and estimates.

ES.4.17 Purchase Price Elasticity

If the installed cost of electric motors increases, end-users could decide to repair or rewind motors instead of purchasing new ones, thereby reducing purchases of new motors. DOE, however, has found no data that would enable it to estimate the elasticity of electric motor shipments with respect to changes in purchase price. DOE seeks comment on any sources of data that could be used to quantitatively estimate motor price elasticity. DOE also seeks comments on any additional sources of data on the share of motor shipments which are for new installation, and the share of shipments which are for replacement.

ES.4.18 Scaling Methodology for Manufacturer Selling Price

DOE seeks comment on its scaled values for MSPs. In particular, DOE seeks comments on its methodology for scaling MSP data from the representative equipment classes to the remaining equipment classes.

ES.4.19 Scaling Methodology for Motor Weights

DOE seeks comment on the scaled values for motor weights. In particular, DOE seeks comments on its methodology for scaling weight data from the representative equipment classes to the remaining equipment classes.

ES.4.20 Trial Standard Levels

For the NOPR, DOE will develop trial standard levels (TSLs) based on the CSLs selected for electric motors. DOE is considering developing TSLs by equipment class group (i.e., all equipment classes in the same equipment class group would be at the same CSL level within this TSL). Further, DOE is considering several criteria in developing the TSLs, including, but not limited to, minimum LCC, maximum NPV, and "max tech" efficiency. The TSLs may include combinations of CSLs. From the TSLs it develops, DOE will select one as its proposed standard for each equipment class group in the NOPR. DOE invites comment on the criteria it should use as the basis for selecting TSLs.