DRAFT TECHNICAL REPORT

ENERGY CONSERVATION PROGRAM FOR CONSUMER PRODUCTS:

Battery Chargers and External Power Supplies

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U.S. Department of Energy
Assistant Secretary
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Building Technologies Program
Appliances and Commercial Equipment Standards
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DRAFT TECHNICAL REPORT
FRAMEWORK DOCUMENT

BUILDING TECHNOLOGIES PROGRAM
APPLIANCES AND COMMERCIAL EQUIPMENT STANDARDS

BATTERY CHARGERS AND EXTERNAL POWER SUPPLIES

CHAPTERS

CHAPTER 1. INTRODUCTION

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1.1 Introduction

The U.S. Department of Energy (DOE) Draft Technical Report presents the preliminary findings of DOE's Determination Analysis for Battery Chargers (BCs) and External Power Supplies (EPSs), Docket No. EERE-2006-DET-0136. The purpose of the determination analysis, mandated by the Energy Policy and Conservation Act (EPCA), as amended by the Energy Policy Act of 2005 (EPACT 2005), was to determine whether energy conservation standards should be set for BCs and EPSs. DOE's analysis was interrupted by passage of the Energy Independence and Security Act of 2007 (EISA 2007). This report provides details of the work undertaken for the determination analysis until that point, and includes inputs, methods, and some draft outputs of the analysis.

This report is published in conjunction with the "Energy Conservation Standards Rulemaking Framework Document for Battery Chargers and External Power Supplies," which outlines the analytical process DOE will follow for the BC and EPS standards rulemaking over the next two years as a result of EISA 2007. This rulemaking may result in updated standards for EPSs and new standards for BCs by July 1, 2011. Unlike the framework document, this report presents a retrospective view of work *already completed*, and should not be construed as setting a precedent for future DOE action. Rather, DOE invites stakeholders to review the report and provide comments on all aspects of the draft analysis that are pertinent to the energy conservation standards rulemaking being initiated.

This chapter describes the regulatory and legislative background for the determination analysis, explains the analytic process, and introduces the work described in detail in the body of the report.

1.2 Regulatory and Legislative History

DOE's Appliances and Commercial Equipment Standards Program, within the Office of Energy Efficiency and Renewable Energy's Building Technologies Program, develops and promulgates test procedures and energy conservation standards for consumer appliances and commercial equipment.

Title III of EPCA (42 U.S.C. 6291 *et seq.*) sets forth a variety of provisions designed to improve energy efficiency. Part A of title III (42 U.S.C. 6291–6309) establishes the "Energy Conservation Program for Consumer Products Other Than Automobiles." On August 8, 2005, the Energy Policy Act of 2005 (Pub. L. 109-58; EPACT 2005) amended sections 321 and 325 of EPCA, inserting definitions for BCs and EPSs and directing the Secretary of Energy to (1) establish test procedures, (2) hold a scoping workshop to discuss plans for developing energy conservation standards, and (3) conduct a determination analysis of energy conservation standards for BCs and EPSs. (42 U.S.C. 6295(u))

DOE complied with the first of these requirements by publishing the test procedure final rule, 71 FR 71340, on December 8, 2006, which included definitions and test procedures for BCs and EPSs. DOE codified a test procedure for BCs in title 10 of the Code of Federal Regulations (CFR), part 430, subpart B, appendix Y ("Uniform Test Method for Measuring the Energy Consumption of Battery Chargers") and a test procedure for EPSs in 10 CFR part 430, subpart B, appendix Z ("Uniform Test Method for Measuring the Energy Consumption of External Power Supplies").

Complying with the second requirement, DOE then published a notice of public meeting and availability of documentation for public review on December 29, 2006. 71 FR at 78389. DOE made two documents available on its website: *Plans for Developing Energy Conservation Standards for Battery Chargers and External Power Supplies* and *The Current and Future Market for Battery Chargers and External Power Supplies*. The public meeting was called a "Scoping Workshop" and was held on January 24, 2007. As required by EPACT 2005, the workshop focused on DOE's plans for developing energy conservation standards for BCs and EPSs.[1]

Complying with the third requirement, DOE initiated a determination analysis of energy conservation standards for BCs and EPSs in 2007, scheduled for completion in August 2008. However, on December 19, 2007, EISA 2007 (Docket No. EERE-2006-DET-0136; Pub. L. 110-140) was enacted, amending sections 321, 323, and 325 of EPCA. These amendments required significant changes to the determination analysis DOE had been conducting on BCs and EPSs. As a result, work on the determination analysis was suspended. The details of the analytical process up to that point are detailed in this report.

1.3 Overview of the Determination Analysis

The purpose of the determination analysis rulemaking was to provide sufficient information to determine whether energy conservation standards should be set for BCs and EPSs. DOE's determination and the possible establishment of energy conservation standards are two separate actions; however, the supporting analyses are similar. A full description of the analyses conducted as part of an energy conservation standards rulemaking can be found in the "Energy Conservation Standards Rulemaking Framework Document for Battery Chargers and External Power Supplies."

1.3.1 Components of a Determination Analysis Rulemaking

Figure **1.1** summarizes the determination analysis process and presents the analytical components discussed in this report. Each component (represented by the boxes with dark numbers) had a set of "key inputs," which represent the information required for the analysis. The numbers correspond to the chapter numbers where these analyses are found. The "approaches" column lists the methods used to obtain these inputs. For example, some key inputs existed in public databases, while others were collected from stakeholders or subject-matter experts. DOE developed the remaining inputs on its own. The "key outputs" column lists the results of each analysis, which feed

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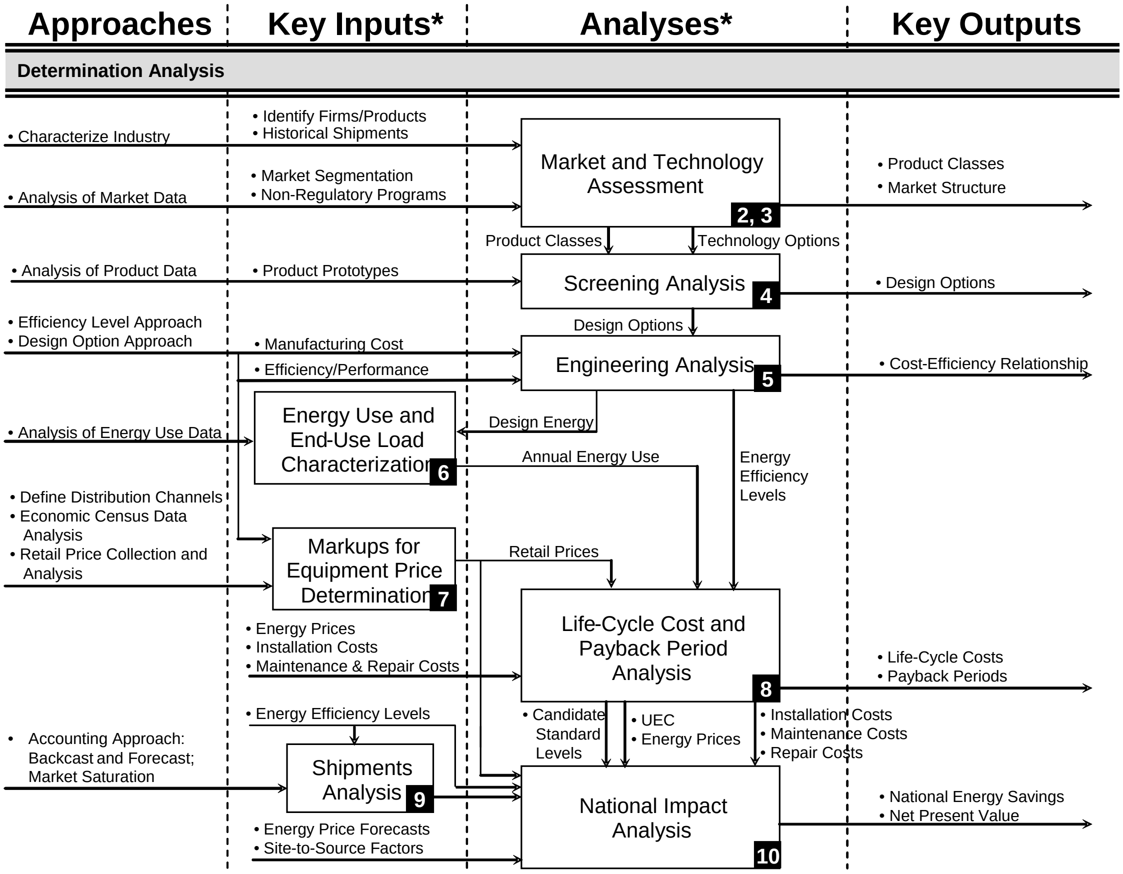
[1] Information pertaining to the Scoping Workshop is available at www.eere.energy.gov/buildings/appliance_standards/residential/battery_external.html.

directly into the rulemaking. The arrows indicate the flow of information between the various analyses.



* Dark boxes indicate Determination Analysis chapters.

Figure 1.1. Flow Diagram of the Components of a Determination Analysis

1.3.2 Overview of Determination Analysis Content

The BC and EPS determination analysis included a market and technology assessment, screening analysis, engineering analysis, energy-use and end-use load characterization, markups for equipment price determination, life-cycle cost (LCC) and payback period analysis, shipments analysis, and national impact analysis (NIA). As described in the framework document, DOE may use the work conducted during the determination analysis as a basis for the analyses it conducts during the energy conservation standards rulemaking process.

Chapters 2 and 3 present the market and technology assessments, respectively, for BCs and EPSs. These chapters outline the typical consumer-product applications of these power converters, as well as the product classes for analysis and technologies for energy efficiency improvement. Chapter 4 describes the screening analysis, which eliminates for technical or economic reasons technology options that DOE will not consider in the rulemaking. Chapter 5 describes the engineering analysis, which involved the selection of representative units for analysis and the calculation of the costs associated with increasing the efficiency of these units.

Chapters 6 and 7 describe approaches DOE used to determine the impacts of the cost-efficiency relationship developed in chapter 5 on end users of products powered by BCs and EPSs. Chapter 8 is an analysis of LCC and payback period, while chapter 9 describes methods for deriving base and standards case shipment forecasts. Chapter 10 describes a national impact analysis, which includes a methodology to calculate national energy savings and the net present value of those savings. DOE will use the methodology described in chapter 10 to measure the impact of Federal energy conservation standards by (1) comparing projected U.S. energy consumption with and without new energy conservation standards, and (2) weighing the cost savings associated with decreased energy consumption against the increased end-user cost of more energy efficient products discounted over the 30-year analysis period.

A determination analysis is typically less rigorous than an energy conservation standards rulemaking, which DOE is initiating with the publication of its framework document. The analyses above focused on finding just one candidate standard level the Secretary could use to decide whether to proceed with setting energy conservation standards. An energy conservation standards rulemaking considers several standards levels. Additionally, the analyses at each standard level are more detailed in a standards rulemaking compared with the determination, which evaluates average or typical cases and does not include sensitivity or subgroup analyses. Nonetheless, many of the inputs and methods used for the determination can be applied to the standards rulemaking, and the Department welcomes stakeholder comment on all aspects of the determination analysis presented in this report.

CHAPTER 2. MARKET ASSESSMENT

LIST OF TABLES

2.1 Introduction

This section of the Draft Technical Report summarizes the key points, data, and methods used in DOE's work during the determination analysis to assess the current and future market for BCs and EPSs.

2.2 The Importance of Applications

To characterize the market for BCs and EPSs, DOE gathered information on the applications that use them. This method was chosen for two reasons. First, the demand for consumer electronics applications drives the demand for BCs and EPSs. Nearly all BCs and most EPSs are custom-designed for use with the application they power, therefore they are bundled with the application. Second, because BCs and EPSs are not stand-alone products, their usage profiles, energy consumption, and power requirements are all determined by the associated application. To develop reliable estimates of the real-world unit energy consumption of a BC or EPS, it is necessary to examine the application.

Sales volume is the primary driver of demand for BCs and EPSs, but trends in consumer product design also affect demand. For example, increased demand for portability in the consumer electronics industry has driven demand for battery-powered products. This has increased demand for BCs and EPSs, which are used to charge batteries in consumer electronics. In terms of volume, the main consumer products that drive demand for BCs are digital cameras and power tools. For EPSs, the drivers are mobile phones, flat panel monitors, cordless phones, and notebook computers.

2.2.1 Market Trends

The major trends that affect the market for BCs and EPSs are related to the consumer products that are powered by these products. During its work on the determination analysis, DOE noted examples of particular importance to the BC and EPS markets.

2.2.1.1 Demand for Consumer Product Applications

Sales of consumer electronics and handheld appliances that use a BC or EPS have increased significantly in recent years. In the BC market, the sales drivers in terms of shipments are power tools and digital cameras. The rechargeable power tool market is growing strongly, partly due to improved batteries and chargers that offer more power and shorter charge times.

For EPSs, DOE's initial analysis shows that market drivers in terms of shipments are wireless phones, flat panel monitors, cordless phones, and notebook computers. Wireless phones account for the largest number of EPS sales. The Consumer Electronics Association estimated that 138.2 million wireless phones were sold in 2007.[1]

Despite the recent rapid growth, EPS sales in this segment are expected to level off as wireless phones become ubiquitous in the United States. Notebook computer sales are the main driver behind shipments of high-power EPSs, and an emerging trend of purchasing notebooks instead of desktops has pushed the nameplate output power of these EPSs upward, sometimes over 100 watts.

2.2.1.2 Convergence

Some applications using BCs and EPSs are in decline as their functions are incorporated into other applications. For example, personal digital assistants (PDAs) have become rare because their functions are increasingly incorporated into wireless phones. Sales of digital cameras are also slowing. This may be due largely to market saturation, but convergence is a factor as well as the cameras built into wireless phones improve in quality. Multi-function devices, some of which use EPSs, combine the features of a printer, copier, scanner, and fax machine into one product, and make the stand-alone, single-function products redundant. The convergence of applications could decrease demand for BCs and EPSs as consumers do more with fewer products.

2.2.1.3 Emergence

The consumer electronics market is quick to adopt new technology and experiment with new consumer products. As battery and charger technology advances, products that are now stationary may become portable in the future. Some of the products that DOE analyzed for its determination did not exist 10 years ago. New BC and EPS applications are likely to emerge during the period of analysis.

2.2.1.4 Substitution

Applications use a number of methods to obtain power, including internal power supplies, external power supplies, primary batteries, rechargeable batteries, and USB ports. Market forces and changing design choices may cause shifts between these methods. For example, a portable digital audio player can receive power from an EPS, a BC, or a USB port. One brand of portable audio player that has dominated this market is typically charged through a USB port. However, users can purchase an EPS to charge their player through a traditional wall outlet. Small LCD televisions may use an EPS, but as they grow larger, power requirements dictate that an internal power supply (IPS) is a better option.

The presence of a standard may cause a shift away from BCs or EPSs toward other power sources. The magnitude of this effect depends on the design considerations (*e.g.*, the need to dissipate heat in high-power applications), and the demands of the consumer (*e.g.*, the desire for portability may exclude the use of an IPS). In its work on the determination, DOE assumed that a standard would cause no substitution effects.

2.2.2 Consumer Products: Impact of Design on the Market for Battery Chargers and External Power Supplies

Manufacturer product design and consumer choice both affect the size and growth of the BC and EPS market. In some consumer product categories, nearly all models are powered the same way. For example, most handheld vacuums are powered by BCs while most Wi-Fi access points are powered by EPSs. In other consumer product categories, the power conversion device can vary by manufacturer or model. For example, designers of digital cameras have a variety of choices when deciding how to power their products, including using a mains-powered BC or EPS, a universal serial bus (USB)-powered BC, or Power over Ethernet. These differences in the source of power relate to the intended use of a product, consumer preferences, and industry norms. Designers choose BCs to power handheld vacuums because users desire portability. Wi-Fi access points are stationary, so designers choose an EPS. If the designer expects a digital camera to be used by professional photographers, a BC or EPS might be a good choice. If the designer expects the camera to be used in close conjunction with a computer, power through USB might be a good option.

An increasing number of portable devices, such as portable digital music players, can be recharged through a connection to a USB computer port. It is also possible to charge a portable digital music player by using an EPS purchased separately from the music player, but because most consumers use a computer's USB port to load music onto the device, most charging also occurs through the USB port. The market trend toward consumer products that are USB-powered could affect the number of products that are shipped with stand-alone power conversion devices considered to be BCs and/or EPSs.

Both technical issues and consumer preferences can influence manufacturer design choices. Technical considerations may relate to the method the device uses to consume power (*e.g.*, short bursts of high current as in a power tool or low levels of consumption as in a portable music player). Consumer preferences can also influence the design choice, such as having longer time between recharge, being able to operate the device from the mains power, and not having to wait for a battery to recharge. Variations in power system designs occur as manufacturers develop different design solutions to these problems.

This variance in design affects the market. The shipments of a given type of consumer product in a given year do not necessarily correspond one-to-one with the number of BCs and/or EPSs that ship with those products. Technical issues and consumer preferences will influence manufacturer design choices, and sales of BCs and/or EPSs could decrease even as total sales of consumer electronics increase.

2.3 Applications That Use Battery Chargers and External Power Supplies

Table 2.1 and Table 2.2 list the applications for which DOE has gathered shipment data.

Table 2.1. Battery Charger Applications for Which DOE Has Shipment Data

Product Application	Notes/Definition
Personal care products	Includes rechargeable shavers, beard trimmers, massagers, toothbrushes, etc.
Floor care products	Includes rechargeable stick vacuums, handheld vacuums, robotic vacuums, etc.
Kitchen products	Includes rechargeable hand-held mixers, blenders, knives, etc.
Universal battery chargers	Used to charge rechargeable batteries.
Digital cameras	Digital cameras that are powered by proprietary batteries.
Camcorders	Camcorders and digital camcorders that are powered by proprietary batteries.
Do-it-yourself (DIY) power tools	Generally less powerful tools aimed at the occasional user; includes drills, saws, grinders, and others.
Professional power tools	Generally more powerful tools aimed at the professional user; includes drills, saws, grinders, and others. Typically use a fast-charging BC.

Table 2.2. External Power Supply Applications for Which DOE Has Shipment Data

Product Application	Notes/Definition
Camcorders	Portable consumer video recorders.*
Cordless phones	Phones lacking a cord between the base station and headset for use in the public switched telephone network, *e.g.*, a traditional land line.
Digital cameras	Includes digital cameras that use an EPS.
Flatbed scanners	Desktop scanning devices.*
Flat panel monitors	Also known as a LCD monitor, to be used with a computer
Ink-jet computer printers	Only ink-jet computer printers are included in this analysis because laser printers, the other dominant technology type, use an internal power supply.
LAN equipment	Local Area Network equipment. This segment includes routers, hubs, and switches.
Modems/fax modems	Broadband modems used for digital subscriber lines (DSL), cable, or broadband over power line (BPL).*
Notebook computers	Desktop computers use an internal power supply and therefore only notebooks are considered for the analysis.
Portable audio players	Includes personal MP3 players, CD and mini disc players, and portable radios powered by EPSs.
Portable gaming devices	Portable gaming devices such as PlayStation Portable and Nokia Ngage.*
Portable video players	Includes portable DVD and multimedia players.
Small LCD TVs	Note: Large LCD TVs (23” screen size or greater) and plasma TVs use an internal power supply..
Telephone answering devices	Stand-alone telephone answering machines and telephones with built-in answering machines.
Wi-Fi access points	IEEE 802.11a/b/g/n access points.* Hardware used as a connecting hub for a wireless network.
Wireless telephones	Also known as mobile or cellular phones. This category includes “smart phones” and personal digital assistants (PDAs).

* Darnell Group. *External AC-DC Power Supplies: Global Market Forecasts and Competitive Environment*. 2nd Edition. 2005. Darnell Group: Corona, California.

DOE identified other products that use a BC or EPS but did not include them in the determination analysis because complete data was unavailable. These applications are listed below. For these products, DOE lacks shipment data, splits between voltage or output power, usage information, or all of the above.

Battery charger applications for which DOE lacks data include:

- Electric carts
- Electric outdoor appliances
- Electric ride on toys
- Golf cars
- Mobility chairs
- Rechargeable light devices
- Toys
- Uninterruptible power supplies

External power supply applications for which DOE lacks data include:

- Alarm clocks
- Amplifiers
- Aquarium pumps/lights
- Baby monitoring devices
- Bluetooth headsets
- Caller ID devices
- Computer speakers
- Distribution amplifiers
- Electronic musical instruments
- External computer drives
- Fluorescent desk lamps
- Guitar effects
- Hair dryers
- Handheld computers
- Handheld image scanners
- Indoor fountain pumps/lights
- MP3 player speaker systems
- MP3 player docking stations
- Multifunction printing/scanning/faxing devices
- Non-portable gaming devices
- Set-top boxes
- Water filters
- Water softeners

References

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[1] Consumer Electronics Association. *U.S. Consumer Sales & Forecasts, 2004–2009.* July 2008. CEA: Arlington, VA.

CHAPTER 3. TECHNOLOGY ASSESSMENT

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3.1 Introduction

This technology assessment examines BC and EPS technology, with a focus on the factors most affecting their efficiency. The assessment begins by explaining the purpose of EPSs and BCs, their legal definitions, and their different modes of operation. Next, it presents the parameters that govern power converter design and, based on those parameters, how DOE considered grouping them into product classes. Last, the technology assessment reviews efficiency metrics as well as methods for improving efficiency. This introduction briefly examines each of these points. In other chapters of this document, discussion begins with BCs; for the purposes of the technology assessment, it is more natural to examine EPSs first.

The assessment presents DOE's current understanding as well as previous unpublished work. In December 2006, DOE published a draft technology assessment in "The Current and Projected Future Market for Battery Chargers and External Power Supplies."[a] DOE then continued to research BCs and EPSs in preparation for a determination analysis it intended to publish in August 2008. This technology assessment presents DOE's understanding of BC and EPS technology as it was developed for the determination analysis until EISA suspended DOE's examination in 2007. The purpose of this technology assessment is to present DOE's understanding of the factors DOE reviewed in the screening analysis and then used in the engineering analysis to establish the relationship between cost and efficiency.

3.1.1 The Role of Power Converters

EPSs and BCs are power converters that support consumer products; hence, their operation and design is primarily governed by the consumer products they support (Figure 3.1 and Figure 3.2). Generally, external power supplies provide power at a constant output voltage and are interchangeable among consumer products with similar power requirements. Alternatively, battery chargers deliver power while controlling the output current, the output voltage is determined by the battery. Battery chargers tend to be custom-designed for the charging and safety requirements of specific battery packs.

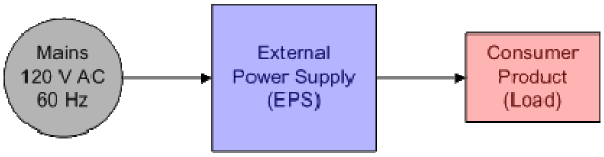

Figure 3.1 Block diagram of power flowing through an external power supply.

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[a] This document is available at www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/market_analysis.pdf.

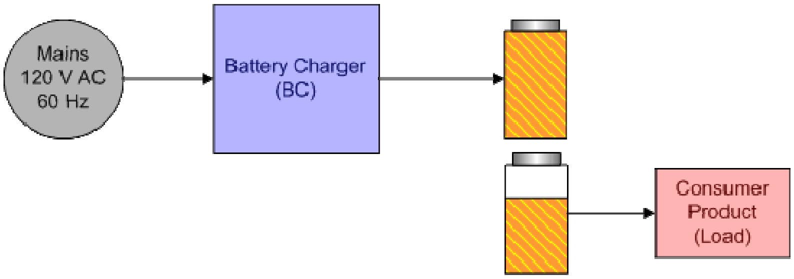

Figure 3.2 Block diagram of power flowing through a battery charger.

To specify, DOE is developing energy conservation standards for battery chargers and external power supplies defined by EPCA, as amended by EPACT. EPCA defines a battery charger as “a device that charges batteries for consumer products, including battery chargers embedded in other consumer products.” (42 U.S.C. 6291(32)) The definition for external power supply is “an external power supply circuit that is used to convert household electric current into DC current or lower-voltage AC current to operate a consumer product” (42 U.S.C. 6291(36)(A)) but Section 301 of EISA further amended this definition by creating a subset of external power supplies called Class A External Power Supplies[b]. EISA defined this subset as those external power supplies that, in addition to meeting several other requirements common to all external power supplies, are “able to convert to only 1 AC or DC output voltage at a time” and that have “nameplate output power that is less than or equal to 250 watts.” (42 U.S.C. 6291(36)(C)(i)) EPCA excludes from Class A an EPS if it “requires Federal Food and Drug Administration listing and approval as a medical device” or if it “powers the charger of a detachable battery pack or charges the battery of a product that is fully or primarily motor operated.” (42 U.S.C. 6291(36)(C)(ii)) This framework document only considers battery chargers and Class A external power supplies. Separately, DOE is conducting a determination analysis for non-Class A external power supplies.

3.1.2 Different Modes of Operation

BC and EPS design choices are driven by the anticipated power requirements and time spent in their modes of operation, including active mode, maintenance mode (for BCs only), and no-load mode. Of these modes, active mode has the largest effect on the power converter’s size and efficiency because the maximum amount of power passes through in active mode. In the other operational modes, power converters provide less power; however, their power consumption is typically larger in proportion to the output power.

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[b] The full EISA definition of a Class A external power supply includes a device that "(I) is designed to convert line voltage AC input into lower voltage AC or DC output; (II) is able to convert to only 1 AC or DC output voltage at a time; (III) is sold with, or intended to be used with, a separate end-use product that constitutes the primary load; (IV) is contained in a separate physical enclosure from the end-use product; (V) is connected to the end-use product via a removable or hard-wired male/female electrical connection, cable, cord, or other wiring; and (VI) has nameplate output power that is less than or equal to 250 watts.” (42 U.S.C. 6291(36)(C)(i)) The EISA definition also excludes from Class A “ any device that-- (I) requires Federal Food and Drug Administration listing and approval as a medical device in accordance with section 513 of the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 360c); or (II) powers the charger of a detachable battery pack or charges the battery of a product that is fully or primarily motor operated.” (42 U.S.C. 6291(36)(C)(ii))

Although both BCs and EPSs are power converters with similar modes of operation, there are important differences between them. An EPS can be in active mode for an indefinite amount of time while providing power to a load. Typically, EPSs spend most of their time in active mode. On the other hand, while in active mode, a BC refills a battery with energy. Therefore, the BC is in active mode only until the battery is filled. After that point, the BC is in maintenance mode, when the BC maintains the battery at full charge.

These differences in operation lead to differences in design. For instance, BCs are designed around the charge type in active mode—fast or slow charging. The power requirements of the EPS load in active mode are the primary criteria affecting the EPS's design.

3.1.3 EPS Design Parameters

EPSs are designed to take power from mains and convert it to a form useful to a consumer product. Thus, it is the consumer product that dictates the output power and output voltage of the EPS, the two design parameters with the biggest effect on EPS efficiency. The voltage requirements of the consumer product also define the tolerance of the EPS output voltage and whether it requires voltage regulation. These and other design parameters help determine whether the EPS is line frequency or high-frequency switched mode, and unregulated or voltage regulated. In turn, those design choices constrain which the technology options that the EPS can use and its consequent efficiency.

3.1.4 BC Design Parameters

BCs are designed to take power from mains and convert that power over time to energy stored in a battery; later, the battery delivers the energy to a consumer product. Thus, the consumer product determines the choice of battery, which also determines the characteristics of the battery charger. The most important design parameters of a BC are the voltage of the battery it will charge and the charge type, either fast or slow. The charge type—a measure of how quickly the BC refills its battery with energy—determines maximum output power. A BC defines the output current, while the battery controls the BC's output voltage. Like an EPS, output power and battery voltage have the largest effect on BC design and efficiency. In turn, those design choices constrain which the technology options that the BC can use and its consequent efficiency.

3.1.5 Product Classes

The Department of Energy groups products into "product classes" for different energy-efficiency standards when a product's characteristics constrain its energy efficiency. As necessary, DOE divides covered products into classes by the type of energy used, the capacity of the product, and any other performance-related feature that justifies different standard levels, such as features affecting consumer utility. (42 U.S.C. 6295(q)) For example, when compared with a standard device, a device with additional functionality that provides extra utility to the consumer would be grouped in a separate product class, if the additional functionality inherently limits its efficiency. DOE then conducts its analysis and considers establishing or amending standards to provide separate standard levels for each product class. For the determination analysis, DOE considered EPS product classes primarily based on output power and output voltage. For BCs, DOE considered charge type and battery voltage.

3.1.6 Efficiency Metrics

Any evaluation of efficiency depends heavily on the measures used to quantify it. This document considers conversion efficiency in active mode for EPSs and power consumption in other modes for both BCs and EPSs. DOE used previously adopted test procedures codified in 10 CFR part 430 appendices Y and Z as the basis for evaluating efficiency for the determination analysis.

3.1.7 Technology Options for Efficiency Improvement

The largest gains in efficiency in EPSs and BCs come from converting power with lower loss components and using more energy-efficient controls in the power converter. DOE analyzed the components in the power converter that consume significant power, such as transformers, or influence power consumption of other components, such as integrated circuits. By identifying sources of power loss and possible methods for improvement, DOE developed technology options that would allow a manufacturer to design a power converter with similar design characteristics but improved efficiency.

3.2 External Power Supply Modes of Operation

3.2.1 EPS Active Mode

When the external power supply takes power from mains and converts it to a form usable by the consumer product or load it is considered to be in "active mode." For the determination analysis, DOE used the definition of active mode codified in 10 CFR part 430 subpart B appendix Z: "Active mode is the mode of operation when the external power supply is connected to the main electricity supply and the output is connected to a load."

In this mode, EPS efficiency is the conversion efficiency when the load draws some or all of the maximum rated output power of the EPS. To provide that output power, the EPS also consumes power due to internal losses as well as overhead circuitry. The amount of power the EPS consumes varies with the power demands of the load; together, those two parameters define the EPS's efficiency at a particular loading point:

$$\eta_{EPS} = \frac{P_{out}}{P_{In}} = \frac{P_{out}}{P_{out} + P_{EPS\_consumption}} \qquad \textbf{Eq. 3.1}$$

where η_{EPS} is the EPS efficiency,
$P_{EPS\_consumptiont}$ is the power consumed by the external power supply itself,
P_{in} is the power from mains into the external power supply, and
P_{out} is the power out of the external power supply to the consumer product.

EPS efficiency varies with the amount of output power as shown in Figure 3.3. Typically, EPS are inefficient at low load (0 percent to 20 percent of maximum rated output power of the EPS) when the consumer product demands little power. However, EPS are more efficient at larger loads (between 20 and 100 percent of maximum rated output power) as when the consumer product is fully functional and demanding more power. The lower efficiency at lower output current is due to the proportionally larger power consumption of internal EPS components, relative to output power. At higher power, EPS losses increase slightly, but have less of an effect on EPS efficiency. The EPS test procedure evaluates active mode conversion efficiency at four loading points: 25 percent, 50 percent, 75 percent, and 100 percent of maximum rated output power, which captures a general picture of EPS efficiency. Figure 3.3 shows an example of a typical efficiency curve for an EPS in active mode.

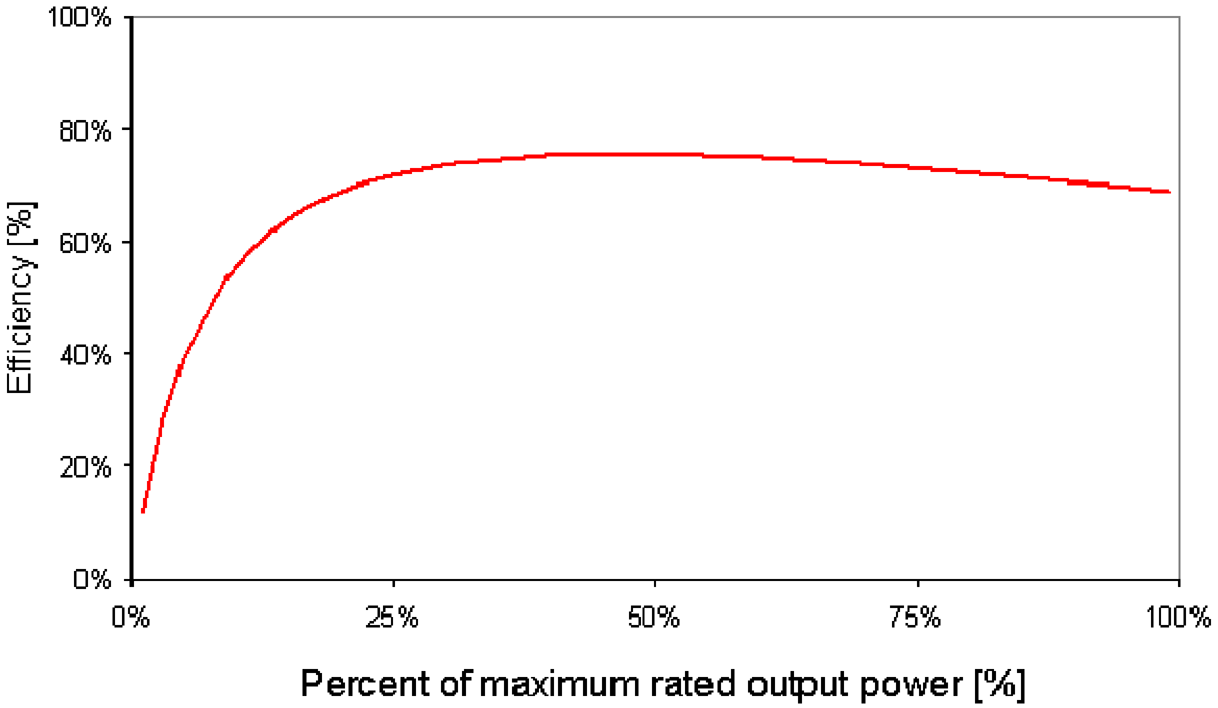

Figure 3.3 Example of an Efficiency Curve of an EPS in Active Mode

3.2.2 EPS No-Load Mode

For the determination analysis, DOE used the definition of no-load mode codified in 10 CFR part 430 subpart B appendix Z: "No load mode means the mode of operation when the external power supply is connected to the main electricity supply and the output is not connected to a load."

EPS efficiency in no-load mode is characterized by EPS power consumption, rather than conversion efficiency, because the EPS does not deliver power to the load in this mode. However, the EPS might provide functionality. For example, certain consumer products may require the EPS to deliver output power within moments of being connected. Thus, the EPS may consume power to provide the useful function of reduced start-up time. Nonetheless, EPS power consumption can be low (less than 1 watt) in no-load mode for Class A EPSs.

3.3 Battery Charger Modes of Operation

3.3.1 BC Active Mode

DOE codified the definition of active mode for battery chargers in the test procedure final rule published in December 2006 (10 CFR part 430 subpart B appendix Y): "Active mode is the condition in which the battery is receiving the main charge, equalizing cells, and performing other onetime or limited-time functions necessary for bringing the battery to the fully charged state." For the determination analysis, DOE studied BC active mode for its effect on BC design and performance. However, DOE used the non-active energy ratio to evaluate efficiency, which does not include active mode.

The output current of a BC in active mode is most critical at two points: when the battery is fully charged and when the battery is empty. When the battery is fully charged, the BC may need to immediately stop sending current to the battery, as in the case of lithium-based batteries. When a battery is empty of charge its voltage becomes very low. In that state, the BC needs to limit its output current because it could damage the battery and pose a safety hazard from heat generation. Therefore, the BC must limit the charging current until the battery voltage increases.

Battery charger efficiency in active mode is governed by BC component losses and overhead circuitry. BCs share with EPSs similar options for reducing component losses in active mode. However, some BCs have safety circuitry to monitor the battery during charging, which EPSs typically do not include. Safety circuits are often present in BCs that are fast chargers; safety concerns also affect design of slow-charging BCs. Thus, if a BC were compared to an EPS with similar power ratings, it might appear to have lower conversion efficiency due to the additional power consumption of its safety circuitry.

3.3.2 BC Maintenance Mode

DOE codified the definition of maintenance mode for battery chargers in the test procedure final rule published in December 2006 (10 CFR part 430 subpart B appendix Y): "Battery maintenance mode or maintenance mode is the mode of operation when the battery charger is connected to the main electricity supply and the battery is fully charged, but is still connected to the charger."

Once the battery reaches a fully charged state, the BC and battery are considered to be in maintenance mode. In this mode, the BC controls the output current to prevent the battery from being damaged due to excess heat generation or unwanted electro-chemical reactions. Specifically, the battery has different requirements depending on its chemistry. Lithium-ion (Li-Ion) batteries do not significantly self-discharge but do pose a serious safety hazard if overcharged. Consequently, Li-Ion BCs stop charging once the battery is full and require no maintenance current. Conversely, nickel-based batteries, such as nickel-cadmium (NiCd) and nickel-metal-hydride (NiMH), significantly self-discharge but are tolerant of overcharging. Hence, their BCs continue to provide maintenance current to keep the battery fully charged. Efficiency can be improved by reducing the charge current to the minimum. For BCs that do not provide charge current in maintenance mode, efficiency can be improved by turning off circuits that are not in use.

3.3.3 BC No-Load Mode

For the determination analysis, DOE used the definition of no-load mode codified in 10 CFR part 430 subpart B appendix Y: "Standby mode or no-load mode means the mode of operation when the battery charger is connected to the main electricity supply and the battery is not connected to the charger."

Similar to the EPS that is disconnected from the load, a BC in no-load mode does not deliver power to a battery. Improved efficiency in these modes stems from reducing BC power consumption. Many of the technology options for reducing no-load mode power consumption in EPSs are also valid for BCs. Some BCs also use a cradle to hold the battery during charging, which offers an additional energy saving technology. A BC could have a switch in the cradle that senses the battery's presence and electrically disconnects the BC from mains when the battery is removed.

3.4 External Power Supply Design

3.4.1 General Design of an External Power Supply

EPS's must meet several specifications in order to power a consumer product; EPSs are generally designed to provide power at a fixed output voltage with variable current to a consumer product. The consumer product is what determines the EPS design criteria, including output power, output voltage and the tolerance of the output voltage. EPSs designed for consumer products that require precise voltages (*e.g.*, computers) will also incorporate output voltage regulation to minimize voltage fluctuations caused by load or power source variations. Other applications that can tolerate some voltage fluctuation may use simpler EPSs that do not regulate the output voltage. Also, EPSs might have other specifications, such as total harmonic distortion or power factor.

Of all these specifications, output power and output voltage have the largest impact on EPS efficiency, because together they determine the output current, which directly affects conduction losses and associated power dissipation in the EPS.

Line-frequency EPSs have that name because the frequency of the current passing through their transformers is the same as that of the AC mains current (nominally 60 Hz in the United States). Switched-mode power supplies (SMPS) convert power differently than line-frequency EPSs. SMPSs first rectify the AC mains voltage to DC, converting it back to AC by switching the current on and off at high frequency. The high-frequency AC current passes through the primary winding of a transformer while the output from the secondary winding of the transformer is rectified, resulting in a low-voltage DC output. Because the AC current passing through the transformer is at high frequency, the transformer is smaller, resulting in lower weight, material costs, and losses in the transformer, all of which decrease with transformer volume.

3.4.2 AC/AC External Power Supplies

An AC/AC external power supply is the simplest type of EPS, typically consisting only of a transformer. A transformer contains two wires wrapped around a metal core; as current passes through the primary wire, power is transferred to the secondary wire at a lower voltage through magnetic induction in the core. The size of the wires and core depend on the output power of the transformer. The output voltage depends on the relative number of turns between the primary and the secondary wires. The windings of the transformer are wound so that the voltage generated in the secondary wire is at the design voltage for the consumer product when mains voltage is applied to the primary wire. Because the primary and secondary windings are two separate wires, the transformer also provides a safety function, electrically isolating the consumer product from the mains. The key factors that determine transformer losses are core size, core material, number of windings, and wire gauge.

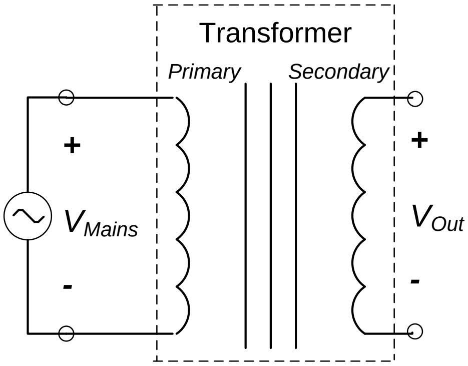

Figure 3.4 Circuit Diagram for an AC/AC External Power Supply

3.4.3 Unregulated Line-Frequency AC/DC External Power Supplies

An unregulated line-frequency EPS is referred to as a "raw supply," which has three distinct stages (Figure 3.5): a transformer to isolate and step down mains voltage, a rectifier to convert AC voltage to DC voltage, and a filter capacitor to smooth the output voltage. The two main sources of loss are the transformer and the rectifying diodes. After passing through the transformer, current passes through rectifier diodes, which have voltage drops that also dissipate power. Typically, diodes have a drop of 0.6 volts, which constitutes a proportionally larger share of the losses at lower output voltages. For AC-DC EPS that have a low output voltage, below approximately 12 V, the power consumed by the diodes also becomes significant in that it is more than 10% of losses, if the rectifier is a bridge with two diodes.

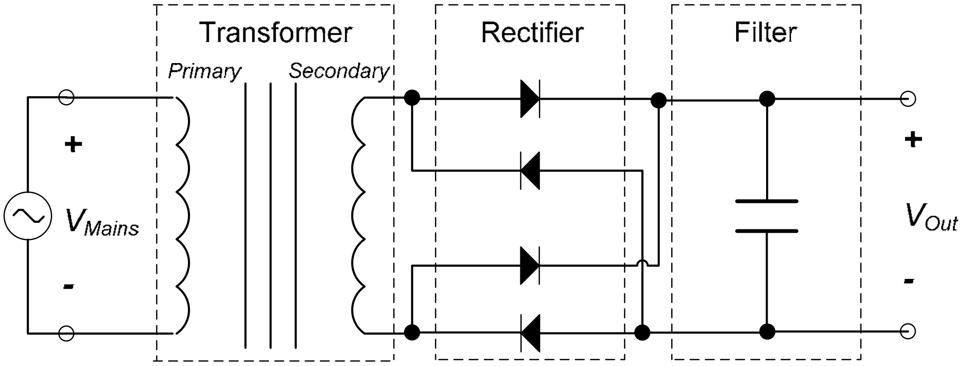

Figure 3.5 Circuit Diagram of a Line-Frequency Raw Supply

The raw supply is directly responsive to the load: A change in the mains power or the resistance of the load directly affects the output voltage of the raw supply. If required, a regulator circuit follows the raw supply circuit, housed either in the EPS or in the device before the load.

3.4.4 Linear-Regulated Line-Frequency AC/DC External Power Supplies

To achieve voltage regulation, manufacturers can add a second stage, such as a linear regulator, to the line-frequency power conversion stage described above, or redesign the power conversion stage entirely using a switched-mode topology. Of the two regulator technologies, linear regulators are simpler, bulkier, cheaper, and generally less efficient at higher power levels than switching regulators. Switching regulators, although more complicated and costly, provide a good alternative when portability is a concern, such as when an EPS is used with a mobile phone.

The AC-DC conversion stage of a regulated line-frequency EPS is essentially the same as that of an unregulated EPS, with the same sources of power consumption. The linear voltage regulation stage adds to these losses by passing power from the AC-DC converter to the consumer product through a power-dissipating element. This regulation stage senses the output voltage and adjusts the voltage across the power-dissipating element to keep the output voltage fixed. Loss in a regulated line-frequency EPS is caused by the conversion stage delivering current at a higher voltage than needed by the consumer product, and dropping the excess voltage across the regulator to achieve the lower regulated output voltage. Dissipated as heat, the power lost in the regulator is the product of the voltage drop and the load current.

Linear regulators have two key elements: a sensor and a pass device, which work together to produce a fixed output voltage (Figure 3.6). To determine those adjustments, the sensor element continuously compares the output voltage to a reference voltage. Whenever there is a difference between the two voltages, the sensor directs the pass device to adjust the output in order to reduce that difference. This continuous adjustment allows the regulator to yield a constant output voltage as the load resistance or mains voltage varies. The output voltage of the linear regulator circuit is what the user sees as the output voltage of the EPS.

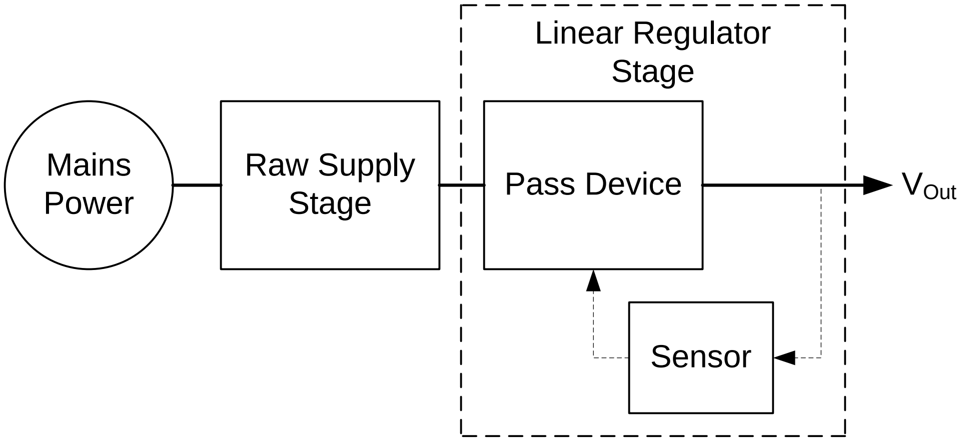

Figure 3.6 Block Diagram of a Linear Regulator

Figure 3.7 shows a circuit diagram of a “low-dropout” linear regulator, one of the more common types of linear regulators. To determine the voltage drop across the pass device, an operational amplifier (commonly referred to as an “op-amp”) acts as a sensor that compares the output voltage against a reference voltage. Based on those two signals, the op-amp controls a transistor, which is the pass device. The voltage drop across the transistor determines the output voltage but also dissipates energy. The energy dissipated by the pass device is the main source of energy consumption in the linear regulator, and hence the main source of inefficiency and heat generation. Together, the sensor and the pass device adjust the output of the regulator to produce a stable output voltage, which is what the load receives as the output voltage of the EPS.

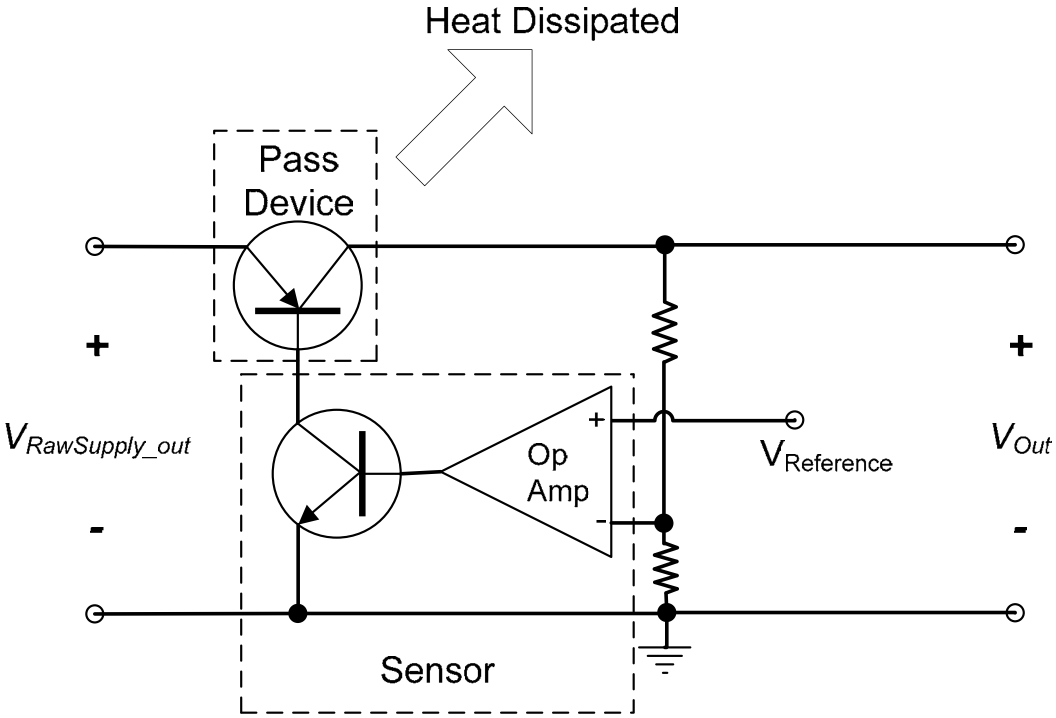

Figure 3.7 Simplified Circuit Diagram of a Linear Regulator

The efficiency of the linear regulator, η_{LinReg}, is:

$$\eta_{LinReg} = \frac{P_{LinReg\_out}}{P_{LinReg\_in}} = \frac{V_{LinReg\_out} I_{LinReg\_out}}{V_{LinReg\_in} I_{LinReg\_in}} \quad \textbf{Eq. 3.2}$$

where I_{LinReg_in} is the current into the linear regulator,
I_{LinReg_out} is the current out of the linear regulator,
P_{LinReg_in} is the power into the linear regulator,
P_{LinReg_out} is the power out of the linear regulator,
V_{LinReg_in} is the voltage into the linear regulator, and
V_{LinReg_out} is the voltage out of the linear regulator.

Because the linear regulator directly attaches to the raw supply, V_{LinReg_in} is equal to $V_{RawSupp\_out}$, the output voltage of the raw supply.

Because the input current flows directly to the output through the pass device, with other currents being negligible, $I_{LinReg\_out} \approx I_{LinReg\_in}$. Therefore, the efficiency of the linear regulator alone is approximately:

$$\eta_{LinReg} \approx \frac{V_{LinReg\_out}}{V_{LinReg\_in}}$$ **Eq. 3.3**

The total efficiency of an EPS with a linear regulator depends on the efficiency of both the linear regulator stage and the raw supply stage. Depending on the load conditions, η_{LinReg} generally ranges from 0.6 to 0.8, meaning the linear regulator is about 60 to 80 percent efficient. The efficiency of raw supply, η_{RawSup}, also varies with load, generally from 0.7 to 0.9. The raw supply and linear regulator each are most efficient at different load conditions. Multiplied, η_{LinReg} and $\eta_{RawSupp}$ yield the total efficiency of an EPS with a linear regulator, η_{Lin_EPS}, which is generally about 50 percent, but is lower for EPSs with output power below 10 W:

$$\eta_{Lin\_EPS} = \eta_{RawSupp} * \eta_{LinReg}$$ **Eq. 3.4**

3.4.5 Switching-Regulated Line-Frequency AC/DC External Power Supplies

An alternate to a linear regulator is a switching regulator that can also follow the raw supply (Figure 3.8). Switching regulators tend to be much more efficient than linear regulators because they do not dissipate excess power. Rather, to regulate output they take power as necessary to maintain constant output voltage. Due to their higher costs, these switching regulators tend not to be as common as linear regulators, since it is typically more cost-effective to use a switched-mode power supply design.

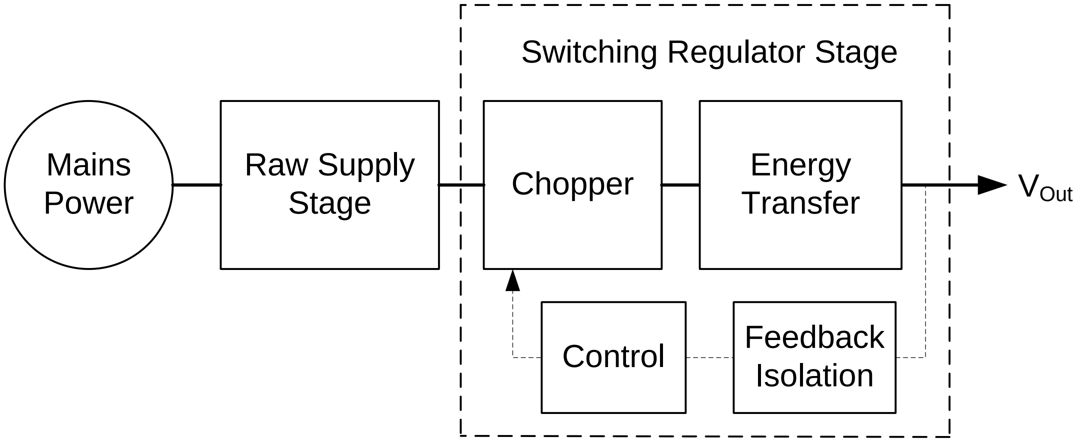

Figure 3.8 Block Diagram of a Switching-Regulated Line-Frequency AC/DC EPS

3.4.6 Switched-Mode AC/DC External Power Supplies

A switched-mode power supply consists of five stages: an AC-DC conversion stage, a chopper stage, an energy transfer stage, a control stage, and a feedback isolation stage (Figure 3.9). First, the current is rectified and passed to the chopper, which converts the DC voltage back to AC, but at high frequency. The energy transfer stage then takes energy from the chopper, briefly stores it, and then passes it to the rectifier to be output to the consumer product. The energy transfer stage also serves to isolate the user from the mains. The level of the output voltage is fed back through a feedback isolation stage to the controller, which tracks the output voltage and adjusts the chopper to make the desired voltage.

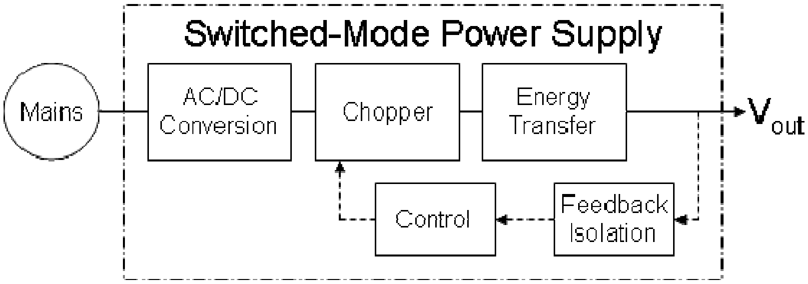

Figure 3.9 Block Diagram of a Switched-Mode Power Supply

The critical elements in a switched-mode EPS are the transistor, output rectifier, bulk capacitor, transformer, and controller. A transistor acts as a switch that constrains the flow of power rectified from mains into the transformer (or choke), through the output rectifier, and, ultimately, to the consumer product. A controller, typically an integrated circuit (IC), switches the transistor on and off based on the output voltage. By adjusting the duty ratio, the IC controls the rectified mains current into the primary winding of the transformer and thereby the output voltage of the EPS. The IC can also limit power dissipation in active mode by reducing switching at low current or low voltage. Further, the IC can greatly increase efficiency by reducing power consumption in no-load mode, the condition when the EPS has been disconnected from the load, resulting in zero output current. After passing through the transformer, the current is rectified and filtered before reaching the consumer product. Principal sources of loss in a switched-mode EPS are the transistor switching transients, magnetization and resistive losses as a result of transformer current, controller IC power consumption, and rectifier losses. Although there are more sources of loss for switched-mode EPSs than line-frequency EPSs, in total, losses in switched-mode EPSs tend to be lower.

The switching regulator usually consists of an integrated circuit controller and discrete components. The circuit diagram in Figure 3.10 depicts a “flyback” switching regulator, the most common type for EPSs used with consumer electronics; however, many other switching regulator designs also exist. The AC/DC conversion stage consists of a diode bridge and filter capacitor, similar to a raw supply. In this case, current flows directly from mains to the diode bridge, rather than through a transformer.

The chopper stage uses a transistor, which switches on and off at high frequency to convert the DC current from the AC/DC converter back to an AC current for the energy transfer stage. A control stage drives the transistor; the duty cycle of the transistor determines how much energy is transferred through the energy transfer stage. The switching frequency is in the kilohertz range, with lower frequencies having lower switching losses. Typically, the minimum frequency is 20 kHz, above the audible range of human hearing.

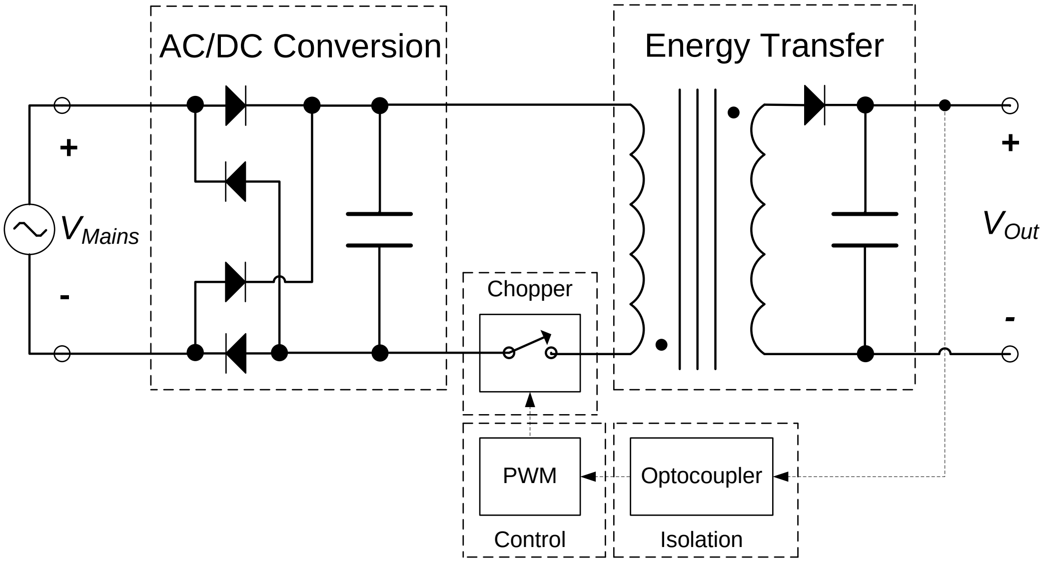

Figure 3.10 Simplified Circuit Diagram of a Flyback Switching Regulator

The energy transfer stage consists of a choke, a capacitor, and a diode. The choke is similar to a transformer and has the same symbol in the circuit diagram. One difference is that a transformer in a line-frequency EPS is designed to pass energy from one winding to another with minimal energy storage, while a choke in a switched-mode EPS is designed to store and release energy. Also, the phasing of the windings is not important in the line-frequency transformer, but it is critically important in the flyback switching regulator. This is represented in Figure 3.10 by dots on the choke.

When the chopper switch is closed, the primary winding of the choke takes energy from the chopper and stores the energy in the choke. When the chopper switch opens, the secondary winding transfers that energy through the diode to the capacitor and provides the output for the switching regulator, electrically isolating the load from the mains. Because the choke operates at a high frequency, it benefits from the associated decreases in size and weight. The energy transfer scheme of the switching regulator is more efficient than a linear regulator, in part because the choke stores and returns energy with relatively low losses.

The feedback isolation stage typically uses an optocoupler that consists of a light source and a photosensitive detector. By converting the electrical feedback signal to an optical one, the optocoupler maintains the load electrically isolated from the mains. The detector converts the optical signal back to an electrical signal for the controller.

Generally, the controller is an integrated circuit that drives the chopper with a high-frequency pulse-width-modulated (PWM) waveform. The controller monitors the EPS output voltage and adjusts the pulse width to increase or decrease the amount of energy transferred by the chopper. If the output voltage dips, the controller will increase the duty cycle, thus increasing the energy passed by the energy transfer stage and increasing the output voltage. Conversely, if the output voltage rises, the controller will decrease the duty cycle or possibly skip cycles. This cycle-skipping feature is especially useful at low-load or when there is no load attached, because the EPS will only take from the mains the small amount of power it needs to keep itself running.

As an alternative to an IC controller, a switched-mode EPS can also use discrete components, as in the case of a ringing choke converter. In that topology, discrete transistors control the chopper and the resulting energy transfer. EPSs without ICs tend to be more common at lower output powers. However, by not having an IC, the EPS may consume less overhead power, but offers less functionality, such as cycle-skipping at low load, which can limit EPS efficiency.

Both linear-regulated and switching-regulated EPS use regulating circuits to achieve a stable output voltage. However, voltage is not the only output variable that can be regulated. Current regulation, as discussed in the following section, is a fundamental consideration in BC design.

3.5 BC Design

BCs are power converters that support consumer products and their associated batteries. The circuit model for the battery is a device with certain electro-chemical characteristics, as shown in Figure 3.11.

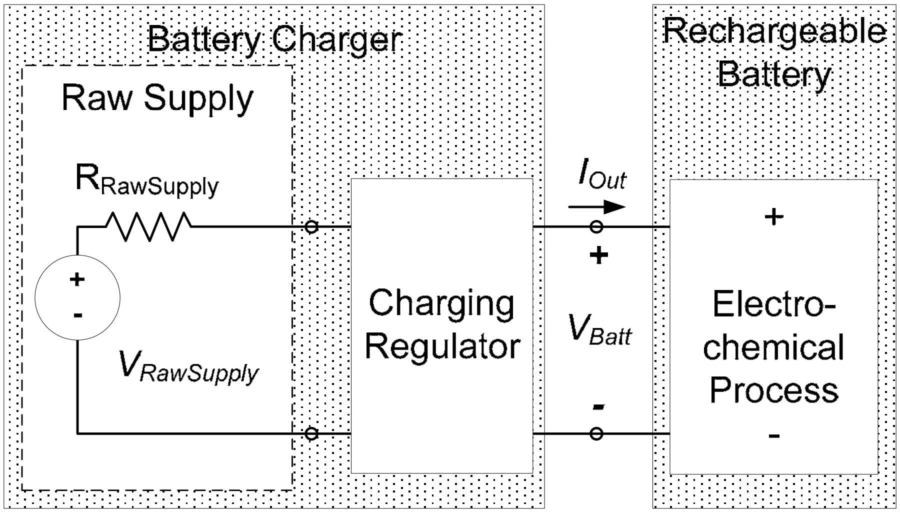

Figure 3.11 Circuit Diagram of a BC

Technology options for improving BC efficiency depend on whether the BC is a slow charger or a fast charger. The distinction is based on the charge rate (also referred to as C-rate), often defined as the average charging current into the battery, divided by the nominal battery charge capacity. For current expressed in amperes and battery capacity expressed in ampere-hours, the resulting quantity is expressed in units of 1/hours or C. For example, a BC with a 100 milliamp (mA) output current charging a 1,000 milliamp-hour (mAh) battery would result in a charge rate of 0.1 C. Charging time is roughly the inverse of the charge rate, adjusted for the efficiency of the battery itself, which varies with chemistry. In the previous example, charging a battery at 0.1 C would take slightly longer than 10 hours to charge. Slow chargers are sometimes referred to as "continuous chargers" because they continuously charge the battery with no distinction between active mode and maintenance mode. Fast chargers are typically considered "terminating chargers" because they charge at high current during active mode, which terminates in maintenance mode when the battery is fully charged.

Slow, continuous-charging BCs are more commonly found in consumer products that operate infrequently and spend most of their life in maintenance mode. An example is a cordless hand-vacuum, which spends most of its life in a charging-base awaiting use. Continuous BCs provide current to the battery using the same circuit regardless of battery state and usually only monitor the battery for safety purposes, not the state of the charge. DOE considers BCs with charge rates less than 0.2 C (typically around 0.1 C) to be slow chargers. At this low charge rate, nickel-based batteries can be charged continuously without concern for excessive battery overheating or safety. Slow chargers do not typically include cutoff or monitoring circuitry. However, as the battery nears full charge and its voltage increases, the charge-control impedance used in a slow charger will cause the charging current to decrease. This reduces power consumption and lessens battery heating due to overcharging, thereby extending battery life. Slow chargers are not typically used in combination with lithium-based batteries, because of the safety concerns associated with overcharging these batteries.

Slow chargers are typically composed of a line-frequency transformer followed by a rectifier. The charger can use either a discrete resistor or the resistance or reactance of the transformer windings to control the battery charging current. The conversion losses in a slow charger are mostly the result of magnetization losses in the transformer core, resistive losses in the transformer windings or other charge-control element, and diode drops in the rectifier. In addition, slow chargers typically continue to deliver current to the battery even after it is fully charged, usually at a rate much higher than that necessary to maintain the charge lost due to battery self-discharge. The excess power is dissipated as heat in the battery. The power conversion losses identified earlier continue to have an impact in this maintenance mode, further increasing power consumption. Even in no-battery mode, when the battery is disconnected from the charger, the slow charger continues to consume power due to the transformer magnetization losses.

Fast-terminating BCs recharge a battery more quickly than continuous BCs because they provide a high-current charge while the battery can safely accept it (during active mode). For example, a cordless power drill with a rapid-charge BC uses a high current to quickly charge the battery, often in an hour. Once the battery is fully charged, the BC maintains the battery at full charge with a lower current. To determine when to charge at high current, terminating BCs monitor inputs such as battery voltage, rate of change of battery voltage, battery temperature, rate of change of battery temperature, charging time, and charging current. These inputs direct a charging regulator in the BC to adjust output current.

Thus, a battery charger that contains monitoring, cutoff, or limiting circuitry can safely charge lithium-based batteries or fast-charge nickel-based batteries. DOE considers BCs with charge rates greater than 0.2 C (typically between 0.6 C and 1 C) and containing safety circuits that monitor the battery to be fast chargers. Because of their faster charge rate, their maximum rated output power is 5 to 20 times greater than that of slow chargers, even when charging a battery of the same voltage and capacity. For this reason, fast chargers typically use switched-mode power supplies, which are smaller and lighter than line-frequency power supplies often used with slow chargers. This design difference means that the designs are susceptible to different loss mechanisms.

The two primary sources of energy consumption (and opportunities for energy savings) in fast-terminating BCs are transformers and battery monitoring circuits. First, there are conversion losses associated with switching and rectification and fixed losses due to overhead power consumption associated with the integrated circuit switching controller and the safety monitoring circuitry in a BC with a switched-mode power supply. Also, although fast chargers terminate (*i.e.*, limit charging current once the battery has reached full charge), most chargers continue to supply a small amount of maintenance current. As with slow chargers, this maintenance current and the associated conversion losses contribute heavily to maintenance-mode power consumption. Even with the battery removed, the charger continues to consume significant power due to overhead losses.

3.6 Product Classes

DOE divides covered products into classes by the type of energy used, the capacity of the product, and any other performance-related feature that justifies different standard levels, such as features affecting consumer utility. (42 U.S.C. 6295(q)) DOE then conducts its analysis and considers establishing or amending standards to provide separate standard levels for each product class. In this section, DOE summarizes the various product classes used by EISA 2007, ENERGY STAR, and the draft analysis prepared by DOE for the determination in 2007.

3.6.1 EPS Product Classes

Because output power and output voltage have the largest impact on achievable EPS efficiency, DOE considered both criteria when developing EPS product classes for its determination analysis. DOE reviewed EPS product classes developed by ENERGY STAR and those proposed by manufacturers. Version 1 of the ENERGY STAR specification only considered EPS output power; however, in interviews, manufacturers prompted DOE to consider output voltage as well.

DOE divided the EPSs under analysis into low-, medium-, and high-power units, with the boundaries at 4 and 60 watts nameplate output power. Based on manufacturer input, DOE expected EPSs in each product class to share design characteristics that would affect the cost of increasing active-mode efficiency and decreasing no-load mode power consumption. For example, DOE expected low-power switched-mode EPSs with output power of less than 4 watts not to contain a controller IC, due to the high cost of an IC in relation to the total cost of the EPS. The high proportional cost of an IC in this case would increase the cost of improving no-load power consumption.

Similarly, DOE expected EPSs with output power greater than 60 watts to be switched-mode EPSs with a two-stage circuit architecture and active power factor correction (PFC). This is because many EPSs are sold in both US and European markets, where there is a standard for power factor. Power factor correction is necessary for meeting power-factor requirements under the European Union Code of Conduct, a voluntary agreement of EPS manufacturers. Due to the global nature of the EPS market, these requirements affect the design and cost-efficiency relationship of high-power EPSs in the United States.

However, after analyzing 32 EPSs with output power less than 6 watts and 18 EPSs with output power greater than 50 watts, DOE was unable to find support for the above product class divisions (discussed further in chapter 5, Engineering Analysis). There did not appear to be clear thresholds at which manufacturers would begin to use controller ICs or PFC circuitry. Therefore, DOE did not consider EPS product classes related to these criteria, although DOE recognizes the important role of ICs and PFC in EPS design and anticipates further analysis of these criteria.

In interviews held in 2007, manufacturers also suggested that DOE differentiate the EPS product classes by output voltage in addition to output power. When comparing EPSs with the same output power, EPSs with lower output voltages have higher conduction and diode-drop losses that pose additional challenges to achieving high efficiency. Manufacturers therefore suggested that DOE further subdivide its product classes by output voltage, with a division at 12 volts, the point where the approximately 0.6-volt diode drop results in losses equal to 5 percent of the output voltage (for a switched-mode EPS with one output rectification diode), and corresponding efficiency losses. Table 3.1 presents the product classes that DOE used in its determination analysis. Again, although there is overlap between the terms, “product class A” from the DOE draft determination analysis is not related to “Class A” EPSs set forth in EISA 2007.

Table 3.1. Product Classes Used in the EPS Draft Determination Analysis.

Nameplate Output Voltage	**Nameplate Output Power**		
	<4 watts	**4–60 watts**	**>60 watts**
<12 volts	A	B	C
>12 volts	D	E	F

3.6.2 BC Product Classes

There are several capacity- and performance-related features of a BC that could be used for classification, including the charging method it uses (continuous charging versus terminating charging), the charge rate, the voltage or capacity of the battery or batteries charged, and/or the battery chemistry. When conducting the determination analysis, DOE divided battery chargers into product classes based on battery voltage. This parameter, more than any other, affects the performance and utility of the battery charger. Battery voltage has a large impact on attainable battery charger efficiency as well as the opportunities for efficiency improvement.

ENERGY STAR also created product classes for battery charging systems based on the voltage of the batteries or battery packs that they charge. The ENERGY STAR specification contains 20 product classes, divided into increments of 1.2 volts, starting at 1.2 volts to greater than 24 volts. ENERGY STAR does not distinguish between battery charging systems by charging method, charge rate, battery capacity, or battery chemistry.

Although manufacturers cannot easily exchange a fast charger for a slow one without significantly affecting consumer utility (i.e., slower charge time provides less utility), the same cannot be said of exchanging a slow charger for a fast one. In fact, exchanging a slow charger that uses a line-frequency power supply for a fast charger with a switched-mode power supply was a technology option manufacturers identified during interviews.

Additionally, class divisions based on battery voltage permitted DOE to analyze the different technological paths to energy efficiency improvement in the major categories of BCs for consumer products. Table 3.2 shows these product classes.

Table 3.2 BC Product Classes Developed for the Draft Determination Analysis

0 V through 3 V	A
>3 V through 9 V	B
>9 V through 48 V	C

3.7 Energy Efficiency Metrics

3.7.1 Using Energy Efficiency Metrics

An evaluation of the effectiveness of technology options for efficiency improvement and the tradeoffs among them depends heavily on the measures used for quantification. This section presents a brief discussion of the test procedures DOE used to measure the energy consumption of BCs and EPSs, and any issues related to the test procedures that may affect the energy conservation standards rulemaking.

Within this document, the term “energy consumption” is used loosely to refer to power dissipation or power consumption by BCs and EPSs in one of several modes. Likewise, “efficiency” can mean EPS active-mode efficiency or BC energy ratio, both discussed in the following sections. More generally, “efficiency” can also refer to the energy consumption of a BC or EPS against that of comparable devices in any of their modes.

3.7.2 Energy Efficiency Metrics for External Power Supplies

On December 8, 2006, DOE codified a test procedure final rule for EPSs in appendix Z to subpart B of 10 CFR part 430 (“Uniform Test Method for Measuring the Energy Consumption of External Power Supplies.”) DOE’s test procedure, based on the U.S. Environmental Protection Agency’s (EPA) ENERGY STAR EPS test procedure, measures active-mode efficiency and no-load-mode (standby-mode) power consumption.

Active mode conversion efficiency is the ratio of output power to input power. DOE averages the efficiency at four loading conditions—25, 50, 75, and 100 percent of maximum rated output current—to assess the performance of an EPS when powering diverse loads. DOE also measures the power consumption of the EPS when disconnected from the consumer product, which is termed no-load power consumption. DOE combines both of the above metrics into “matched pairs” that describe the candidate standard levels (CSLs) used in setting potential energy conservation standards. This “matched pairs” combination affected the analysis and is discussed further in chapter 5, Engineering Analysis.

3.7.3 Energy Efficiency Metrics for Battery Chargers

On December 8, 2006, DOE adopted a test method to measure the efficiency of battery chargers. 71 FR at 71340. This test method, based on the EPA ENERGY STAR “Test Methodology for Determining the Energy Performance of Battery Charging Systems,” integrates the power consumed by BCs in maintenance and no-battery modes over fixed periods of time. This “nonactive energy” is divided by the battery energy, measured at a discharge rate of 0.2 C, resulting in an energy ratio. Normalizing by battery energy is meant to account for proportionally higher losses in chargers intended for higher energy batteries. A higher energy ratio represents higher nonactive power dissipation in the BC – i.e., a less efficient battery charger.

3.8 Technology Options for Efficiency Improvement

3.8.1 EPS Technology Options

DOE considered seven technology options for the determination analysis that may improve the efficiency of EPSs:

- *Improved Transformers.* In line-frequency EPSs, the transformer has the largest effect on efficiency. Transformer efficiency can be improved by replacing their cores and windings with ones made of lower-loss material or adding extra material. Section 3.8.3 elaborates on transformers further.

- *Switched-Mode Power Supply*. Line-frequency EPSs often use linear regulators to maintain a constant output voltage. By using a switched-mode circuit architecture, a designer can limit both losses associated with the transformer and the regulator. The differences between the two EPS types are discussed in section 3.4.4 and section 3.4.5.

- *Low-Power Integrated Circuits.* The efficiency of the EPS can be further improved by substituting low-power IC controllers to drive the switching transistor, which can switch more efficiently in active mode and reduce power consumption in no-load mode. For instance, the IC can turn off its start-up current (sourced from the primary side of the power supply) once the output voltage is stable. This increases conversion efficiency and decreases no-load power consumption. In addition, when in no-load mode, the IC can turn off the switching transistor for extended periods of time (termed "cycle-skipping").

- *Schottky Diodes and Synchronous Rectification*. Both line-frequency and switched-mode EPSs use diodes to rectify output voltage. Schottky diodes and synchronous rectification can replace standard diodes to reduce rectification losses, which are increasingly significant at low output voltage. Section 3.8.4 elaborates on rectification further.

- *Low-Loss Transistors*. The switching transistor dissipates energy due to its drain-to-source resistance (R_{DS_ON}) when the current flows through the transistor to the transformer. Using transistors with low R_{DS_ON} can reduce this loss.

- *Resonant Switching.* In addition to reducing the R_{DS_ON} of the transistor, power consumption can be lowered further by the IC controller decreasing switching transients through zero-voltage or zero-current switching. The power consumption of the transistor is influenced by the voltage across the R_{DS_ON} and the current flowing through it. An IC can control the switching to minimize that voltage or current, although some components in addition to the IC may also be needed.

- *Resonant ("Lossless") Snubbers*. In switched-mode EPSs, a common snubber protects the switching transistor from the high voltage spike that occurs after the transistor turns off by dissipating that power as heat. A resonant or lossless snubber recycles that energy rather than dissipating it.

3.8.2 BC Technology Options

These EPS technology options can also benefit BCs. Following is a list of four preliminary technology options that DOE studied for the determination analysis that apply to BCs in particular.

- *Termination*. Substantially decreasing the charge current to the battery after it has reached full charge, either by using a timer or sensor, can significantly decrease maintenance-mode power consumption. Most fast chargers use this technology option, but many slow chargers do not. Because most slow chargers have a charge rate of approximately 0.1 C and maintenance-mode current below 0.05 C is typically sufficient to keep a battery fully charged, a slow charger that employs termination can roughly halve its maintenance-mode power consumption.

- *Elimination/Limitation of Maintenance Current*. Constant maintenance current is not required to keep a battery fully charged. Instead, the BC can provide current pulses to "top off" the battery as needed. Elimination or limitation of maintenance can decrease maintenance-mode power consumption even further and has the added benefit of extending the battery lifetime by reducing overcharge.

- *Elimination of No-Load Current*. A mechanical AC line switch inside the battery charger "cup" automatically disconnects the BC from the mains supply when the battery is removed from the charger. Although manual (*i.e.*, user-controlled) switches are also possible, this method guarantees that the BC ceases to consume power once the battery is removed from the battery charger.

- *Phase Control to Limit Input Power*. Even when a typical BC is not delivering its maximum output current to the battery, its power conversion circuitry continues to draw significant power. A phase control circuit, like the one present in most common light dimmers, can be added to the primary side of the BC power supply circuitry to limit input current in lower-power modes. This technology option is particularly applicable to fast chargers that have high maximum output current.

3.8.3 Transformers

For line-frequency BCs and EPSs, the largest losses are in the transformer, particularly at light loads. The most effective means to reduce transformer power loss at light loads is to select a transformer with higher quality core material and a lower level of magnetic induction. At line frequency, the transformer core material typically is thinly laminated steel alloyed with silicon. The amount of silicon affects the core power loss and the cost of the transformer. Core performance is enhanced by magnetically orienting the grain structure in the metal. The industry standard for common non-oriented grain-structure core material ratings range from M19 to M45, with the lower number having fewer electrical losses. M6 core steel is used in an energy efficient EPS transformer because it is a high-quality grain-oriented core steel that has very low electrical losses.

The second important factor contributing to core loss is the level of magnetic induction. Core losses are measured in watts per pound (W/lb), and induction is given in kilogauss (kG). Induction levels in these devices typically range between 10 kG and 15 kG. Reducing the induction level will reduce the core losses, but increase the winding losses. Reducing the induction requires more wire turns and therefore a larger core for a given power rating. The trade-off of these improvements is the increased size and weight of the transformer, and ultimately the EPS. Table 3.3 shows the effects of material type and induction on core loss. Power loss in the transformer core can be reduced by an order of magnitude by increasing the quality of the core steel and reducing the level of magnetic induction: 0.28 W/lb versus 3.1 W/lb.

Table 3.3 Quality of Core Steel and Level of Magnetic Induction

Steel	**Core Losses at Various Levels of Magnetic Induction**		
	10 kG	12 kG	15 kG
M6	0.28 W/lb	0.40 W/lb	0.60 W/lb
M19	0.85 W/lb	1.2 W/lb	2.0 W/lb
M45	1.4 W/lb	1.9 W/lb	3.1 W/lb

Additionally, some primary transformer windings have high resistance to prevent failure in the case of overload conditions. Using a separate fuse or thermal cutout to prevent failure would allow the transformer to have a lower winding resistance, thus reducing electrical losses.

A large potential source of energy loss in a high-frequency EPS is the flyback choke, similar to the transformer in line-frequency EPSs. Methods of improving the energy efficiency of chokes are similar to those for improving transformers, that is, improving the core material and increasing the amount of copper to reduce copper losses.

Particularly, for EPSs with output power greater than 10 W, a switched-mode power supply is generally a more efficient alternative to a line-frequency. At lower wattages, however, neither regulation technology has a clear efficiency advantage. This is partly because the switching regulator circuit components themselves consume some energy, regardless of the output power of the device. At lower wattages, this fixed energy consumption is a more significant proportion of total EPS energy consumption.

3.8.4 Diode Losses and Synchronous Rectification

Diodes are another source of loss for DC line-frequency EPSs. These losses increase as the output voltage decreases, and become particularly significant below 12 V. The power consumed by a diode is the product of the current flowing through the diode multiplied by the voltage drop across it. When a line-frequency EPS is designed for low-output voltage, that drop becomes a significant portion of the overall losses in the EPS. Using Schottky diodes[c] reduces the voltage drop across the diodes, thus improving efficiency. Conventional diodes have a voltage drop of about 0.6 V, which can be reduced to about 0.3 V to 0.4 V by using Schottky diodes.

Synchronous rectification offers even lower losses by replacing diodes with transistors. In this situation, the transistor mimics the rectification effect of the diode. However, the loss across the source-to-drain resistance of the transistor is much lower than that of a diode. Typically, synchronous rectification replaces diodes on the secondary side of the transformer in switched-mode EPSs because that is where it offers the most energy savings.

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[c] A Schottky diode is a metal-semiconductor diode with a smaller voltage drop than a conventional diode, therefore consumes less power.

CHAPTER 4. SCREENING ANALYSIS

LIST OF TABLES

4.1 Introduction

The purpose of the screening analysis is to identify and eliminate any technology options that DOE will not consider in the rulemaking for BCs and EPSs. For the determination analysis, DOE began with the technology options presented in the technology assessment (chapter 3), which were developed following consultations with industry, technical experts, and other interested parties, and by reviewing the available literature. Before considering the technology options in the engineering analysis (chapter 5), DOE reviewed each technology option or best available technology in light of the following four criteria, as adapted from sections 4(a)(4) and 5(b) of the Process Rule[1]:

1. Technological feasibility. DOE will not consider technologies that are not incorporated in commercially available products or working prototypes.

2. Practicability to manufacture, install, and service. If DOE determines that mass production of a technology in commercial products and reliable installation and servicing of the technology could not be achieved on the scale necessary to serve the relevant market by the time of the effective date of the standard, it will not consider that technology further.

3. Adverse impacts on product or equipment utility or availability. If DOE determines that a technology has significant adverse impact on the utility of the product to significant subgroups of consumers, or results in the unavailability of any covered product type with performance characteristics (including reliability), features, size, capacities, and volumes that are substantially the same as products generally available in the United States at the time of the rulemaking, it will not consider that technology further.

4. Adverse impacts on health or safety. If DOE determines that a technology will have significant adverse impacts on health or safety, it will not consider that technology further.

This chapter discusses all the technology options DOE considered for improving the energy efficiency of BCs and EPSs, and describes how DOE applied the screening criteria. Technology options that were not screened out through this process were termed “design options” and became instrumental to the development of cost-efficiency curves in the engineering analysis.

4.2 Technology Options for Improving BC and EPS Efficiency

The technology options for improving BC and EPS efficiency, previously identified in chapter 3, are listed again in Table 4.1 for convenience. As noted in chapter 3, BCs contain a power supply, either external or internal, for converting high-voltage AC wall current to low-voltage DC, necessary for charging the battery. Therefore, because many of the technology options are general improvements to power supply efficiency, they are applicable to both BCs and EPSs.

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[1] 10 CFR part 430, subpart C, appendix A.

Table 4.1. Technology Options for Improving BC and EPS Efficiency

Technology Option	Area of Improvement	Applicability (BC or EPS)
Improved Transformer Cores	Magnetization Losses	BC, EPS
Improved Transformer Windings	Conduction Losses	BC, EPS
Switched-Mode Power Supply Architecture	General	BC, EPS
Low-Power Integrated Circuit (IC) Controllers	General	BC, EPS
Schottky Diode Rectifiers	Rectification Losses	BC, EPS
Synchronous Rectification	Rectification Losses	BC, EPS
Low-Loss Transistors	Switching Losses	BC, EPS
Resonant Switching	Switching Losses	BC, EPS
Resonant Snubbers	Switching Losses	BC, EPS
Charge Termination	Non-Active BC Losses	BC
Elimination or Limitation of Maintenance Current	Non-Active BC Losses	BC
Elimination of No-Battery Current	Non-Active BC Losses	BC
Primary-Side Phase Control	Non-Active BC Losses	BC

4.3 Design Options Not Screened Out of the Analysis

In the subsections that follow, these technology options are evaluated as design options based on the four screening analysis criteria.

4.3.1 Improved Transformer Cores

In line-frequency power supplies, whether for BC or EPS applications, the transformer has the largest effect on efficiency. Even in switched-mode power supplies, gains in efficiency can be made by improving the core of the high-frequency choke, a component with a similar structure and function as the transformer. In either case, DOE found that efficiency can be improved by replacing cores with ones made of lower-loss material.

DOE did not screen out improved cores as a means of improving efficiency. Because this design technique is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with improved cores. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with improved cores.

4.3.2 Improved Transformer Windings

Besides the core, a transformer or choke also consists of windings. These are typically composed of long lengths of thin copper wire, which contribute significant resistance. As explained in chapter 3, increasing the thickness of the wire is one method of decreasing the losses due to winding resistance.

DOE did not screen out improved windings as a means of improving efficiency. Designers routinely vary winding resistance to meet specifications. Because this design technique is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with improved windings. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with improved windings.

4.3.3 Switched-Mode Power Supply Architecture

Despite improvements that can be made to line-frequency designs, the topology is fundamentally limited in efficiency. By redesigning the power supply to use a switched-mode circuit architecture, a designer can limit losses associated with both the transformer and the linear regulator that is typically used in line-frequency designs.

DOE did not screen out switched-mode architectures as a means of improving efficiency. Despite the fact that a switched-mode architecture represents a complete redesign of the power supply, it is becoming increasingly common even in lower-power applications, where its smaller size promotes mobility. Because this design technique is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. Although DOE received input during the determination analysis about some applications whose usability was affected by lower output current limits and lesser electromagnetic compatibility of switched-mode EPS designs, DOE does not regard these as insurmountable obstacles to the adoption and commercialization of this technology option. DOE is not aware of any adverse impacts on health or safety that might be associated with a change to switched-mode architecture.

4.3.4 Low-Power Integrated Circuit Controllers

The efficiency of the EPS can be further improved by substituting in low-power integrated circuit (IC) controllers, which can switch more efficiently in active mode and reduce power consumption in no-load mode.

DOE did not screen out low-power IC controllers as a means of improving efficiency. IC manufacturers offer numerous low-power controllers for use in BCs and EPSs, and many designs already incorporate these components. Because it is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with low-power controllers. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with low-power IC controllers.

4.3.5 Schottky Rectifier Diodes

Except for limited applications that require an AC output, both line-frequency and switched-mode power supplies use rectifier diodes to convert the AC output of the transformer to DC, usable by the application. Schottky diodes, which have lower voltage drops, can replace standard p-n junction diodes to reduce rectification losses, which become increasingly significant at lower output voltages.

DOE did not screen out Schottky diodes as a means of improving efficiency. These devices are commonly used in BCs and EPSs with lower output voltages. Because it is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with Schottky diodes. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with Schottky diodes.

4.3.6 Synchronous Rectification.

Synchronous rectification, only used in switched-mode power supplies, further reduces losses by substituting transistors for the rectifying diodes. The voltage drop across a transistor is much lower than that across even a Schottky diode, leading to lower losses in the output rectifier.

DOE did not screen out synchronous rectification as a means of improving efficiency. Despite its high cost and complexity of implementation, synchronous rectification is available today and is used in EPSs when the application merits it. Because it is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with synchronous rectification. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with synchronous rectification.

4.3.7 Low-Loss Transistors

The transistor in a switched-mode power supply dissipates energy because of its drain-to-source resistance (R_{DS_ON}) when the current flows through the transistor to the transformer. Using transistors with low R_{DS_ON} can reduce this loss.

DOE did not screen out low-loss transistors as a means of improving efficiency. Switching transistors continually improve, providing options for increasing efficiency with little added design complexity. Because it is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with low-loss transistors. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with low-loss transistors.

4.3.8 Resonant Switching

In addition to reducing the R_{DS_ON} of the transistor, power consumption can be lowered further by the IC controller decreasing switching transients through zero-voltage or zero-current switching, which greatly limits losses due to switching transients in the transistor.

DOE did not screen out resonant switching as a means of improving efficiency. Resonant switching does involve some additional circuit complexity, but is a common method of increasing efficiency. Because it is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with resonant switching. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with resonant switching.

4.3.9 Resonant Snubbers

In switched-mode EPSs, a snubber protects the switching transistor from the high voltage spike that occurs after the transistor turns off. Whereas a conventional snubber dissipates the energy in the voltage spike as heat, a resonant or lossless snubber recycles that energy, leading to lower losses.

DOE did not screen out resonant snubbers as a means of improving efficiency. As with resonant switching, resonant snubbers involve some additional circuit complexity, but are a common method of increasing efficiency. Because it is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with resonant snubbers. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with resonant snubbers.

4.3.10 Termination

Substantially decreasing the charge current delivered by the BC to the battery after it has reached full charge, either by using a timer or sensor, can significantly decrease maintenance-mode power consumption. Whereas fast chargers already universally employ this technology option for safety reasons, many slow chargers do not, and wider popularity could lead to increased energy savings.

DOE did not screen out termination as a means of improving efficiency. While termination may require redesign and significant circuit cost in the case of slow chargers, it is already universal in fast chargers. Because it is in commercial use today, DOE considered this technology option to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with termination. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with termination.

4.3.11 Elimination or Limitation of Maintenance Current

Constant maintenance current is not required to keep a battery fully charged. Instead, the BC can provide current pulses to "top off" the battery as needed. Elimination or limitation of maintenance can further decrease maintenance-mode power consumption.

DOE did not screen out elimination or limitation of maintenance current as a means of improving efficiency. While this technology may add some circuit complexity in the form of timers or sensors, DOE did not consider the added design difficulty insurmountable. Unlike many of the other technologies, elimination or limitation of maintenance current is not widespread today, but several manufacturers have suggested it as an option for further eliminating maintenance current. Because manufacturers familiar with the intricacies of BC design identified this technology, DOE considered it to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with limitation of maintenance-mode current, and in some applications complete elimination of the current may be possible. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with the elimination or limitation of maintenance-mode current.

4.3.12 Elimination of No-Battery Current

A mechanical AC line switch inside the charger "cup," or charging base, automatically disconnects the BC from the mains supply when the battery is removed from the charger, thereby eliminating no-battery power consumption without incurring energy consumption penalties in any of the other modes.

DOE did not screen out elimination of no-battery current as a means of improving efficiency. Although AC line switches are not in widespread use today, the fundamentals of this technology option are simple and DOE considered it to be both technologically feasible and practicable to manufacture, install, and service. DOE considered, but was not aware of any adverse impacts on consumer utility or reliability associated with elimination of no-battery current. Similarly, DOE was not aware of any adverse impacts on health or safety that might be associated with elimination of no-battery current.

4.3.13 Phase Control to Limit Input Power

Even when a typical BC is not delivering its maximum output current to the battery, its power conversion circuitry continues to draw significant power. A phase control circuit, like the one present in most common light dimmers, can be added to the primary side of the BC power supply circuitry to limit input current in lower-power modes.

DOE did not screen out phase control as a means of improving efficiency. Similar to AC line switches, this technology option is not in widespread use today, but it is well understood and common in other applications outside of BCs and EPSs. DOE therefore considered it to be both technologically feasible and practicable to manufacture, install, and service. DOE considered but is not aware of any adverse impacts on consumer utility or reliability associated with elimination of no-battery current. Similarly, DOE is not aware of any adverse impacts on health or safety that might be associated with elimination of no-battery current.

4.4 Conclusion

Because all of the technology options summarized in Table 4.1 met the four screening criteria, none were eliminated in the screening analysis. DOE therefore evaluated all of the technology options as design options in the engineering analysis described in chapter 5.

CHAPTER 5. ENGINEERING ANALYSIS

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5.1 Introduction

The purpose of the engineering analysis is to determine the relationship between a power converter's efficiency and its manufacturer selling price (MSP).[1] This relationship serves as the basis for the underlying costs and benefits to individual consumers (chapter 8, life-cycle cost analysis) and the nation (chapter 10, national impact analysis). The output of the engineering analysis provides the MSP at selected, discrete levels of efficiency for several "representative" BCs and EPSs. The levels are termed candidate standard levels (CSLs). This chapter details the development of this portion of the rescheduled determination analysis, which DOE conducted in 2007, and includes descriptions of the analysis structure, inputs, and some draft outputs for stakeholder review and comment.

Representative product classes and units allow DOE to focus on a few specific power converters and expand that knowledge to all units. Thus, DOE began the engineering analysis by identifying the representative product classes and selecting one representative unit for analysis from each of the representative product classes. The representative product classes, a subset of the product classes identified in chapter 3, contain the majority of the covered devices available in the market. The representative units, in turn, are idealized models of the most popular or typical devices within the representative product classes. Representative units are defined partly by specifications on output power and/or voltage.

During the determination analysis, DOE presumed that findings relating to the representative unit would be applicable to all the units in the product class. Later, in the national impact analysis (NIA), DOE scaled the analytical findings for each representative unit to other units in the same representative product class, and from the representative product classes to other product classes that DOE did not explicitly analyze. See section 5.2 for a description of representative product classes and units used in the determination analysis.

Although the efficiency of power converters in the market forms an almost continuous spectrum, DOE focused its analysis at several discrete CSLs (described in section 5.3). In the engineering analysis, DOE examined the cost of meeting each CSL for each representative unit. The resulting relationship, which followed a path of increasing cost with increasing efficiency, was termed an "engineering curve" or "cost-efficiency curve."

The analysis began with the baseline CSL, which models the most common, cheapest, least-efficient devices in a product class, and ended with the maximum technologically feasible ("max-tech") CSL, which is typically the most expensive. To construct engineering curves for the determination analysis conducted in 2007, DOE relied on manufacturer interviews as its primary source of data, structuring the collection of this data around the interview guide presented in appendix 5.A.

In its interviews, DOE asked manufacturers to speculate on the costs of improving each representative unit from the baseline CSL to the maximum technologically feasible CSL. DOE also asked manufacturers to describe the markups they would be likely to apply to the cost of

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[1] This is the price that a power converter manufacturer charges original equipment manufacturers, distributors, and/or retailers. The MSP forms the basis for the price consumers eventually pay.

production, resulting in a manufacturer selling price to distributors, original equipment manufacturers (OEMs), or retailers. For a detailed discussion of the interview process, see section 5.4. To validate the information provided by manufacturers, DOE performed its own testing and teardowns.

In addition to obtaining information through manufacturer interviews, DOE developed a range of possible costs of production, beginning with component costs. DOE then applied markups to arrive at an MSP. The process of evaluating the cost of a BC or EPS started with DOE conducting efficiency tests of commercially available BCs and EPSs, followed by teardowns, parts counts, and preparation of bills of materials (BOMs). DOE then scaled these BOM costs to account for the lower prices paid by manufacturers purchasing at higher volumes.

Following the teardowns, and in cases when manufacturers provided BOM costs rather than MSPs, DOE applied typical manufacturer markups to the resulting high-volume BOM cost to account for additional manufacturer costs not included in the BOM. The manufacturer markups included (1) a production markup, (2) an add-on for packaging and mechanical components, and (3) a non-production markup. The result of this markup chain was an MSP, which could be compared against the prices provided directly by manufacturers. Throughout this process, DOE consulted publicly available literature and datasets, which served as a third type of validation. For detailed discussion of testing and teardowns, see section 5.5.

5.2 Selection of Representative Product Classes and Representative Units

5.2.1 BC Representative Product Classes and Representative Units

Each product class discussed in chapter 3 was represented by a unit that served as the focus of the analysis, except for product class C, which was represented by two units. Although fast chargers exist in all three BC product classes, they are particularly prevalent in high-voltage power-tool chargers, so DOE decided to split the analysis of the high-voltage product class C by charge rate. Table 5.1 shows the characteristics of the representative units. DOE chose these units because they represent high-volume BCs within each of the BC product classes. The engineering analysis that DOE performed on each of these units served as the basis for subsequent analyses of the impacts of potential energy conservation standards on consumers and the Nation.

Table 5.1 Representative Unit Characteristics for Battery Chargers

Product Class	Battery Voltage	Battery Capacity	Charge Rate	Typical Application
A	1.2 V	1.2 Ah	0.1 C	Shaver
B	4.8 V	1.2 Ah	0.1 C	Vacuum
C	18 V	1.5 Ah	0.15 C	DIY* tool
C	18 V	2.4 Ah	1 C	Pro tool

* Do-it-yourself (DIY) tools are typically purchased by non-professional users.

The efficiency of BCs is affected by other parameters besides battery voltage, battery capacity, and charge rate. These other parameters include the length of the DC output cord (if one exists) and venting, among others. Again, to isolate the impacts of efficiency on cost, these parameters were fixed throughout the analysis to the values listed in Table 5.2.

Table 5.2 Additional Characteristics of BC Representative Units

Parameter	Value
Input Voltage	115 volts rms, 60 Hz
Input Protection	Primary current fuse
Unit Volume	200,000 units/year
Packaging	Sealed plastic
Cord Length	6 feet
Regulatory Compliance	UL, FCC
Product Lifetime	> 2 years

5.2.2 EPS Representative Product Classes

Initially, DOE divided EPSs into six product classes, presented in chapter 3. These classes were based on output power and voltage because of the impact these design parameters have on the efficiency of an EPS. Following further discussion with manufacturers, DOE narrowed its focus within the list of the six product classes to three representative product classes. While the six EPS product classes were based on output power and voltage, the three representative product classes, presented in Table 5.3, were based solely on output power. DOE chose these representative product classes and criteria for division because manufacturers design “families” of EPSs with the same output power, but different output voltages. Therefore, for a given output power, low-voltage and high-voltage EPSs share the same design, often differing only in the choice of component values. Because of this similarity in design, there is a functional relationship between the efficiency achievable by units of different output voltage. Therefore, DOE did not perform a differential analysis of separate voltage-based representative product classes.

Table 5.3 Representative Product Classes Used in the EPS Determination Analysis

	Nameplate Output Power		
	< 4 watts	**4–60 watts**	**> 60 watts**
Product Class	A	B	F

5.2.3 EPS Representative Units

For each of the three representative EPS product classes described in section 5.2.2, DOE identified a representative unit for evaluation in the engineering analysis. A representative unit is an idealized EPS that shares the design specifications of popular EPS in the product class. Using these idealized units allows DOE to vary the active mode efficiency and no-load current while holding all other parameters (*e.g.*, nameplate output power, voltage, safety requirements, etc.) constant.

The representative units for each of the three representative product classes discussed previously are listed in Table 5.4. These units model typical EPSs that ship with high-volume applications, such as laptop computers or video-game consoles, in the case of the 90-watt, 19-volt representative unit for product class F.[2]

Similarly, the other EPS representative units model typical nameplate output power and voltage combinations for other high-volume products. DOE chose the representative unit for product class A to represent a typical wall adapter for a cellular telephone, the consumer product associated with the highest volume of EPS sales. DOE chose product class B's representative unit to be characteristic of mid-power applications such as modems or wireless routers.

Although DOE recognizes that laptop computer EPSs span a wide range of nameplate output powers and voltages, 90 watts is near the shipment-weighted average output power for the product class, while 19 volts is a common output voltage. Similarly, the nameplate output powers and voltages of the other representative units are also typical, with the output powers falling near the shipment-weighted averages for each class.

Table 5.4 External Power Supply Representative Unit Characteristics

Representative Product Class	Output Power (W)	Output Voltage (V)	Typical Application
A	2.75 W	5 V	Cellular Telephone
B	18 W	12 V	Modem
F	90 W	19 V	Laptop Computer

In addition to output current and voltage, manufacturers and customers specify other EPS parameters to ensure safe compatibility of the EPS design with the product it is meant to power. These other parameters, like output cord length, input protection, or transient response, can also have an impact on EPS efficiency and no-load power. Therefore, when conducting the engineering analysis, DOE fixed these parameters to eliminate certain design options, such as a shorter output cord, that might negatively affect the usability or interoperability of the EPS.

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[2] The associated framework document includes a discussion of the BC and EPS definitions and how they would be applied to a battery powered product, such as a laptop computer, that uses an external wall adapter. For the determination analysis, DOE used the ENERGY STAR delineation whereby wall adapters for electronic products such as laptop computers and cellular telephones were considered EPSs.

A full list of EPS design parameters that DOE fixed for isolating the impacts of efficiency is presented in Table 5.5. In addition to the usability, safety, and interoperability parameters already mentioned, the table also includes the yearly manufacturing volume at which cost information associated with efficiency improvements was obtained or calculated during the engineering analysis. A yearly manufacturing volume was also specified to permit comparisons between data from different sources, and to isolate efficiency improvement as the only variable under analysis. This volume was 1,000,000 units/year for representative unit A (due to the popularity of cellular telephones) and 500,000 units/year for the other two representative units.

Table 5.5 Additional Characteristics of EPS Representative Units

Parameter	Value
Input Voltage	115 volts rms, 60 Hz
Input Protection	Primary current fuse, inrush current limiting
Output Voltage Regulation	± 1% (excluding cord)
Output Voltage Ripple	1% maximum (peak-to-peak)
Transient Response	0.5 ms for 50% load change typical
Output Protection	Overcurrent protection, short-circuit protection
Unit Volume	1 M/year for product class A 500 k/year for product classes B & F
Application	Information technology/consumer electronics
Package	Sealed polycarbonate
Output Cord Length	6 feet
Regulatory Compliance	UL, FCC, PFC for $P_{IN} > 75$ W
Product Lifetime	> 2 years

5.3 Selection of Candidate Standard Levels

In the determination engineering analysis, selection of CSLs followed the identification of representative product classes and representative units, described in section 5.2. Although the production cost and manufacturer selling price of a unit would appear in the aggregate as a continuous function of efficiency, data for each point along the curve were not available, so DOE focused its analysis at discrete efficiency levels, or CSLs.

CSLs are generally based on (1) efficiencies achievable by commonly used design options, (2) voluntary guidelines or mandatory standards already in existence that have prompted manufacturers to develop products at particular efficiency levels, and (3) the max-tech level.[3] For example, DOE often considers the ENERGY STAR level as one CSL, while the least efficient models in a product class serve as the baseline CSL. Basing CSLs on established guidelines or standards increases the availability of data because manufacturers may have already designed products to meet the CSL, and may therefore be able to provide cost information. Furthermore, products meeting the CSL may exist in the marketplace and be available for testing and teardowns, further strengthening the analysis.

However, even if CSLs are based on design options in units currently being manufactured, they should not be seen as technologically prescriptive. In other words, manufacturers are free to use any combination of design options to achieve the efficiency specified by a given CSL. To maintain this approach throughout the analysis, DOE specifically did not examine CSLs that could only be achieved through proprietary design options not available to all manufacturers.

5.3.1 BC Candidate Standard Levels

As described in chapter 3, the DOE test procedure references the U.S. Environmental Protection Agency's (EPA) ENERGY STAR "Test Methodology for Determining the Energy Performance of Battery Charging Systems," which combines measurements of maintenance and no-battery mode power consumption into an integrated metric called the energy ratio. Manufacturers are free to trade off power consumption in one mode versus the other to meet the energy ratio requirements imposed by each CSL. The CSLs DOE used in the BC determination analysis are presented in Table 5.6.

As the table shows, DOE did not analyze the cost-efficiency relationship at the max-tech CSL due to a lack of data. Instead, DOE increased the level of detail by analyzing data at efficiency levels between such established CSLs as ENERGY STAR and baseline. Because DOE initially obtained data on a more limited set of CSLs, DOE calculated cost-efficiency data at these additional levels through interpolation.

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[3] The max-tech level represents the most efficient design that has been demonstrated in a prototype with materials or technologies available today. Max-tech is not constrained by economic justification, and typically is the most expensive design option considered in the engineering analysis.

Table 5.6 BC Candidate Standard Levels by Representative Unit

CSL		Energy Ratio Representative Product Class A 1.2 V, Slow	Representative Product Class B 4.8 V, Slow	Representative Product Class C 18 V, Slow	Representative Product Class C 18 V, Fast
0	Baseline	66.5	14.0	13.0	13.0
1	Above Baseline	27.9	12.3	5.5	5.5
2	ENERGY STAR	22.0	11.6	3.8	3.8
3	Beyond Standard	15.0	6.3	2.5	2.5
4	Best-in-Market Technology	8.8	4.5	1.5	1.5

5.3.2 EPS Candidate Standard Levels

The CSLs in the determination analysis were specified in terms of DOE’s efficiency metrics for EPSs (active mode efficiency and no-load power) and BCs (energy ratio). Because both of the efficiency metrics output by the EPS test procedure affect the energy consumption of the unit, DOE developed CSLs that included “matched pairs” of limits on both metrics simultaneously.

Matched pairs allowed DOE to base CSLs on existing EPS standards, such as those developed by ENERGY STAR or the California Energy Commission (CEC). As these CSL matched pairs progress from least to most efficient, either the active mode efficiency or no-load power-consumption requirements, or both, increase in stringency. By preventing a decrease in the stringency of these metrics, DOE makes a tacit assumption that there is no trade-off between EPS performance in the two modes, and increasing the energy savings in one mode does not necessarily cause a decrease in energy savings in the other.

To verify this assumption, DOE analyzed the relationship between active mode efficiency and no-load power consumption for products currently in the market. Figure 5.1 plots efficiency measurements conducted by DOE on EPSs with nameplate output power around 5 watts and 60 watts. The figure shows that EPSs with higher active mode efficiencies tend to also have lower no-load-mode power consumption. This is probably true only up to a point, however, and one can imagine cases in which an EPS manufacturer tries to minimize no-load power, but can only do so at the expense of lower active mode efficiency. Therefore, DOE based its matched pairs on those currently seen in the market. The CSLs followed—as much as possible—the efficiency metrics achieved by actual EPSs at representative-unit output powers and voltages. This ensured that for CSLs below max-tech, current EPSs would be able to meet both active mode and no-load-mode requirements.

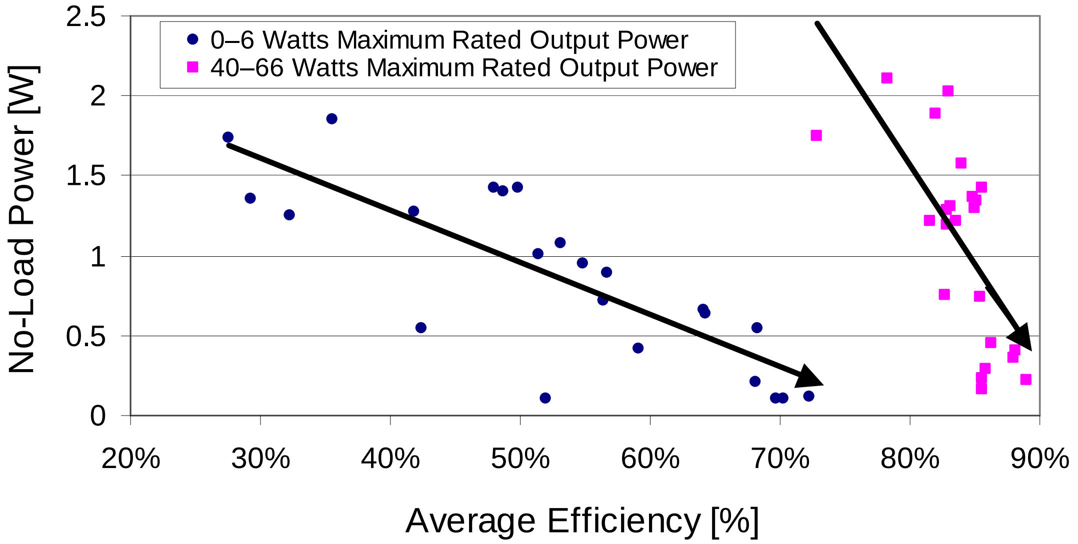

Figure 5.1 Comparison of Active Mode Efficiency and No-Load Power; Arrows Point in Direction of Increased Efficiency

DOE evaluated the relationship between EPS cost and efficiency for each representative unit at seven CSLs:

- CSL 0: baseline line-frequency
- CSL 1: baseline switched-mode
- CSL 2: meeting CEC Tier 1
- CSL 3: meeting CEC Tier 2
- CSL 4: surpassing CEC Tier 2
- CSL 5: best in market
- CSL 6: maximum technologically feasible

In each case, the name of the CSL refers to the standard upon which the CSL is based, or indicates the types of EPSs that can generally meet the CSL. For example, switched-mode EPSs that contain conventional integrated circuit (IC) pulse-width modulation (PWM) controllers without any specific provisions for efficiency are likely to meet CSL 1 (baseline switched-mode), but not CSL 2.

The active mode efficiency and no-load power requirements corresponding to each CSL are listed in Table 5.7. As can be seen, even though the names of the CSLs are the same for each representative unit, they correspond to different active mode efficiencies and no-load power consumptions. This is because of technological and scaling differences between the representative units, highlighted in chapter 3. For example, the EPS design a conventional PWM controller (CSL 1) may only achieve 71% efficiency and 1.5 watts of no-load power consumption at 18 watts and 12 volts, but it should be able to achieve 78% and 2 watts of no-load power when redesigned for 90 watts and 19 volts. DOE did not analyze representative unit F at CSL 0 due to a lack of high-power EPSs that use a linear-regulated line-frequency design.

Table 5.7 EPS Candidate Standard Levels by Representative Unit

	Representative Unit A 2.75 W, 5 V		Representative Unit B 18 W, 12 V		Representative Unit F 90 W, 19 V	
CSL	**Minimum Efficiency (%)**	**Max. No-Load Input Power (W)**	**Minimum Efficiency (%)**	**Max. No-Load Input Power (W)**	**Minimum Efficiency (%)**	**Max. No-Load Input Power (W)**
0	30	2.00	66	2.00	n/a	n/a
1	55	0.80	71	1.50	78	2.00
2	58	0.50	75	0.75	84	0.75
3	59	0.50	76	0.50	85	0.50
4	65	0.40	80	0.40	87	0.40
5	72	0.30	85	0.20	89	0.31
6	75	0.20	88	0.15	92	0.15

5.4 Manufacturer Interviews

DOE interviewed eight BC and eight EPS manufacturers to obtain price estimates for representative units at the CSLs listed in Table 5.7 and Table 5.6. Following aggregation and validation, this price information was combined with efficiency data to form one of the key outputs of the engineering analysis.

The interviews were structured according to the manufacturer surveys presented in appendices 5.A and 5.B. In the course of the interview, DOE contractors asked manufacturers to provide the costs of reaching each CSL for each representative unit. Manufacturers listed the least expensive technology options that met the CSLs and their costs, either as a BOM cost or the marked-up MSP.

Although manufacturers were initially asked about a more limited set of CSLs than those listed in Table 5.7 and Table 5.6, they provided additional information on the costs at other efficiency levels. Additional CSLs were developed later by fitting curves to data obtained during the interviews and interpolating between the points. These CSLs enabled greater resolution in the downstream analyses.

A further caveat was that manufacturers sometimes provided data for products with parameters close to, but not the same as, the representative units. This occurred when manufacturers had direct experience with a similar unit and could provide cost and efficiency data with greater confidence than for the idealized representative unit. In these cases, DOE scaled the data the manufacturer provided to align with the representative unit. Although DOE could have requested that the manufacturer perform the scaling from manufacturer-supplied unit to the representative unit, some manufacturers were reluctant to make statements about BCs or EPSs they had designed. By performing the scaling itself, DOE could also use a consistent and transparent method.

For example, some manufacturers provided data on EPSs that were similar to the representative units in terms of capacity, functionality, and design, but had slightly different output power or output voltage. DOE then used typical relationships between power and efficiency or voltage and efficiency to adjust the efficiency data so that it would apply to the representative unit. This normalization accounted for any differences in output power, output voltage, volume, and other characteristics, and permitted aggregation of all the manufacturers' cost-efficiency data. Sections 0 and 5.4.9 present the normalization methods for BCs and EPSs, respectively.

5.4.1 BC Manufacturer Interview Overview

Under non-disclosure agreements, DOE interviewed representatives of several consumer-product firms that manufacture battery-powered products. Interviewers asked each representative to provide information about technology options for increasing the energy efficiency of BCs that ship with their products. The following list shows the number of manufacturers that provided data for each representative unit:

- representative product unit A (personal-care products): 3 manufacturers
- representative product unit B (small tools and floor care): 4 manufacturers
- representative product unit C (DIY power tools): 3 manufacturers
- representative product unit C (professional power tools): 3 manufacturers

Before each interview, each manufacturer received a Cost-Efficiency Estimation Survey (appendix 5.A) to guide their estimates. To ensure consistency among manufacturers, the survey specified the parameters of each BC representative unit under consideration (Table 5.1 and Table 5.2). Although battery chemistry was not specified, most manufacturers provided information for nickel-based chemistries (NiMH and Ni-Cd). Although lithium chemistries have lower self-discharge and may decrease maintenance current, DOE did not expect significant differences in BC energy consumption due to the increased safety and monitoring overhead associated with lithium batteries.

The interviewers asked manufacturers to describe the technological improvements for each representative unit and associated costs necessary to meet each CSL (section 5.3.1). Although the CSLs for battery chargers are specified in terms of energy ratio, the DOE metric of non-active energy consumption, the survey presented them as disaggregated maintenance and no-battery mode power consumption levels.[4] DOE decided to disaggregate the metrics after finding that manufacturers were more responsive to CSLs directly specified in terms of maintenance and no-battery mode power consumption.

DOE recognizes that separating the integrated energy ratio metric and asking manufacturers to meet two separate power consumption levels instead of a CSL expressed in terms of a single metric risked over-constraining the manufacturers. Because DOE was in effect asking them to estimate the costs of meeting standards on power consumption in two distinct

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[4] The energy ratio is calculated as the sum of maintenance mode power, integrated over 36 hours, and no-battery power, integrated over 12 hours, divided by the battery energy, measured under a 0.2 C discharge.

modes, there was a chance that manufacturers could not make the necessary tradeoffs between the two and meet the specified CSL at the lowest cost.

To mitigate this potential problem, DOE used typical maintenance to no-battery mode power consumption of devices currently in the market to disaggregate the energy ratio CSLs. When possible, DOE used BC test results[5] to select maintenance and no-battery mode power consumption of typical BCs that met a particular CSL. DOE then extrapolated additional data from related work on EPSs. Table 5.8 lists the resulting maintenance and no-battery mode power consumption limits for each CSL.

As will be presented later (see Figure 5.2), there is actually a moderate correlation between BC maintenance and no-battery mode power. This correlation implies that there are currently no significant tradeoffs between decreasing power-consumption in one mode versus the other, further decreasing the risk that DOE over-constrained manufacturer design options during its interviews.

Table 5.8 Maintenance and No-Battery Mode Power Consumption Levels Used in Manufacturer Interviews

	Representative Unit A		Representative Unit B		Representative Unit C		Representative Unit F	
CSL	**Maintenance Mode Power [W]**	**No-Battery Mode Power [W]**	**Maintenance Mode Power [W]**	**No-Battery Mode Power [W]**	**Maintenance Mode Power [W]**	**No-Battery Mode Power [W]**	**Maintenance Mode Power [W]**	**No-Battery Mode Power [W]**
0	0.80	0.60	1.90	0.60	6.00	1.50	4.70	2.10
1	0.70	0.50	1.70	0.50	1.50	0.80	4.00	1.80
2	0.35	0.04	1.50	0.40	1.00	0.30	3.00	1.00
3	0.10	0.01	0.50	0.05	0.30	0.10	1.20	0.10

5.4.2 BC Manufacturer Interview Responses and Preferred Design Options

Representative unit A models battery chargers for such small, low-voltage consumer product applications as shavers and beard trimmers. Because of the low battery voltage and small battery capacity, these BCs have a very low output power, and are typically composed of a line-frequency center-tapped transformer followed by a full-wave rectifier. Battery charge control is performed through current limiting with a discrete resistor or the winding resistance of the transformer.

The BC described above would charge the battery in 10 or more hours. To decrease the charge time, some manufacturers replaced the slow BC's line-frequency power supply with a switched-mode power supply, which permits the same size package to deliver higher output power, resulting in faster charging. This development also improved the efficiency of the power supply, both due to the higher efficiency of the switched-mode power supply and the need for

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[5] DOE used its own test results as well as datasets provided by Ecos Consulting (a CEC contractor) and ENERGY STAR.

termination when charging at a higher rate. A list of technology improvements that manufacturers suggested during interviews appears below.

- CSL 0: line-frequency transformer, center-tapped rectifier, standard *p-n* junction rectifier diodes, current-limiting resistor or winding resistance
- CSL 1: same design as CSL 0, but with improved transformer core, Schottky rectifier diodes
- CSL 2: switched-mode power supply
- CSL 3: switched-mode power supply with improved components
- CSL 4: not available

Representative unit B models battery chargers for household appliances, such as kitchen tools, floor-care products, and small power tools that are typically packaged with integral batteries, such as cordless screwdrivers. As for representative unit A, these devices are used infrequently enough that users do not require a fast recharge, so they typically ship with slow chargers. However, as for representative unit A, some higher-end manufacturers have begun packaging products with fast chargers, which require switched-mode power supplies and therefore tend to be more efficient than slow chargers, which use line-frequency power supplies.

According to manufacturers interviewed during the determination analysis, the technology options for improving the efficiency of representative unit B are similar to those for representative unit A. Because of the higher battery voltage of representative unit B, more power is delivered to the battery during maintenance mode, leading to higher charger power consumption during that mode. As a result, termination, or significant reduction of current into the battery during maintenance, becomes a bigger concern. Manufacturers proposed sensors and timers as a way of limiting power consumption in maintenance mode. A list of manufacturer-suggested technology options for representative unit B appears below.

- CSL 0: line-frequency transformer, center-tapped rectifier, standard *p-n* junction rectifier diodes, current-limiting resistor or winding resistance
- CSL 1: same design as CSL 0, but with improved transformer core, Schottky rectifier diodes
- CSL 2: same design as CSL 1, but with timer or other termination circuitry
- CSL 3: switched-mode power supply
- CSL 4: switched-mode power supply with improved components

Representative unit C models slow, higher-voltage BCs that typically ship with power tools for DIY use. Because the architecture of this charger is similar to representative unit B, the technology options for efficiency improvement are generally similar as well. However, due to the much higher battery voltage[6] and consequent battery charger output power, certain technology options result in much greater savings than in the case of representative unit B. For example, the amount of power delivered to the primary side of a line-frequency power supply can be controlled with the use of a phase-control circuit, limiting the power dissipated in the transformer core. A list of some of the typical technology options that manufacturers identified for representative unit C appears below.

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[6] Representative unit C has an 18-volt battery, compared to the 4.8-volt battery of representative unit B.

- CSL 0: line-frequency transformer, center-tapped rectifier, standard *p-n* junction rectifier diodes, current-limiting resistor or winding resistance
- CSL 1: same design as CSL 0, but with improved transformer core
- CSL 2: same design as CSL 1, but with timer or other termination circuitry and/or primary-side phase control
- CSL 3: switched-mode power supply
- CSL 4: switched-mode power supply with improved components, termination, and/or AC switch during no-battery mode

Representative unit D is also typically used for charging power-tool batteries. This unit differs from the power tool chargers described previously because the application—professional power tools—gets frequent use and requires frequent recharging. As a result, the BCs are fast chargers, with charge rates typically at or above 1 C.

Because the output power of a BC is directly proportional to the charge rate, professional power-tool fast chargers can have output power an order of magnitude higher than the slow chargers modeled by representative product unit C. Therefore, the following technology options differ significantly from those discussed for the other representative units:

- CSL 0: switched-mode power supply and charge controller, or line-frequency transformer followed by silicon-controlled rectifiers (SCRs)
- CSL 1: switched-mode power supply, but with improved components
- CSL 2: same design as CSL 1, but with improved power supply compensation
- CSL 3: same design as CSL 2, but with lower power consumption during maintenance mode
- CSL 4: same design as CSL 3, but with improved startup circuit, synchronous rectification, and/or automatic AC-side switch during no-battery mode

5.4.3 BC Manufacturer Interview Data Analysis

During interviews, manufacturers followed the power consumption levels contained in the survey only loosely. When responding, they typically considered a unit currently under production as the baseline, reporting its measured power consumption in maintenance, no-battery, and in some cases, active mode. They then speculated on methods for improving the baseline unit, such as improving components, adding or exchanging subcircuits, or redesigning the topology. They accompanied each set of improvements with the increased costs over the baseline as well as incremental gains in efficiency, again expressed in terms of power consumed during the three modes of operation.

DOE calculated a non-active energy ratio from the maintenance and no-battery mode power consumption provided by manufacturers. To represent active mode energy consumption, DOE used integrated, 24-hour, active and maintenance mode energy consumption that represents consumption experienced by a typical user over a 24-hour charging cycle. Manufacturers, however, expressed the active mode performance of their BCs in terms of power consumption during active mode, if at all. DOE therefore calculated the 24-hour integrated energy consumption figure using the following formula:

$$E_{24} = \frac{1}{r\eta_{CELL}} P_{ACTIVE} + (24\,\mathrm{hr} - \frac{1}{r\eta_{\mathrm{CELL}}}) P_{MAINT}\ ,$$

Eq. 5.1

where:

r is the charge rate of the BC in units of 1/hours;

η_{CELL} is the cell efficiency, assumed to be 80 percent;

P_{ACTIVE} is the power consumption of the BC in active mode while charging the battery; and

P_{MAINT} is the power consumption of the BC in maintenance mode after the battery has been fully charged.

As Equation 1 shows, DOE used the BC's charge rate to calculate the charge time, which also depends on the cell efficiency of the battery being charged. During the remainder of the 24 hours, DOE assumed the charger to be in maintenance mode. Most manufacturers, however, only provided estimates of power consumption in maintenance mode, not in active mode.

When manufacturers did not provide the active mode power consumption, DOE estimated this metric in one of two ways. If the charger was a slow charger and no additional information was available, DOE substituted the maintenance mode figure for active mode power consumption because of the lack of clear distinction between active mode and maintenance mode in slow chargers. If the manufacturer provided BC "efficiency," defined as the power delivered to the battery over the power consumed, DOE calculated the active mode power consumption from the power required to charge the battery, divided by this BC efficiency. In either case, these calculations allowed DOE to estimate the typical energy consumption of a BC in all three modes.

5.4.4 Supplements to BC Manufacturer Interview Data

Although some of the consumer-product manufacturers DOE interviewed designed BCs for their products in-house, many acquired their BCs from outside vendors. These manufacturers were therefore unable to provide detailed information about the design options necessary to meet the CSLs or even to decrease energy consumption in the three modes.

This lack of familiarity with energy efficient design prevented many manufacturers from providing detailed power consumption estimates in the three modes of BC operation. They were often able to supply only two cost-efficiency points, one before and one after the enactment of California's Title 20 appliance efficiency standards for EPSs, which affected some BCs. Because many slow BCs fell under the California Energy Commission (CEC) definition of EPSs, many manufacturers had to ensure their products complied with these standards, which went into effect July 1, 2007.

Nonetheless, the burden of redesigning for compliance remained with the outside BC vendors, and some of the manufacturers interviewed could not offer more detail than the CEC compliance status of the wall adapter. Where manufacturers could not provide detailed efficiency data, DOE sought to acquire the specific units described by the manufacturer, performing efficiency tests and using that information to fill in gaps in the data.

When DOE could not purchase the requisite BC and therefore no direct substitution of measurement results was possible, DOE averaged the performance of the wall adapter components of other BCs in its test database that were in the same product class. DOE then paired these averages with the manufacturer costs to arrive at an estimate of the manufacturer's cost-efficiency relationship.

Table 5.9 Product Class-Average BC Wall Adapter No-Load Power Consumption

Product Class	Voltage Range	Non-CEC Compliant		CEC Compliant	
		Number of Adapters	Class-Average No-Load Power [W]	Number of Adapters	Class-Average No-Load Power [W]
A	0 V–3 V	4	0.93	0	–
B	3 V–9 V	20	0.81	6	0.15
C	9 V–36 V	4	1.13	2	0.35

Manufacturers, however, only specified whether the BC's wall adapter component had met the CEC EPS standard based on its active mode efficiency and no-load power, as measured by the EPS test procedure. Because nothing more was known about these units, DOE had to extrapolate from the wall adapter to the entire BC system, by estimating the energy consumption in all three BC modes based on the average BC wall-adapter no-load power consumption in Table 5.9.

Figure 5.13 shows, however, that no-load power consumption is a fairly good predictor of battery charger power consumption in no-load and maintenance modes. DOE therefore used the relationship between the two metrics to estimate class-average no-load- and maintenance mode power consumption for pre- and post-CEC BCs. Again, because these were slow chargers without a clear distinction between maintenance and active modes, DOE substituted maintenance mode power consumption for active mode power consumption. The resulting three average metrics appear in Table 5.10.

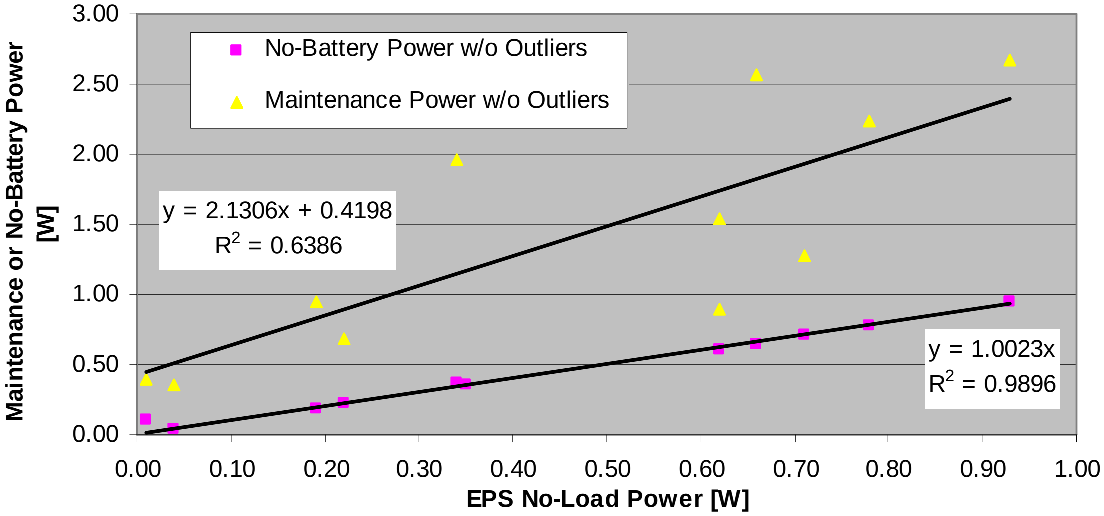

Figure 5.2 Relationship Between BC Wall-Adapter No-Load Power and System No-Battery and Maintenance Power

Table 5.10 Average Calculated BC Performance Used to Supplement Manufacturer Data

		Non-CEC Compliant			CEC Compliant		
Product Class	**Voltage Range**	**Maint. Mode Power [W]**	**No-Battery Power [W]**	**24-Hour Charge and Maint. Energy [Wh]**	**Maint. Mode Power [W]**	**No-Battery Power [W]**	**24-Hour Charging and Main. Energy [Wh]**
A	0 V–3 V	2.36	0.93	56.56	1.06	0.30	25.39[7]
B	3 V–9 V	2.10	0.81	50.49	0.76	0.15	18.15
C	9 V–36 V	2.77	1.13	66.39	1.15	0.35	27.61

5.4.5 Scaling of BC Manufacturer Interview Data to Representative Units

Following the collection of data from the manufacturers and supplementation with test results, DOE scaled the cost-efficiency data, aligning them with the representative units to permit aggregation of data from various sources. As described earlier, manufacturers often based their data submission on actual BCs currently in production. These did not always have the same specifications as the representative units, but were similar enough that DOE could scale the power consumption estimates provided by manufacturers to be applicable to the representative units.

For example, the BC upon which a manufacturer had based its data submission could have been charging a battery with a capacity twice that of the closest representative unit. In this case, DOE calculated what the energy consumption would have been had the battery capacity

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[7] Since no data were available on low-voltage CEC-compliant chargers (Table 5.9), DOE assumed a moderate no-load power consumption value of 0.3 W.

been decreased to that of the representative unit, keeping all other characteristics of the design constant.

Only the maintenance and no-battery mode power consumption metrics were scaled to the representative units. DOE did not scale the active mode power consumption or the 24-hour integrated active and maintenance mode energy consumption because of the excessive complexity of modeling the effects of unit parameters on active mode performance and the lack of empirical data upon which to base a simpler, linearized model.

DOE scaled the maintenance mode power consumption by the ratio of the battery voltages of the representative unit and the manufacturer-described unit as follows:

$$P'_{MAINT} = \frac{V'_B}{V_B} P_{MAINT} ,$$

Eq. 5.2

where the primed quantities pertain to the representative unit.

Since a maintenance current into a battery of a higher voltage results in proportionally higher power into the battery, DOE modeled the change in the maintenance mode power consumption as proportional to the ratio of battery voltages. DOE did not include a dependence on battery capacity after learning from manufacturers that the maintenance current into the battery is typically held constant by the BC and does not vary with battery capacity, even though higher-capacity batteries will have a higher self-discharge current, and should compensate with a higher maintenance current. DOE also did not include a dependence on charge rate, as maintenance mode power consumption did not depend on charge rate.[8]

No-battery mode power consumption was likewise scaled, using the following equation:

$$P'_{NO\_BATTERY} = \left(\frac{V'_B C'_B r'}{V_B C_B r} \right)^{2/3} P_{NO\_BATTERY} ,$$

Eq. 5.3

where:

V_B is the battery voltage;

C_B is the battery capacity, expressed in ampere-hours;

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[8] Chargers of 1 C and 2 C (where C is the unit of charge rate equivalent to 1/hour) made by the same manufacturer are likely to have the same maintenance current, and therefore maintenance mode power consumption, as the operational characteristics of the BC in active and maintenance modes are specified independently.

r is the charge rate or the charge current divided by the battery capacity, expressed in units of C or 1/hour; and

all primed quantities refer to the representative unit.

Most no-battery mode power consumption in a slow battery charger can be attributed to magnetization and winding losses in the line-frequency transformer, which typically scale in relation to its volt-ampere (VA) rating, raised to the 2/3 power. Furthermore, in a battery charger, the volt-ampere rating of the transformer is determined by the peak power delivered to the battery during active mode, which is the product of the battery voltage, battery capacity, and the charge rate. Although this scaling of no-load power consumption should also affect maintenance mode power consumption because transformer losses are always present, the scaling model did not account for this second-order effect.

5.4.6 BC Manufacturer Markups

The BOM costs manufacturers provided incorporate only a portion of the full production cost. Full production cost is defined as the sum of direct material, direct labor, and overhead (including investment depreciation). Other cost elements (sales, general and administrative, research and development, interest, and profit) comprise the non-production costs. Together these costs make up the full cost, or manufacturer's selling price, of a product (Figure 5.3).

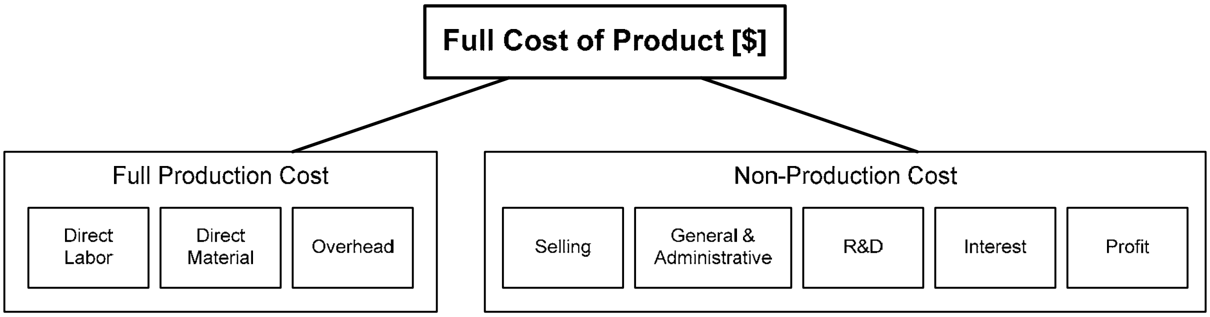

Figure 5.3 Full Cost of Product: Breakdown of Production and Non-Production Costs

In addition to the electronics, the direct material costs also include the BC's plastic enclosure, AC or DC cord, and mechanical components such as contacts and springs. For the determination analysis, DOE assumed that the costs of these components would stay constant as efficiency improved and would not scale in proportion to the electronics BOM cost, in contrast with production overheads such as direct labor.

Figure 5.11 shows the relationship between the two types of direct material costs, the other production cost (consolidated into a single production markup), and the non-production costs (another markup). DOE used the typical values in Figure 5.11, aggregated from data obtained during manufacturer interviews, in conjunction with this markup chain to scale manufacturer-provided electronics BOM costs to MSP.

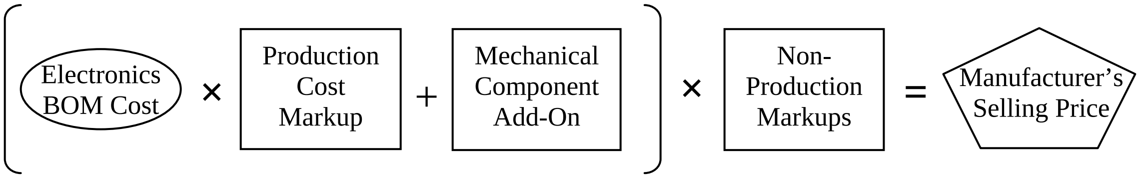

Figure 5.5 Markup Chain Diagram for Battery Chargers

Table 5.11 Typical Markups and Add-Ons for Each BC Representative Unit

Representative Unit	Electronic Component Production Markup	Case, Cord, and Mechanical Components Add-On	Total Non-Production Markups (Includes Corporate, Shipping, and Tariffs)
A	28%	$0.24	92%
B	28%	$0.40	77%
C	32%	$0.73	63%
D	32%	$1.50	63%

5.4.7 EPS Manufacturer Interview Overview

Between October and December 2008, DOE conducted interviews and received data from manufacturers of EPSs and manufacturers of integrated circuits (ICs) for EPSs. Each manufacturer reviewed DOE's methodology and assumptions, and in addition to cost-efficiency data, supplied DOE with information about the EPS design process, the structure of the supply chain, production volumes, and related issues.

The manufacturer survey (appendix 5.B) sought to obtain estimates of the MSP paid to the manufacturer by distributors or OEMs for representative-unit EPSs at each CSL. To develop a more accurate price estimate, DOE also asked manufacturers to list and cost the design options they would use to meet the CSLs. The consensus views for each representative unit follow.

5.4.8 EPS Manufacturer Interview Responses and Preferred Design Options

Representative unit A models EPSs with nameplate output power intended for such applications as charging cellular or cordless telephones or powering small appliances. Because of the popularity of cellular telephones, EPSs in product class A are typically sold in large volumes but, because of the high degree of competition, are subject to smaller manufacturer markups.

Portability also affects the cost-efficiency relationship of representative unit A. The lower the power, the smaller the transformer in a baseline line-frequency EPS, and the lower the costs associated with the steel core and copper windings. Throughout representative product class A, switched-mode designs cost significantly more than line-frequency designs, which would be universally adopted were it not for the need for portability. Because consumers demand smaller, more portable EPSs for charging cellular telephones while traveling, manufacturers use switched-mode power supplies[9] for this application, by far the biggest in terms of volume. This change in design from line-frequency to switched-mode also decreases the energy consumption of the EPS, allowing it to meet CSL 1. Manufacturers provided the following list of design options that are necessary for the representative unit to meet each CSL:

- CSL 0: line-frequency transformer, Schottky rectifier diodes
- CSL 1: switched-mode EPS with standard IC PWM controller or ringing-choke controller
- CSL 2: switched-mode EPS with energy-efficient IC PWM
- CSL 3: same design as above, with improved components
- CSL 4: same design as above, with improved components
- CSL 5: switched-mode EPS with zero-voltage switching, lower-resistance field-effect transistor (FET) switch, more copper in choke
- CSL 6: not available

The representative unit for product class B has a nameplate output power of 18 watts and output voltage of 12 volts. This unit is typically used to power household networking appliances such as modems or other computer peripherals. Because of the immobility of these devices, there has been no strong pressure on manufacturers to produce smaller and lighter EPSs. During the determination analysis, the typical EPS in product class B featured a line-frequency design, which at this output power tended to still be less expensive than an equivalent switched-mode design. A switched-mode design, however, would be necessary for meeting CSL 1, as the following list of design options—suggested by a consensus of manufacturers during interviews—shows.

- CSL 0: line-frequency transformer, standard rectifier diodes
- CSL 1: switched-mode EPS with standard IC PWM controller
- CSL 2: switched-mode EPS with energy-efficient IC PWM
- CSL 3: same design as above, with improved components
- CSL 4: same design as above, with improved components
- CSL 5: better core material, improved FET switch
- CSL 6: synchronous rectification, resonant snubbers, zero-voltage/zero-current switching

The final representative unit analyzed during the determination analysis (for product class F) has a nameplate output power of 90 watts and output voltage of 19 volts. The main application of this high-power device is supplying laptop computers and video-game consoles. Throughout product class F, it is no longer practical to produce line-frequency EPSs due to the large size of the transformer and high cost of the necessary steel and copper. Therefore, even though DOE did not consider line-frequency designs applicable for this representative unit,

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[9] Switched-mode power supplies are smaller and lighter than line-frequency designs at the same nameplate output power.

CSL 0 was reserved in the analysis for consistency with the other representative units. The design options necessary for meeting the other CSLs are listed below.

- CSL 0: not applicable
- CSL 1: switched-mode EPS with standard IC PWM controller
- CSL 2: switched-mode EPS with energy-efficient IC PWM
- CSL 3: same design as above, with improved components
- CSL 4: same design as above, with improved components
- CSL 5: better core material, more copper, improved components
- CSL 6: synchronous rectification, resonant snubbers, zero-voltage/zero-current switching

5.4.9 Scaling of EPS Manufacturer Interview Data to Representative Unit Volume

After marking up the BOM costs to arrive at manufacturer selling prices, DOE had to further adjust the individual manufacturer prices to a common yearly volume. Although manufacturers were asked to provide their prices at a common volume, not all were able to do so. Therefore, DOE marked up or marked down the MSP, as appropriate, to arrive at common-volume prices that were comparable to one another. Table 5.12 presents these common volumes and the rate DOE used to scale the prices according to volume.

Table 5.12 Unit Volumes and Volume Discount Rates for Each EPS Representative Unit

Representative Unit	Volume of Representative Unit	Per-Decade Discount Rate (percent)
A	1,000,000 units/year	17.7
B	500,000 units/year	17.7
C	500,000 units/year	17.7

The discount rate DOE used to scale prices across decades (*i.e.*, factors of ten) of volume was based on MSPs for 2-watt and 5-watt switched-mode EPSs reported by the manufacturer Ten Pao in a public comment submitted by the Natural Resources Defense Council to the California Energy Commission during the 2006 Appliance Efficiency Standards rulemaking.[10] Table 5.13 shows the prices and discount-rate calculations, which result in an average volume discount rate of 17.7 percent per decade.

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[10] This comments is available at www.energy.ca.gov/appliances/2006rulemaking2/documents/comments/NRDC.PDF.

Table 5.13 Volume Prices Used to Calculate Average per-Decade Discount Rate

Quantity [Units/Year]	2 W EPS Manufacturer Selling Price at Quantity [$]	Percentage Difference from 2 W Price at Next-Lowest Volume	Percentage Difference in 2 W Price per Decade	5 W EPS Manufacturer Selling Price at Quantity [$]	Percentage Difference from 5 W Price at Next-Lowest Volume	Percentage Difference in 5 W Price per Decade
50,000	1.65	–	–	2.10	–	–
100,000	1.50	-09.1	-30.2	1.89	-10.0	-33.2
1,000,000	1.35	-10.0	-10.0	1.60	-15.3	-15.3
10,000,000	1.20	-11.1	-11.1	1.50	-6.3	-6.3
Average			-17.1			-18.3
Average across 2 W and 5 W Units						-17.7

5.4.10 Scaling of EPS Manufacturer Interview Data to Representative Unit Power

Similarly to how it scaled manufacturer-provided data to the volume of the representative unit, DOE also scaled data to the power of the representative unit. Although manufacturers provided data on units within the same representative product class, not all manufacturers produce EPSs with 90-watt nameplate output power or 19-volt output voltage. Therefore, both the price and efficiency data they provided had to be scaled to the representative unit output power to account for the fact that higher-power units tend to be not only more expensive, but also more efficient.

To determine the dependence of cost on output power, DOE examined an EPS manufacturer's price list, obtained under a confidentiality agreement. The price charged by the manufacturers to distributors seemed to be proportional to the output power, across a wide range of efficiencies and spanning output powers from 4 watts to 150 watts. DOE used the slope of the least-squares line passing through the points, with an R^2 value of 0.984, to scale the costs to the output powers of the representative unit.

Because the practically achievable efficiency of an EPS also depends on the output power, DOE expects that shifting the manufacturer-provided cost-efficiency data to the output power of the representative unit would result in a change in active mode efficiency. Figure 5.6 is a schematic representation of the EPS efficiency distribution with power, which shows the general trend in EPS. DOE therefore assumed that if a manufacturer were to design two similar EPSs with slightly different powers, the efficiency of the higher-power EPS would be higher, and vice versa. However, there is a wider range of efficiency at low output power than at high output power. Any shift of a manufacturer's unit to the representative unit output power should therefore preserve a unit's relative standing in terms of efficiency among other units in the market.

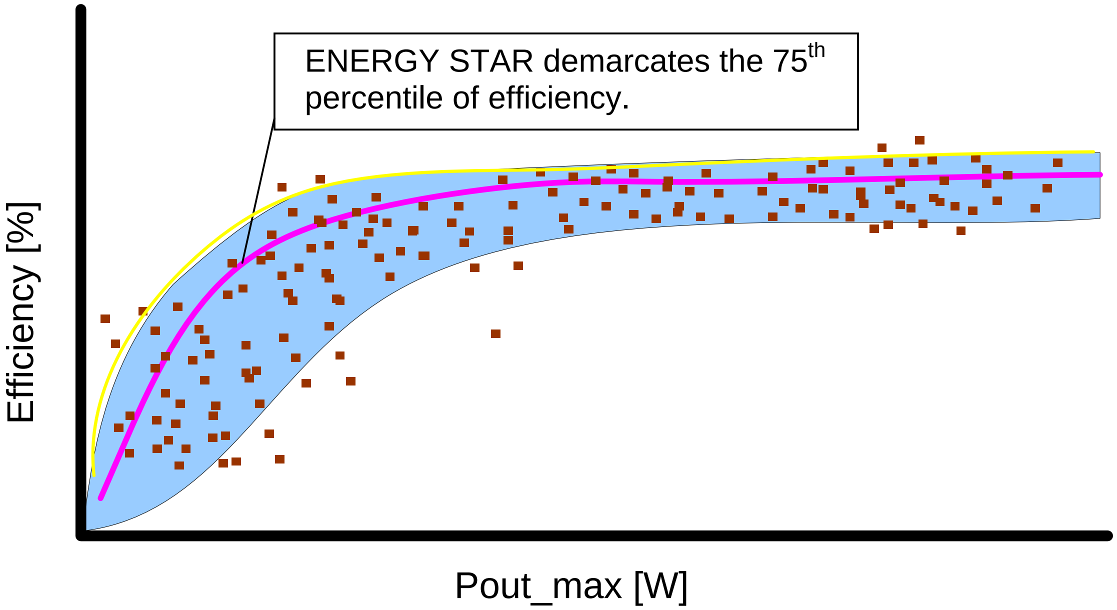

Figure 5.6. Schematic Illustration of the Distribution of Efficiency Versus Maximum Rated Output Power; the ENERGY STAR Level Is Shown as a Pink Line, while the Blue Background Indicates Where Most of the Units Lie

To preserve the relative standing of the manufacturer's unit in the market, while shifting the results to the representative unit output power, DOE maintained the ratios among the unit's efficiency, the ENERGY STAR level, and the best-in-market level. Figure 5.8 shows how DOE generated the best-in-market curve-fit using data on the highest-performing units taken from the ENERGY STAR qualifying products database. Since no correlation has been found between no-load power and output power, DOE did not scale the no-load power.

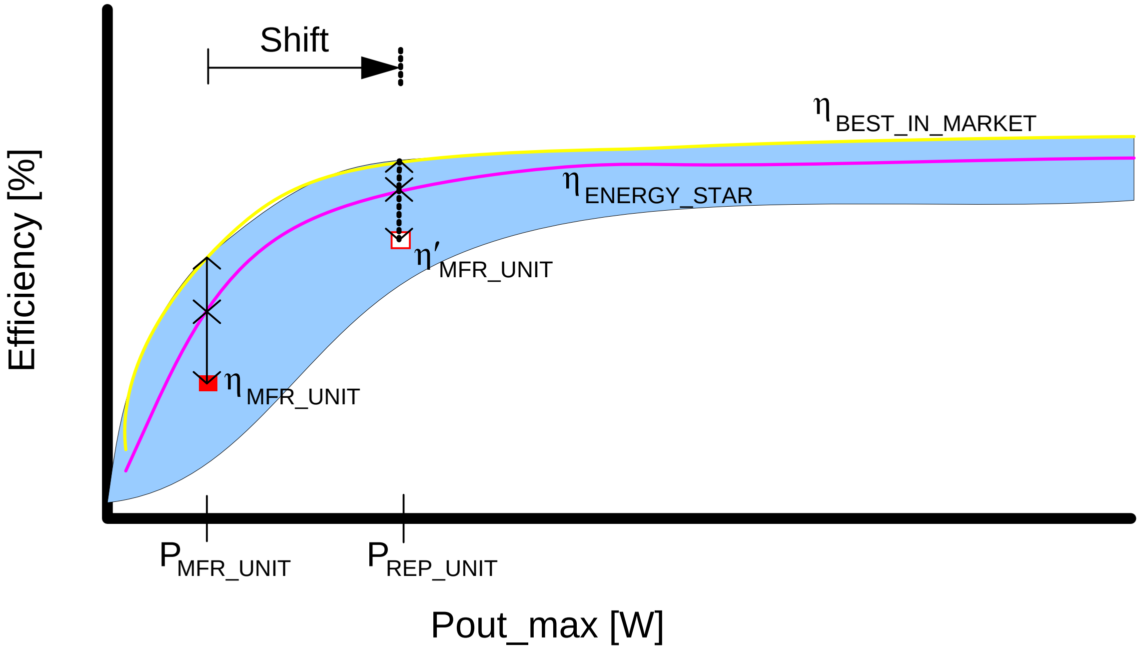

Figure 5.7. Schematic Illustration of Scaling EPS Efficiency with Output Power

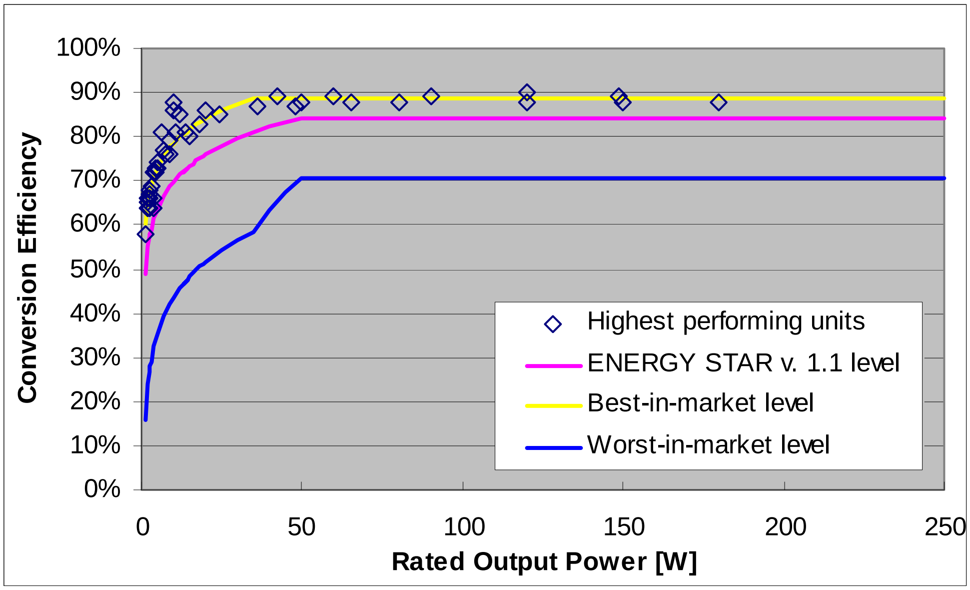

Figure 5.8. ENERGY STAR Level and Calculated Best-in-Market and Worst-in-Market Curves

DOE performed the shift in efficiency relative to the best-in-market and ENERGY STAR levels using the following equations:

$$\eta'_{MFR\_UNIT} = \eta'_{BEST\_IN\_MARKET} - r \cdot \left(\eta'_{BEST\_IN\_MARKET} - \eta'_{ENERGY\_STAR}\right)$$

Eq. 5.4

and

$$r = \frac{\eta_{BEST\_IN\_MARKET} - \eta_{MFR\_UNIT}}{\eta_{BEST\_IN\_MARKET} - \eta_{ENERGY\_STAR}},$$

Eq. 5.5

where:

η_{MFR_UNIT}, $\eta_{BEST\_IN\_MARKET}$, and η_{ENERGY_STAR} are the efficiencies of the unit under analysis, the best-in-market point, and the ENERGY STAR level, respectively, at the manufacturer-provided nameplate output power, while

the primed terms refer to the same quantities at the nameplate output power of the representative unit, to which the unit efficiency is being scaled, and

r is a scaling ratio that represents the position of the efficiency of the manufacturer-provided unit to that of other EPSs in the market.

5.4.11 Scaling of EPS Manufacturer Interview Data to Representative Unit Voltage

After scaling manufacturer-provided cost-efficiency data to account for any differences in output power, DOE scaled the efficiency to account for any differences in output voltage. As mentioned in chapter 3, for a given output power, EPS output voltage has a strong effect on efficiency because of conduction losses and rectifier voltage drops.

By testing families of EPSs produced by the same manufacturer with the same nameplate output power but different voltage, DOE was able to establish a relationship between voltage and efficiency. The relationship is illustrated in Figure 5.9, which shows the results of tests conducted on four pairs of EPSs with nameplate output power of 60 watts. Each pair was part of the same product family, and included a 12-volt unit and another unit with an output of 18 volts or 24 volts. The gains in efficiency due to increasing the output voltage are described well by a best-fit line with an R^2 value of 0.914; DOE used the slope of the line to scale the manufacturer-provided efficiency data.

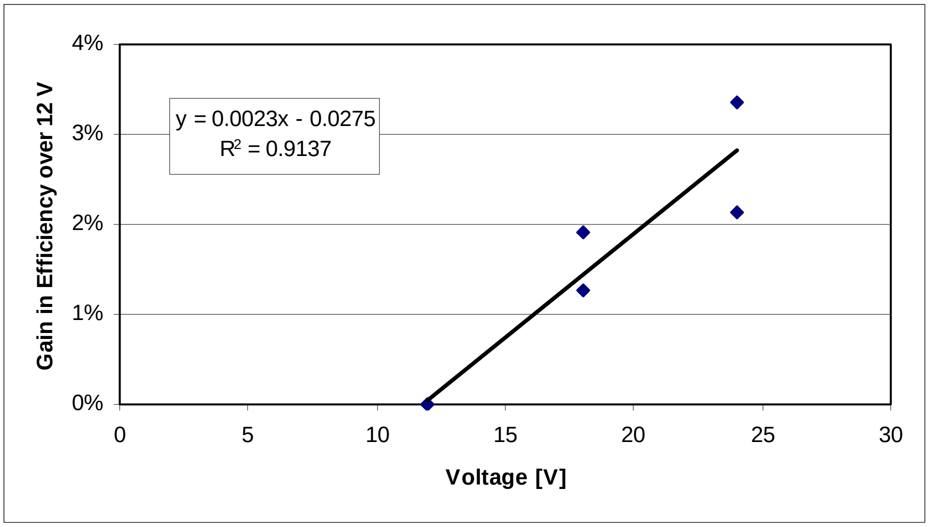

Figure 5.9 Relationship Between Output Voltage and Efficiency

While EPS output voltage has a pronounced effect on efficiency, available literature suggests and manufacturer interviews confirm that output voltage does not influence EPS price. Therefore, DOE did not scale the price with voltage as it had done for efficiency.

5.4.12 EPS Manufacturer Markups

Although the output of the engineering analysis is the MSP of the representative units at each CSL, some manufacturers did not provide it during the interviews. Instead, they focused on what they knew most intimately and reported the total BOM cost, which in contrast with the BC interviews, included both electronic components and mechanical hardware and packaging. DOE therefore asked additional questions to construct an appropriate model of manufacturer markups and obtain the MSP from the BOM cost.

As in the description of BC markups in section 5.4.6, manufacturer markups fall into two categories: production and non-production markups (Figure 5.5**).** Low and high estimates for the two types of markups, constructed from averages of data provided by manufacturers during interviews, appear in Table 5.14. To obtain the MSP of a representative unit, DOE multiplied the BOM cost first by the production markup and then by the non-production markup appropriate to that representative unit. Because EPS manufacturers provided a total BOM cost, DOE did not have to apply a separate mechanical component add-on, as during the BC analysis.

Table 5.14 Manufacturer Markups Used in the EPS Engineering Analysis

Representative Unit	Typical Production Markup (%)		Typical Non-Production Markup (%)		Average Total Manufacturer Markup (%)	
	Low	High	Low	High	Low	High
A	18	37	18	25	45	74
B	24	39	18	30	47	81
F	24	39	18	30	47	81

Following the markups and scaling described above, the manufacturer-provided MSPs at each CSL were validated through DOE testing and teardowns. The MSPs and CSLs served as inputs into subsequent analyses.

5.5 Efficiency Testing and Teardowns

To validate data manufacturers provided during interviews (section 5.4.7), DOE conducted tests and teardowns of commercially available BCs and EPSs. The tests and teardowns also served to validate publicly available efficiency data and identify common EPS design features in support of the product classes described in chapter 3.

DOE conducted the efficiency tests in accordance with its BC and EPS test procedures, as codified in appendices Y and Z of subpart B to 10 CFR part 430. DOE also disassembled numerous BCs and all 46 of the purchased EPSs, noting the defining features of their circuits. DOE also tore down a subset of these units to evaluate the relationship between cost and efficiency among units with comparable design characteristics. The teardowns involved a detailed parts count and cost estimate (sections 5.5.2 and 5.5.4). Because it is not possible to purchase and test models with the maximum technologically feasible efficiency, DOE was only able to examine devices with efficiencies between baseline and best-in-market.

5.5.1 BC Testing

In September 2007, DOE purchased 29 battery chargers for testing and teardown. The BCs were purchased either as part of a kit that included a battery-operated consumer product and battery or independently of the product and packaged with just the battery.

DOE performed the testing and teardowns to achieve the following goals, listed from general to specific:

1. gain an understanding of BCs and battery-powered products in the market today,
2. evaluate the DOE and CEC BC test procedures, and also test BC wall adapters using the DOE EPS test procedure,
3. validate efficiency test data stakeholders provided in comments to DOE, and
4. validate efficiency and cost data manufacturers provided during interviews.

The BCs purchased for testing spanned a wide range of applications and voltages and were selected for the apparent popularity of the products with which they were sold,[11] ensuring a sample typical of the market.

Figure 5.10 shows the results of the efficiency tests conducted on the BCs, expressed in terms of energy ratio. The consumer product applications served by the BCs are also indicated on the plot, confirming the typical voltage-based divisions described in chapter 3. Figure 5.11 superimposes the results of DOE's efficiency data on CEC test data gathered by its contractor, Ecos Consulting, showing general agreement between DOE test data and that gathered during prior tests.

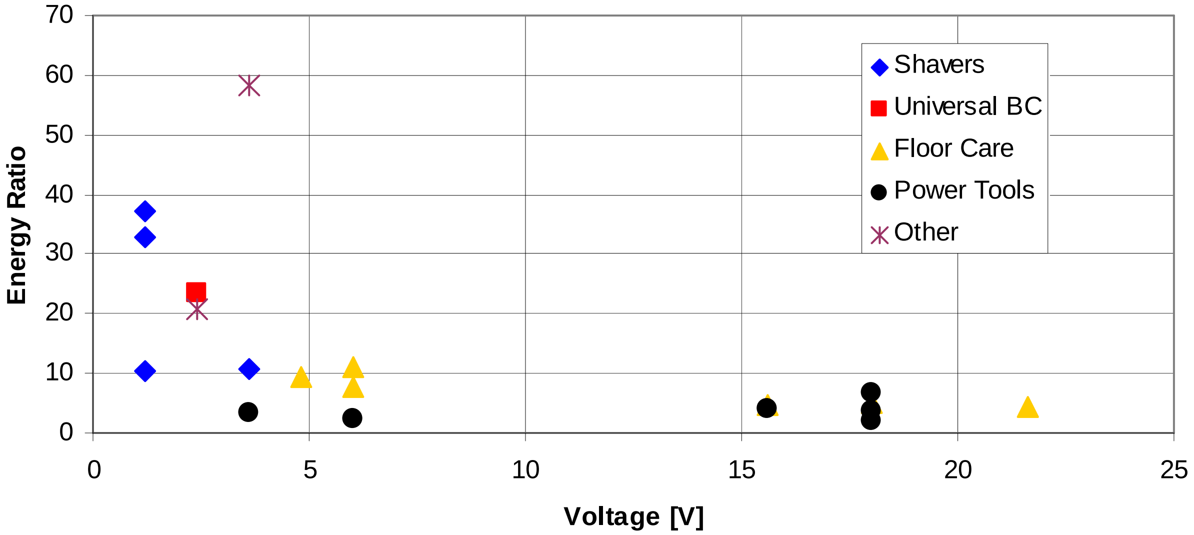

Figure 5.10 DOE Battery Charger Test Results by Consumer Product Application

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[11] DOE evaluated popularity based on the product's sales rank on retailer websites and ConsumerReports.com.

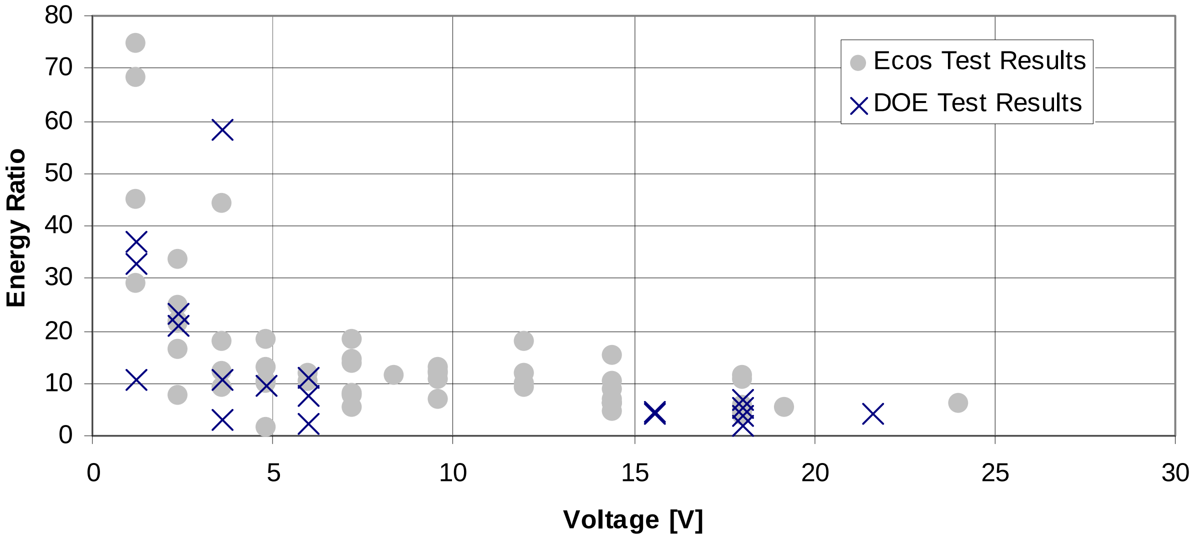

Figure 5.11 DOE Battery Charger Test Data Superimposed over CEC Data gathered by Ecos Consulting

5.5.2 BC Teardowns

Following efficiency testing, DOE tore down the purchased BCs to evaluate costs. The process began with the disassembly of the battery chargers, and when any battery charging circuitry resided outside the charger, the associated consumer products itself. Following disassembly, DOE listed all the electronic components pertaining to battery charging. As explained in section 5.2.1, the batteries were excluded from the analysis.

To aid in the next step, DOE compiled a master list of component costs taken from two online electronic component distributors[12] at quantities of 1,000 pieces. For components that were either unmarked or unavailable in the manufacturer catalogs (*e.g.*, magnetic components), DOE estimated their costs based on the costs of parts with similar specifications, construction, weight, and materials. Appendix 5.C provides an example teardown analysis report.

Although DOE purchased 29 BCs, not all were comparable to the four representative units described in section 5.2.1.Therefore, DOE only tore down the 11 units that could be immediately used to validate or complete the cost-efficiency data manufacturers supplied. The results of the teardowns appear in Figure 5.12, which plots BOM cost versus energy ratio for each unit. Data points of different cost and shape denote different battery voltages.

Although there are some outliers, Figure 5.12 shows a clear pattern for BCs with the same output voltage. For example, the BOM cost of a 6-volt unit with an energy ratio of 2.4 is

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[12] The Digi-Key catalog can be viewed at www.digikey.com. The Mouser catalog can also be viewed at www.mouser.com.

greater than $5, while the costs of two other less efficient units, as well as a comparable 4.8-volt unit, with energy ratios between 7 and 11, are around $0.50.

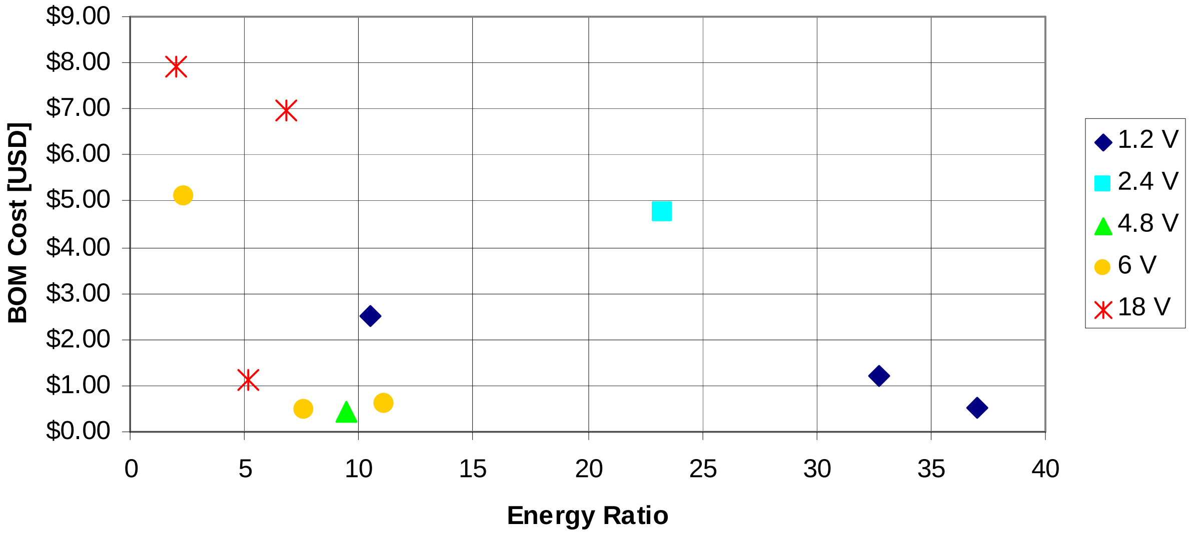

Figure 5.12 Low-Volume Cost Versus Efficiency for Tested and Torn-Down Battery Chargers

Although DOE had not thoroughly analyzed the outliers at the time the determination analysis was rescheduled in December 2007, one possible explanation may lie in the BC charge rate. The more expensive units are all fast chargers that charge the battery in up to one-tenth the time of the slow chargers, requiring higher charger output power and more expensive components capable of handling the higher power. There are numerous such complicating factors, such as the ability of a BC to double as an EPS in a “cord-cordless” product; additional circuitry in multi-voltage or multi-port chargers; and proprietary designs that may distinguish products by different manufacturers, especially at the higher charge rates and costs.

One of the goals of the first round of BC testing and teardowns was to identify these sorts of dependencies, though further BC purchases may be necessary to establish a clearer relationship between cost and efficiency, independent of the complicating factors mentioned above. Nonetheless, because there was significant overlap between the units torn down and those described by manufacturers (section 5.4), the results of the tests and teardowns were immediately useful in validating the information manufacturers provided.

To compare data provided by manufacturers and the materials costs calculated by DOE’s subject matter experts,[13] DOE discounted the calculated costs to reflect the higher volumes at which BC manufacturers typically operate. DOE scaled volume with the aid of a high-volume quote and simplification of the method described in section 5.5.3, which resulted in an 80-

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[13] DOE relied on two subject matter experts (SMEs), who are independent engineering contractors with extensive experience in the design of battery chargers and external power supplies, when conducting its analyses.

percent discount on all electronic components. Magnetic components were not discounted, as their price was already estimated based on high-volume commodity (*i.e.*, steel and copper) prices.

In subsequent calculations, the scaled, high-volume BOM costs were marked up to include additional production and non-production costs, as was done for data provided during manufacturer interviews (section 5.4. DOE then aggregated the MSP and efficiency data for each teardown unit with data provided by manufacturers to create average price-efficiency curves. These curves fed into subsequent analyses of the potential impacts of standards on consumers and the Nation.

5.5.3 EPS Testing

As with BC testing, DOE conducted EPS testing and teardowns to gain insight into the design of commercially available EPSs, which influenced the technology assessment presented in chapter 3. A further goal was the validation of cost-efficiency data obtained during manufacturer interviews.

DOE performed EPS testing and teardowns for the determination analysis in two phases. Phase 1 consisted of two groups of EPSs whose nameplate output power ranged between 1 watt and 6 watts, and between 40 watts and 66 watts. Within these two ranges, DOE subjected EPSs with 5-watt and 60-watt output power to detailed teardowns to assess the cost-efficiency relationship at these two wattage ratings. DOE selected the 5-watt and 60-watt ratings due to their popularity, based on a review of eight EPS manufacturer catalogs[14] and the advice of its subject matter experts.

Table 5.15 lists some of the parameters of the 46 units purchased in phase 1. In the batch of units purchased, 12 units (26 percent) were ENERGY STAR/CEC Tier 1 compliant.

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[14] DOE surveyed the websites of the following companies: Delta Electronics, Astec, FRIWO Group, Phihong, Leader Electronics, AcBel Polytech, FSP Group, and Dee Van Enterprises.

Table 5.15 Phase One Units Purchased and Their Characteristics

Number of Units	Output Power	Output Voltage	ENERGY STAR
1	1.125	5	
1	2.4	6	
1	2.5	5	Yes
3	3	5	
2	3.6	6	
3	4.8	6	
2	5	5	Yes
7	5	5	
1	5.15	5.15	
1	5.2	5.2	Yes
1	6	5	
1	40	24	
1	40	24	Yes
1	40	48	
1	45	12	
1	45	18	
1	48	12	Yes
1	48	24	Yes
1	50	5	
1	50	12	
1	50	18	
1	50	24	
1	55	19	
2	60	12	Yes
2	60	12	
1	60	18	
1	60	20	
2	60	24	Yes
1	65	24	Yes
1	66	15	
1	66	18	
46 total	-	-	-

Following the development of the EPS product classes described in chapter 3, DOE purchased additional EPSs, many selected to have the same power or almost the same power as the representative units. To further isolate the effect of efficiency on cost, DOE strove to purchase multiple units by the same manufacturer. Additional EPSs by the same manufacturer were purchased, with output powers either higher or lower than the representative unit, to determine how the cost and efficiency scales with power within a product class, to validate the product-class boundaries defined in chapter 3, and to asses the variability of EPSs design within each product class.

Figure 5.13, Figure 5.14, and Figure 5.15 present diagrams of EPSs purchased in phase 2, with efficiency on the *y*-axis and output power on the *x*-axis. To promote comparisons within and among different output power ranges, the EPSs were purchased such that a plot of their output power and efficiency would form an “inverted letter T.” The leg of each inverted T in the figures helped determine the cost-efficiency relationship, while the arms allowed DOE to validate product class divisions and improve its understanding of scaling. EPSs contributing additional points in the figures were purchased to enable additional comparisons.

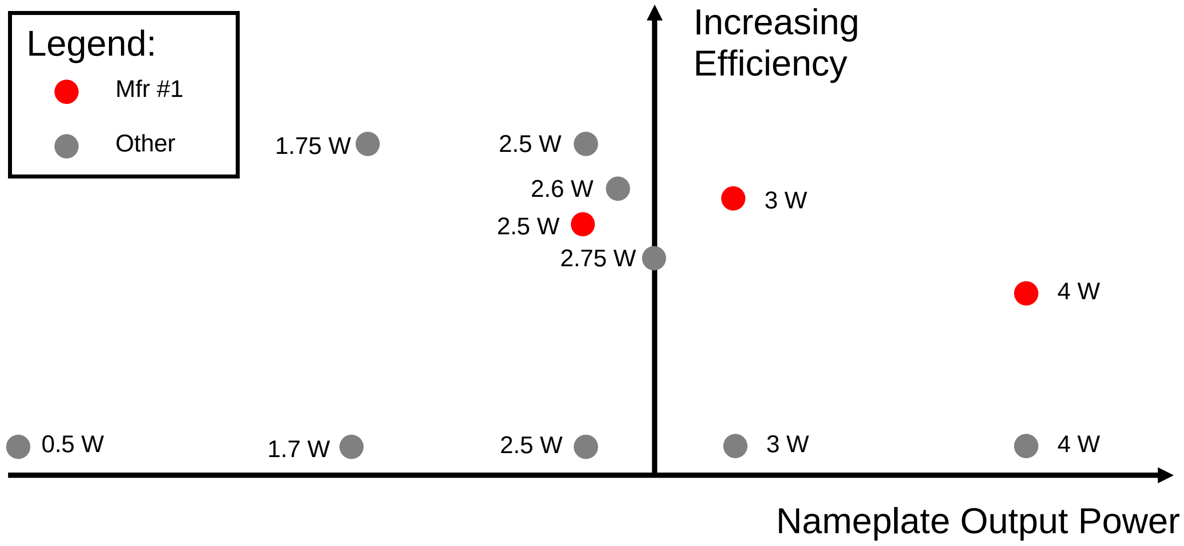

Figure 5.13 Illustration of Units in Product Class A Selected for Phase 2 Testing and Teardowns

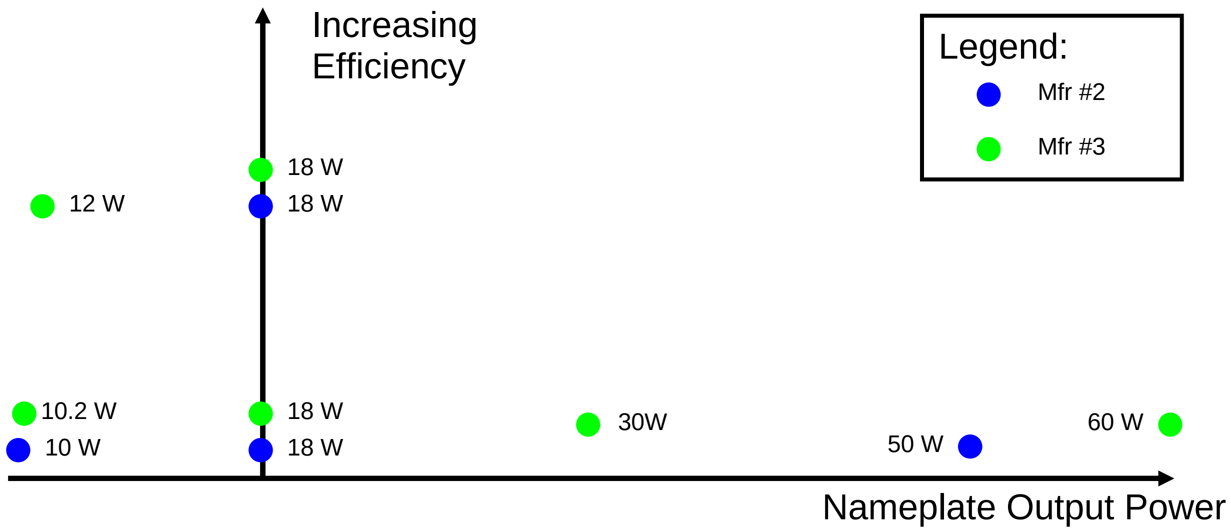

Figure 5.14 Illustration of Units in Product Class B Selected for Phase 2 Testing and Teardowns

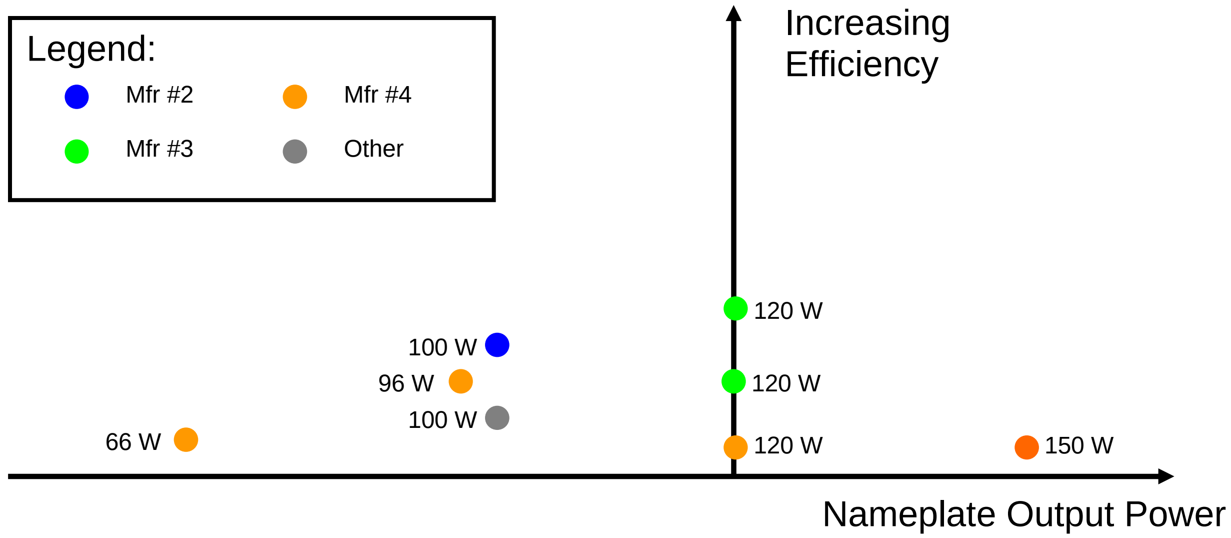

Figure 5.15 Illustration of Units in Product Class F Selected for Phase 2 Testing and Teardowns

5.5.4 EPS Teardown Methodology

DOE tore down a subset of the previously tested EPS units to identify design characteristics that can be used to improve EPS efficiency and to determine their associated costs. The end result of each teardown was a bill of materials, which included the electronic components of the EPS. This BOM was the only component of costs directly evaluated by DOE during the teardown portion of the EPS determination analysis. DOE estimated electronics BOM costs using the same method as for BCs (section 5.5.2). This included a master list of commonly available components, combined with catalog lookups and price estimates of similar parts when a given part was unavailable.

While the online distributor catalogs provide a consistent set of prices at low volumes, most EPS are manufactured in very large volumes. Thus, DOE developed a second cost estimate assuming large-volume orders of 100,000 to 1,000,000 pieces. To develop the high-volume estimate, a separate volume discount was applied to each component category in the BOM (*e.g.*, resistors, capacitors, semiconductors, magnetic parts). DOE developed these volume discounts by obtaining a high-volume quote for a power converter BOM and comparing the high-volume costs, from the quote, with low-volume costs obtained from distributor catalogs. The results of this comparison were then averaged by component category. DOE used the averages to scale the low-volume BOM costs of components in each category.

5.5.5 EPS Teardown Results

Using the above scaled BOM costs, DOE developed cost-efficiency plots for 5-watt and 60-watt power supplies. Table 5.16 summarizes the 5-watt units DOE evaluated, which all had the same output voltage. The 60-watt EPSs were analyzed at four different output voltages: 12 volts, 18 volts, 20 volts, and 24 volts. Because active mode efficiency depends on voltage, the 12-volt units would have a different efficiency than the 24 volt units, even given the same energy-efficient design and components. Therefore, only the results for the 60-watt, 12-volt unit were analyzed.

Table 5.16 Phase One Units Torn Down

Maximum Rated Output Power (W)	Rated Voltage (V)	Number of Units Analyzed
5	5	9
60	12	4
60	18	1
60	20	1
60	24	2

Figure 5.16 presents the cost versus active mode average efficiency plot for the 5-watt EPS units. The costs are shown for the two component cost estimates—high and low—calculated using the low-volume catalog lookup and the high-volume quote, respectively.

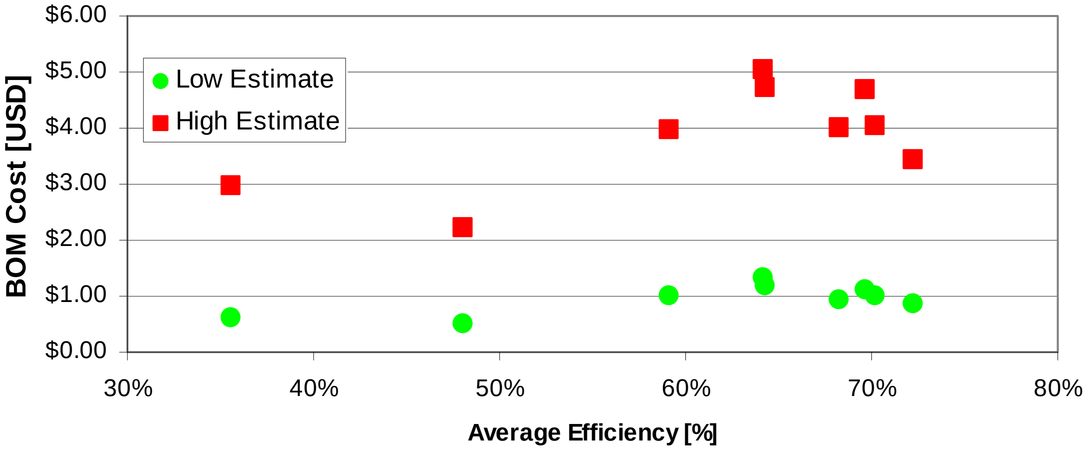

Figure 5.16 BOM Cost versus Average Efficiency of 5-Watt Units

Figure 5.16 shows that there was approximately a four-fold difference in BOM costs between the high estimate calculated using distributor catalogs alone and the low estimate calculated through the volume quote and discounting. Considering that the electronics BOM costs presented in the figure would be marked up to account for mechanical components and packaging, as well as production and non-production costs, to arrive at an MSP, the low cost estimate is more representative of typical EPS costs.

Figure 5.16 also shows that costs tended to increase significantly between 35-percent efficiency and 60-percent efficiency due to the necessary transition from line-frequency to switched-mode power supply (SMPS) technology. However, once the designs incorporated SMPS technology and surpassed 65 percent efficiency, there was no clear relationship between cost and efficiency.

Figure 5.17 presents the BOM cost versus no-load energy consumption for the 5-watt EPS units. As was the case with active mode efficiency, there was a significant cost increase associated with lowering no-load power from approximately 1.5 watt to 0.5 watt, corresponding with the shift from line-frequency to switched-mode designs. Further reductions in no-load power seem to incur no additional cost.

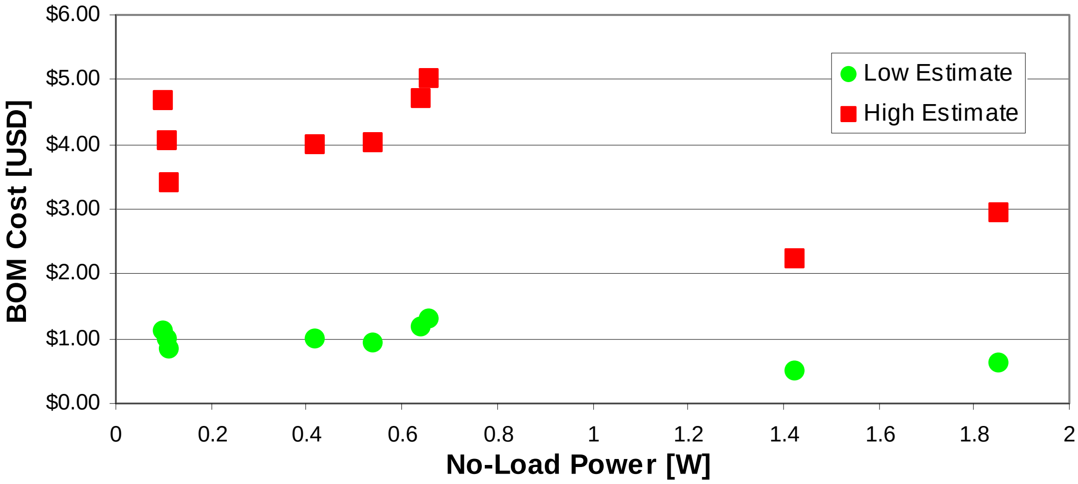

Figure 5.17 BOM Cost vs. No-Load Power of 5-Watt Units

Figure 5.18 presents the high-volume (*i.e.*, low estimate) BOM costs versus average efficiency of 5-watt EPS units, but combines energy consumption in both active and no-load modes. The color and shape of the data points reflect the CSL (section 5.3.2) met by each unit. For example, green circles represent units exceeding the CEC Tier 2 standard for active mode efficiency and no-load power consumption. The figure shows that increases in average efficiency track reductions in no-load power for the 5-watt units analyzed, but the only significant change in price is the increase caused by the shift in technology from line-frequency to switch-mode designs.

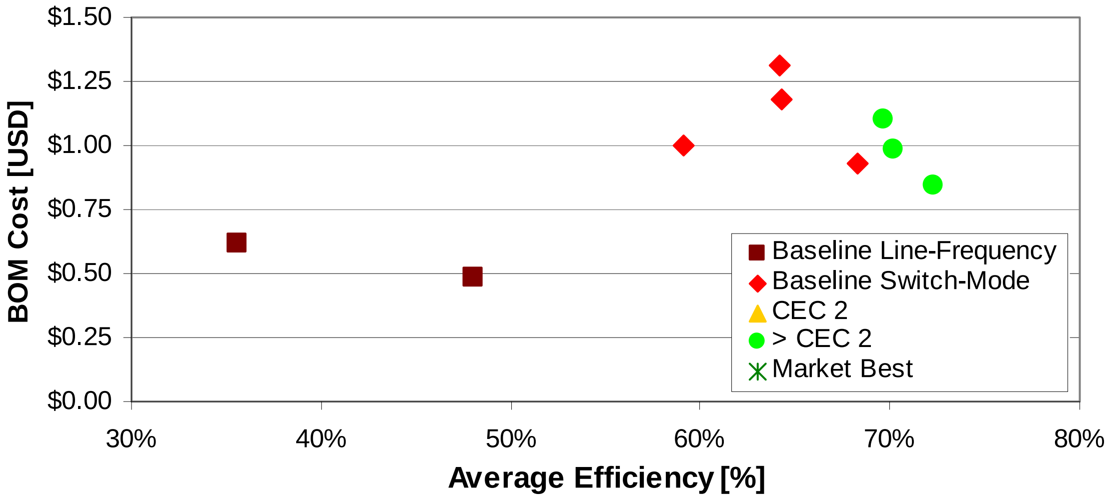

Figure 5.18 BOM Cost and Efficiency of 5-Watt EPS Units

Figure 5.19 displays the same data in a different way, plotting the active mode efficiency of the 5-watt EPSs directly against the no-load power consumption. Because the CSLs are defined in terms of these two metrics, they are also portrayed in the figure as shaded rectangles, with the most efficient CSLs grouped in the lower right of the figure. The shape and color of the data points indicate the low estimate of the BOM cost. Once an EPS uses switch-mode technology, there are no discernable incremental costs associated with meeting levels just beyond CEC 2.

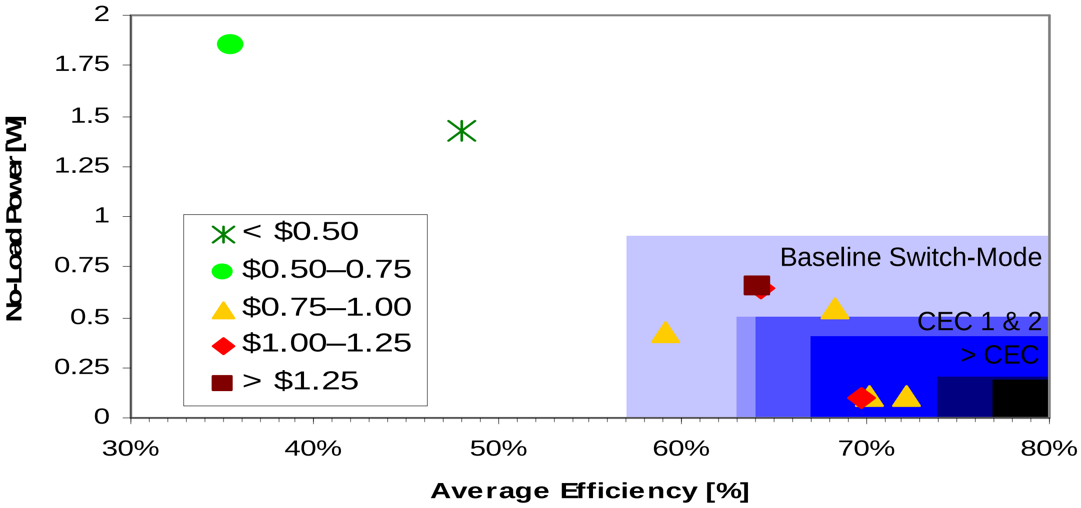

Figure 5.19 Average Efficiency and No-Load Power Consumption of 5-Watt EPSs with BOM Costs; Increasingly Stringent CSLs Are Represented by Darker Shades of Blue

As with its analysis of the 5-watt units, DOE tore down 60-watt, 12-volt EPSs and estimated high and low BOM costs using the same methodology that included the master price lists and volume discounting using the high-volume quote. Figure 5.20 presents the cost versus active mode average efficiency for the 60-watt EPS units. Figure 5.20 shows there is no apparent increase in cost for efficiency points greater than 65 percent. Since all the 60-watt EPSs DOE tore down incorporated switch-mode designs, these findings are consistent with the cost relationship for switch-mode 5-watt units presented in Figure 5.16. The small sample size, however, made robust comparisons difficult.

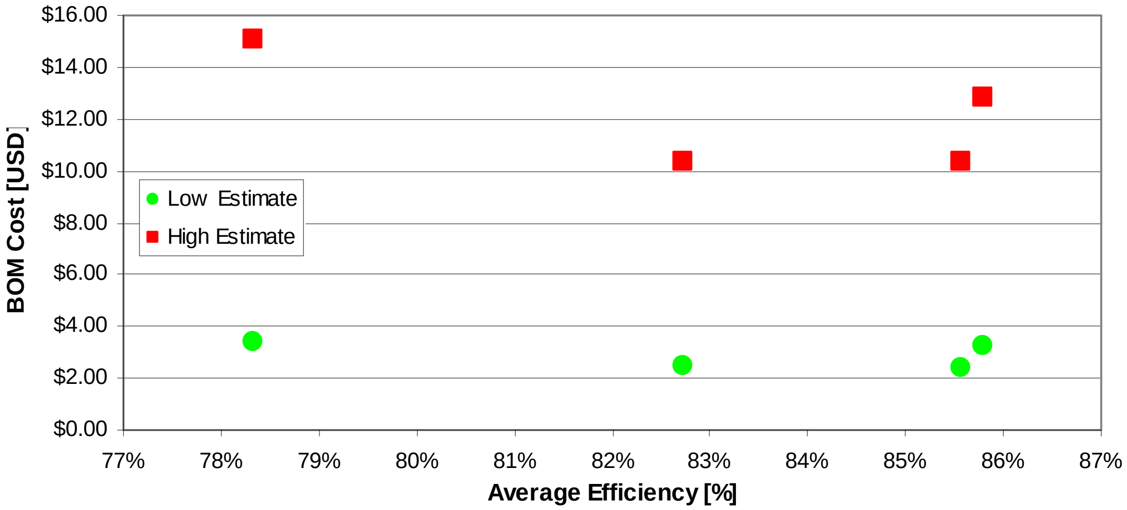

Figure 5.20 BOM Cost vs. Average Efficiency of 60-Watt Units

Figure 5.21 presents the BOM cost and no-load energy consumption for the 60-watt EPS units. The costs are shown again for the low and high price estimates. Figure 5.21 shows there was no significant relationship between cost and no-load power for the EPSs DOE analyzed. This is similar to the conclusion DOE reached for 5-watt switched-mode EPSs.

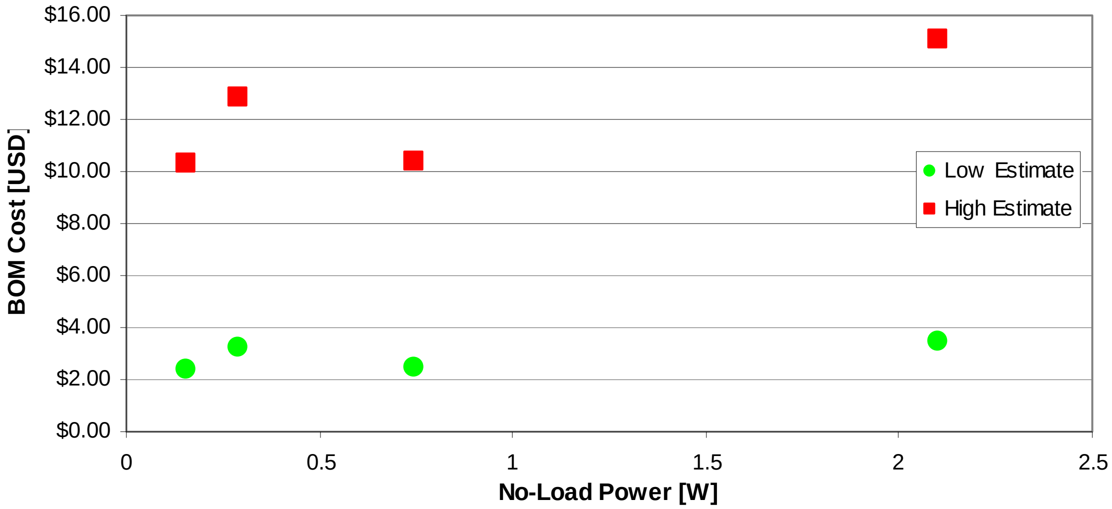

Figure 5.21 BOM Cost versus No-Load Power of 60-Watt Units

Figure 5.22 presents the high-volume BOM costs and active mode efficiency of 60-watt EPS units. The color and shape of the data points provide a measure of the no-load mode efficiency for each unit. For example, the yellow triangles represent 60-watt, 12-volt EPSs that meet the CEC Tier 2 standard for active mode efficiency and no-load power consumption. The figure seems to show that increases in average efficiency tended to track reductions in no-load power in the sample of torn-down units, and that efficiency appeared to increase without a corresponding increase in cost.

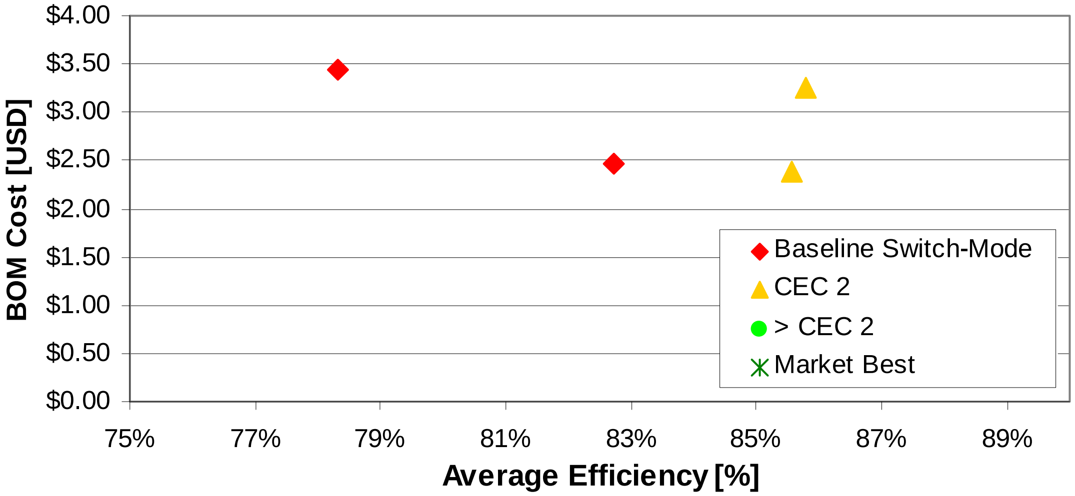

Figure 5.22 BOM Cost and Efficiency of 60-Watt EPS Units

Figure 5.23 rearranges the same data, presenting active mode efficiency and no-load power. Units in the lower-right corner meet the highest CSLs of efficiency, in terms of both active mode efficiency and no-load power. The shape and color of the data points indicate the calculated BOM costs.

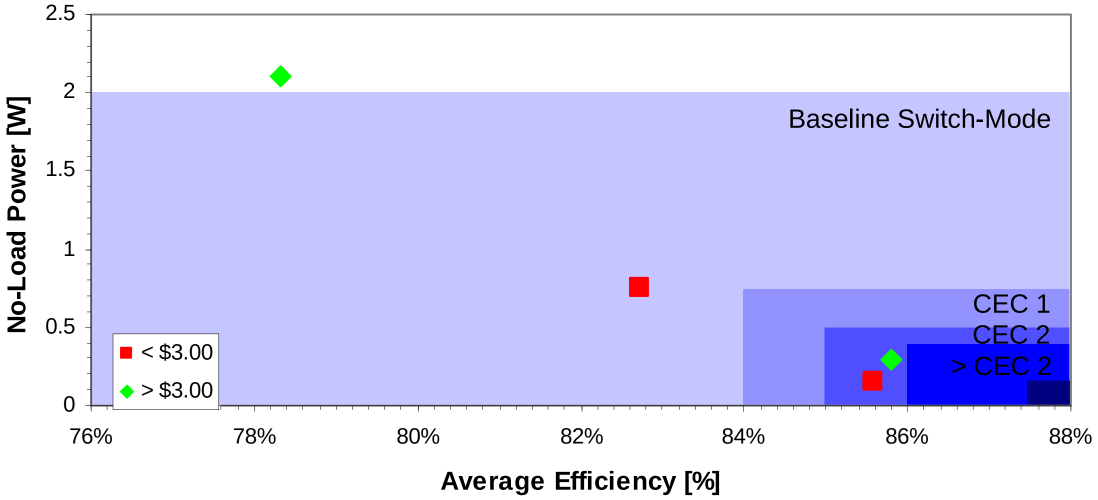

Figure 5.23 Average Efficiency and No-Load Power Consumption of 60-Watt EPSs with BOM Costs; the Increasing CSLs Are Represented by Darker Shades of Blue

5.6 Conclusion

DOE did not finish the validation component of the engineering analysis, which consisted of testing and teardowns, before the rescheduling of the determination analysis in December 2007. As a result, additional teardowns of BCs and EPSs, necessary to address some of the issues raised above, remained unfinished. Despite its incompleteness, the above description provides examples of the methods that DOE had planned to use to arrive at cost-efficiency estimates, such as output power and voltage scaling, as well as volume discounts and manufacturer markups. These results would have been incorporated into the life-cycle cost and payback period analyses and the national impact assessment described in the following chapters.

APPENDIX 5.A Battery Charger Cost-Efficiency Estimation Survey

Navigant Consulting, Inc. (NCI) is conducting an engineering analysis to understand the relationship between manufacturers' cost and the energy efficiency of Battery Chargers. This engineering analysis is part of a larger determination analysis on whether the U.S. Department of Energy should conduct an energy conservation standards rulemaking on battery chargers and external power supplies (BC-EPSs). Through this survey, NCI is seeking your guidance on design improvements you might make to battery chargers to improve their efficiency. All information you provide is covered by the Non-Disclosure Agreement between NCI and your company.

NCI is focusing the engineering analysis on four types of battery chargers with differing charge rates, operating voltages, battery capacities, and consumer product applications. NCI believes each of these units is representative of other commonly used consumer-product chargers. These four battery chargers are:

- C/10, 1.2 V, 1.2 Ah, representing chargers for **infrequently** used personal care products, such as electric shavers;
- C/10, 4.8 V, 1.2 Ah, representing chargers for **cradle** devices that typically remain in the charging cradle, such as handheld vacuums and kitchen appliances;
- C/8, 18 V, 1.5 Ah, representing chargers for **do-it-yourself (DIY)** power tools that are used sporadically; and
- 1 C, 18 V, 2.5 Ah, representing chargers for **professional** power tools that are used frequently.

For each of the above chargers, please use the tables on the following pages to describe the changes in factory cost and manufacturer's selling price associated with redesigning a baseline unit to achieve higher energy-efficiency levels. The efficiency levels are defined as:

0. The industry-average energy consumption for typical chargers manufactured today (i.e., the "baseline" charger).
1a. The energy consumption of infrequently-used and some cradle chargers with a wall adapter that meets CEC Tier 1 standards for external power supplies, adopted in January 2007.
1b. The energy consumption of chargers without a wall adapter (i.e., some cradle, DIY-tool, and pro-tool chargers) that meet the voluntary ENERGY STAR battery-charger standard.
2. The lowest energy consumption achieved by comparable battery chargers in the market today.
3. The lowest energy consumption feasible, regardless of price (e.g., by using premium components, redesigning the architecture, using exotic materials, etc.).

In the data tables that follow, the energy consumption target at each efficiency level is based on the results of tests commissioned by the Department of Energy, the Environmental Protection Agency, and the California Energy Commission, as well as NCI estimates. In each case, the energy-efficiency of a charger is evaluated in terms of its maintenancemode power and No-Battery mode power. The former is defined as the power consumed by the charger to maintain a fully-charged battery, while the latter is the power consumed by the charger once the battery or appliance has been disconnected from the charger.

In addition to providing the manufacturer's selling price of a unit that meets a given efficiency level, please also describe the design improvements that would be necessary to attain that level, as well as the resultant active mode efficiency exclusive of cell efficiency. Also, please estimate the incremental change in production cost over the baseline for each design improvement. If it is not possible to itemize the cost changes, please specify the total factory bill-of-materials (BOM) cost increase for all the improvements.

We would also welcome your input on the current distribution of battery chargers in each category by efficiency level, as well as the typical lifetime of the consumer products that use those chargers.

We recognize that detailed designs would be burdensome to prepare; therefore, in the interests of generating reasonable results in a short amount of time, we invite you to use your best judgment and experience when completing the following tables.

Please use the following design specifications for all chargers (or please indicate to us if one or more of these need modification):

Input voltage:	115 volts rms, 60 Hz
Input protection:	Primary current fuse
Unit volume:	500,000 units/year
Packaging:	Sealed plastic
Cord length:	6 feet
Regulatory compliance:	UL, FCC
Product lifetime:	> 2 years

Thank you for your input. If you have any questions or suggestions, please contact:

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Example: Infrequently-Used Charger; C/10, 1.2 V, 1.2 Ah;

The table on this page provides an example of the kind of information we are seeking to create an engineering-analysis cost-efficiency curve for battery chargers. In this particular example, we show one set of improvements for increasing the efficiency of a charger for a 1.2 V electric shaver to meet the requirements of the CEC Tier 1 external power supply standard. This example is purely illustrative, and should not be interpreted as the only path to making a CEC-compliant shaver adapter. However, this table does provide an indication of the level of detail being requested for the following tables. The column labeled “Incremental Change in Mfr. Production Cost” represents the cost of the specific improvement described. If additional rows are needed to describe all the design improvements you would make, please feel free to modify the tables. The column labeled “Total Mfr. Unit Selling Price” is your final selling price to your customers, such as retail chains or other manufacturers (for bundling with a consumer product).

#	Efficiency Level	Maint.-Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Mfr. Production Cost [$]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
0	Baseline: Lowest-cost Battery Charging System	0.80 W	0.60 W	30 %	60-Hz linear power supply	$0.69	$1.50	60 %
					Rectifier diode	$0.01		
					1.2 Ah NiMH cell	$0.30		

#	Efficiency Level	Maint.-Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Incremental Change in Mfr. Production Cost [+/- $]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
1a	Charger Wall Adapter Meets CEC Tier 1	0.70 W	0.50 W	60 %	Improved core steel	+ $0.20	$1.95	35 %
					Schottky diodes	+ $0.10		

BC 1: Infrequently Used Charger; C/10, 1.2 V, 1.2 Ah;

#	Efficiency Level	Maint. -Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Mfr. Production Cost [$]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
0	Baseline: Lowest-cost Battery Charging System	0.80 W	0.60 W					

#	Efficiency Level	Maint. -Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Incremental Change in Mfr. Production Cost [+/- $]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
1a	Charger with Wall Adapter that Meets CEC Tier 1	0.70 W	0.50 W					
2	Best in Market	0.35 W	0.04 W					
3	Maximum Technologically Feasible	0.10 W	0.01 W					

BC 2: Cradle Charger; C/10, 4.8 V, 1.2 Ah;

#	Efficiency Level	Maintenance Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Mfr. Production Cost [$]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
0	Baseline: Lowest-cost Battery Charging System	1.9 W	0.6 W					

#	Efficiency Level	Maintenance Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Incremental Change in Mfr. Production Cost [+/- $]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
1a	Charger with Wall Adapter that Meets CEC Tier 1	1.7 W	0.5 W					
2	Best in Market	1.5 W	0.4 W					
3	Maximum Technologically Feasible	0.5 W	0.05 W					

BC 3: DIY Tool Charger; C/8 18 V, 1.5 Ah;

#	Efficiency Level	Maint.-Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Mfr. Production Cost [$]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
0	Baseline: Lowest-cost Battery Charging System	6 W	1.5 W					

#	Efficiency Level	Maint.-Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Incremental Change in Mfr. Production Cost [+/- $]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
1b	Charger Meets ENERGY STAR Requirements	1.5 W	0.8 W					
2	Best in Market	1 W	0.3 W					
3	Maximum Technologically Feasible	0.3 W	0.1 W					

BC 4: Pro Tool Charger; 1 C, 18 V, 2.5 Ah;

#	Efficiency Level	Maint.-Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Mfr. Production Cost [$]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
0	Baseline: Lowest-cost Battery Charging System	4.7 W	2.1 W					

#	Efficiency Level	Maint.-Mode Power [W]	No-Battery Power [W]	Active-Mode Conversion Efficiency [%]	Defining Design Characteristics	Incremental Change in Mfr. Production Cost [+/- $]	Total Mfr. Unit Selling Price [$]	Proportion of Products at this Efficiency Level [%]
1b	Charger Meets ENERGY STAR Requirements	4.0 W	1.8 W					
2	Best in Market	3.0 W	1.0 W					
3	Maximum Technologically Feasible	1.2 W	0.1 W					

APPENDIX 5.B EPS Cost-Efficiency Estimation Survey

Navigant Consulting, Inc. (NCI) is conducting an engineering analysis to understand the relationship between manufacturers' cost and the efficiency[15] of EPSs. This engineering analysis is part of a larger determination analysis on whether the U.S. Department of Energy should conduct an energy conservation standards rulemaking on battery chargers and external power supplies (BC-EPSs). Through this worksheet, NCI is seeking your guidance on design changes you might make to external power supplies to improve their efficiency. All information you provide is covered by the Non-Disclosure Agreement between NCI and your company.

NCI is focusing its analysis on three *switch-mode* power supplies (SMPSs) with output powers of 75 W, 12 W and 2.75 W. NCI believes each of these units represents similar SMPSs. In particular:

- The 75 W, 12 V SMPS represents higher-power models that require power-factor correction (PFC) and therefore typically employ a two-stage forward topology;
- The 12 W, 12 V SMPS represents general-purpose models with a single-stage flyback topology and PWM controller IC; and
- The 2.75 W, 5 V SMPS represents lower-power models that typically employ a single-stage ring-choke converter topology, foregoing a PWM controller IC to save costs.

For each of the supplies, please describe the discrete design steps you would undertake to achieve the efficiency level and no-load power specification shown in the table. In each case, start with a baseline SMPS, and list the necessary design changes to enable it to meet the higher efficiency levels. The efficiency levels are defined to be:

0. The industry-average efficiency level, circa 2005, prior to the adoption of ENERGY STAR and California Energy Commission (CEC) Tier I, efficiency standards
1. The level specified by the (voluntary) EPA ENERGY STAR program in 2006 and (mandatory) CEC Tier I standard in 2007
2. The Tier II level adopted by the CEC, which will become the (mandatory) CEC standard on July 1, 2008.
3. The maximum efficiency level achieved by products in the market today.
4. The maximum efficiency level feasible regardless of price, using premium components and exotic materials.

For each design change, please also provide an estimate of your incremental production cost over the baseline, as well as the total unit selling price to an OEM or distributor. In case it is not possible to list the increase in cost per design change, please specify the total bill-of-materials (BOM) cost increase for all the improvements. Finally, please describe your markup structure to make it clear how increases in production costs impact the total per-unit manufacturer's selling price.

We recognize that detailed designs may be difficult to prepare; therefore, in the interests of generating reasonable results in a short space of time, we invite you to use your best judgment and experience when completing the following tables.

---

[15] "Efficiency" is used in this worksheet as a proxy for both conversion efficiency and no-load power.

Please use the following design specifications for all three SMPSs (or please indicate to us if one or more of these are problematic):

Input voltage:	115 volts rms, 60 Hz	Unit volume:	1 million units
Input protection:	Primary current fuse, inrush current limiting	Application:	Information technology/ consumer electronics
Output voltage regulation:	± 1% (excluding cord)	Package:	Sealed polycarbonate
Output voltage ripple:	1% V_{P-P} maximum	Output cord length:	6 feet
Transient response:	0.5 ms for 50% load change typical	Regulatory compliance:	UL, FCC, PFC for $P_{IN} > 75$ W
Output protection:	Overcurrent protection, short-circuit protection	Product lifetime:	> 2 years

Thank you for your input. If you have any questions or suggestions, please contact:

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202-481-7304	202-481-7323
Matt.Malinowski@NavigantConsulting.com	MVladimer@NavigantConsulting.com

The table on this page provides an example of the kind of information we need in order to create a cost-efficiency curve for SMPSs. In this particular example, we show one set of improvements for increasing the efficiency of an 80%-efficient 75 W, 12 V SMPS to meet the requirements of the ENERGY STAR program. This example is purely illustrative, and should not be taken as the only pathway to make a 75 W ENERGY-STAR SMPS. However, this table does provide an indication of the level of detail being requested for the tables on pages 3 through 5. The column labeled "Incremental Unit Cost per Improvement" represents the cost of the specific improvement described. If additional rows are needed to describe all the design changes you would make, please feel free to modify the tables. The column labeled "Total Mfr. Unit Selling Price" is your final selling price to your customers, such as OEMs or distributors.

Example: EPS 1: P_{OUT} = 75 W, V_{OUT} = 12 V

#	Efficiency Level	End-of-Cord Conversion Efficiency	No-Load Power	Defining Design Characteristics	Mfr. Production Cost	Total Mfr. Unit Selling Price
0	Baseline: lowest-cost SMPS	74%[16]	1 W	2-stage topology with PFC	-	$8
				UC3844 PWM controller	-	
				E-type transformer	-	
				Output rectifier w/ Schottkies	-	
				Size: 4 in x 2.5 in x 1.5 in	-	

#	Efficiency Level	End-of-Cord Conversion Efficiency	No-Load Power	Improvements over Baseline to Meet Efficiency Level	Incremental Cost (over Baseline) per Improvement	Total Mfr. Unit Selling Price
1	Efficiency Level III (ENERGY STAR, CEC Tier I)	84 %	0.75 W	Variable-frequency PWM controller IC	+ $0.05	$10
				Change in transformer due to higher IC switching frequency	+ $0.20	
				Additional filtering caps due to higher IC EMI	+ $0.12	
				Miscellaneous additional components (e.g., XXXXX)	+ $0.10	

---

[16] These are NCI's straw-man estimates of efficiency values. We welcome your input on these values.

EPS 1: P_{OUT} = 90 W, V_{OUT} = 12 V

#	Efficiency Level	End-of-Cord Conversion Efficiency[17]	No-Load Power	Defining Design Characteristics	Mfr. Production Cost	Total Mfr. Unit Selling Price
0	Baseline: lowest-cost SMPS	82%[18]	0.8 W[4]			

#	Efficiency Level	End-of-Cord Conversion Efficiency	No-Load Power	Improvements over Baseline to Meet Efficiency Level	Incremental Cost (over Baseline) per Improvement	Total Mfr. Unit Selling Price
1	Efficiency Level III (ENERGY STAR, CEC Tier I)	84%	0.75 W			
2	Efficiency Level IV (CEC Tier II)	85%	0.5 W			
3	Maximum Commercially Achieved (U.S. EPA, 2007)	88%	0.18 W			
4	Maximum Technologically Feasible	92%[4]	0.1 W[4]			

- **How do you apply markups to your production costs in order to arrive at an OEM and distributor selling price?**

---

[17] Conversion efficiency, as defined by DOE, ENERGY STAR, and CEC test procedures, is the arithmetic mean of efficiencies at 100%, 75%, 50%, and 25% of maximum rated output current.

[18] These are NCI's straw-man estimates of efficiency values. We welcome your input on these values.

EPS 2: P_{OUT} = 18 W, V_{OUT} = 12 V

#	Efficiency Level	End-of-Cord Conversion Efficiency[19]	No-Load Power	Defining Design Characteristics	Mfr. Production Cost	Total Mfr. Unit Selling Price
0	Baseline: lowest-cost SMPS	67%[20]	1.4 W[6]			

#	Efficiency Level	End-of-Cord Conversion Efficiency	No-Load Power	Improvements over Baseline to Meet Efficiency Level	Incremental Cost (over Baseline) per Improvement	Total Mfr. Unit Selling Price
1	Efficiency Level III (ENERGY STAR, CEC Tier I)	75%	0.5 W			
2	Efficiency Level IV (CEC Tier II)	76%	0.5 W			
3	Maximum Commercially Achieved (U.S. EPA, 2007)	85%	0.06 W			
4	Maximum Technologically Feasible	88%[6]	0.04 W[6]			

- **How do you apply markups to your production costs in order to arrive at an OEM and distributor selling price?**

---

[19] Conversion efficiency, as defined by DOE, ENERGY STAR, and CEC test procedures, is the arithmetic mean of efficiencies at 100%, 75%, 50%, and 25% of maximum rated output current.

[20] These are NCI's straw-man estimates of efficiency values. We welcome your input on these values.

EPS 3: P_{OUT} = 2.75 W, V_{OUT} = 5 V

#	Efficiency Level	End-of-Cord Conversion Efficiency[21]	No-Load Power	Defining Design Characteristics	Mfr. Production Cost	Total Mfr. Unit Selling Price
0	Baseline: lowest-cost SMPS	55%[22]	0.77 W[8]			

#	Efficiency Level	End-of-Cord Conversion Efficiency	No-Load Power	Improvements over Baseline to Meet Efficiency Level	Incremental Cost (over Baseline) per Improvement	Total Mfr. Unit Selling Price
1	Efficiency Level III (ENERGY STAR, CEC Tier I)	58%	0.5 W			
2	Efficiency Level IV (CEC Tier II)	59%	0.5 W			
3	Maximum Commercially Achieved (U.S. EPA, 2007)	72%	0.02 W			
4	Maximum Technologically Feasible	75%[8]	0.01 W[8]			

---

[21] Conversion efficiency, as defined by DOE, ENERGY STAR, and CEC test procedures, is the arithmetic mean of efficiencies at 100%, 75%, 50%, and 25% of maximum rated output current.

[22] These are NCI's straw-man estimates of efficiency values. We welcome your input on these values.

APPENDIX 5.C Example BC Teardown Analysis Report

Cost Estimate - External Power Supplies

BC #2 Rev. B

Estimate conducted by:	J. Wexler
Date:	2Dec07
EPS Testing Label Number:	2
Maximum Rated Output Power [W]:	6.3
Output Voltage [V]	15
Regulation Type:	switch mode
Manufacturer:	China-made for Philips
Model Number	8000X
Estimated part costs taken from:	Mouser, Digi-Key
Total number of parts:	54; 23 leaded, 31surface mount
Estimated Total Cost [$]	$2.529

Cost per part breakdown breakdown:

Part Type	**mount: Surface/ Lead**	**Part Details**	**Part count**	**Cost/ part [$]**	**Cost [$]**
Choke	L	Axial lead choke 3.9mH TDK in Mouser	2	0.35	0.70
Diode	L	FR07	5	0.05	0.25
Capacitor	L	10uF, 400V	1		0.23
Capacitor	L	1500pF ceramic	1		0.025
Zener	L	1/2W	4	0.025	0.10
Resistor	L	1/4W	2	0.012	0.024
Diode	L	1N4148	2	0.02	0.04
Transistor	L	TO-92 STBV32	1		0.10
Capacitor	L	100uF 25V	1		0.10
Capacitor	L	0.47uF 50V	1		0.05
Diode	L	HEF02	1		0.07
Transformer	L	Flyback choke	1		0.40
Choke	L	Ferrite bead wound as small common mode choke	1		0.10
Resistor	S	0603	13	0.007	0.091
Resistor	S	1206	13	0.012	0.156
Capacitor	S	0603	3	0.014	0.042
Transistor	S	SOT-23	1		0.03
Zener	S	SOT-23	1		0.021

CHAPTER 6 ENERGY USE AND END-USE LOAD CHARACTERIZATION

LIST OF FIGURES

LIST OF TABLES

6.1 Introduction

For the determination analysis, the Department of Energy (DOE) calculated unit energy consumption (UEC) using a combination of the inputs described in the following sections. The UEC represented the weighted average energy consumption of a single unit within a representative product class, and allowed for the simplified calculation of aggregate savings when combined with shipments. As a simplification, DOE assumed that the power and energy requirements of external power supply (EPS) applications would not change during the analysis period. In this section, DOE describes the calculation of usage profiles and unit energy consumption for battery chargers and for external power supplies.

6.2 Battery Chargers

6.2.1 Battery Charger Usage Profiles

For the determination analysis, DOE developed usage profiles for each of the four representative product classes of battery chargers (BCs) by considering how their associated applications are used. Given the lack of published data on the subject, DOE relied heavily on input from industry experts to determine how applications are used.

DOE developed usage patterns for each BC application, as an expression of the total time (in hours) spent per week in active mode, maintenance mode, no-battery mode, and stowed/unplugged. To better capture energy consumption across all potential usage behaviors, active mode and a portion of maintenance mode were grouped into 24-hour charge cycles. A 24-hour charge cycle is composed of the time spent in active mode to charge the battery and the remaining hours, which are spent in maintenance mode. Therefore, the modified usage profiles were expressed as a combination of the number of 24-hour charge cycles, additional time spent in maintenance mode, no-battery mode, and unplugged. Figure 6.1 and Table 6.1 detail the weekly usage profiles for each BC application.

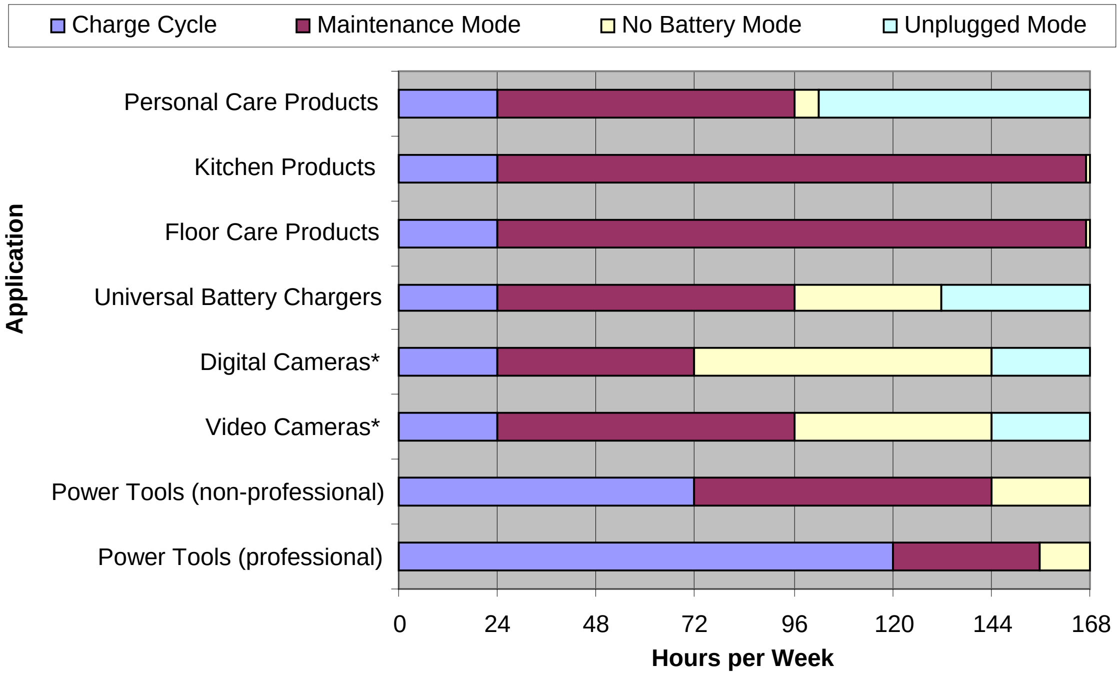

Figure 6.1. Weekly Usage Profiles for BC Applications

Source: DOE, based on input from the Power Tool Institute and the Association of Home Appliance Manufacturers.
* Only those digital cameras and camcorders that have a separate charging base and a battery designed to be removed from the camera for charging were considered BC applications.

Table 6.1. Weekly Usage Profiles for BC Applications–Numeric Values

Representative Product Class	Product Application	Weekly Usage Profile			
		Number of 24-Hour Charge Cycles	**Maintenance Mode Hours**	**No-Battery Mode Hours**	**Unplugged Hours**
Class A (0 to ≤ 3 V)	Personal Care Products	1	72	6	66
Class B (3 < to ≤ 9 V)	Kitchen Products	1	143	1	0
	Floor Care Products	1	143	1	0
	Universal Battery Chargers	1	72	36	36
	Digital Cameras*	1	48	72	24
	Video Cameras*	1	72	48	24
	All Applications (shipment-weighted avg.)	1	83	38	23
Class C (> 9V, Slow Charge)	Power Tools (non-professional)	3	72	24	0
Class F (> 9V, Fast Charge)	Power Tools (professional)	5	36	12	0

Source: DOE, based on input from the Power Tool Institute and the Association of Home Appliance Manufacturers.

* Only those digital cameras and camcorders that have a separate charging base and a battery designed to be removed from the camera for charging were considered BC applications.

6.2.2 Battery Charger Energy Consumption

For the determination, DOE expressed BC energy consumption as the sum of energy consumed during 24-hour charge cycles (UEC_{24hr}), maintenance mode ($UEC_{Maintenance}$) and no-battery mode ($UEC_{NoBattery}$). DOE calculated energy consumption for each representative product class using the following formulas:

$$UEC = (UEC_{24hr} + UEC_{Maintenance} + UEC_{NoBattery}) * 365/7 \qquad \textbf{Eq. 6.1}$$

Where:

$$UEC_{24hr} = E_{24hr} \times N_{24hr}$$
$$UEC_{Maintenance} = P_{Maintenance} * t_{Maintenance}$$
$$UEC_{NoBattery} = P_{NoBattery} * t_{NoBattery}$$

and

E_{24} represents the energy consumed from mains by the battery charging system during a 24 hour charge cycle, less the energy capacity of the battery, expressed in watt-hours (Wh);
N_{24} represents the total number of 24-hour charge cycles per week;
$P_{Maintenance}$ represents the average input power consumption of the battery charging system while in maintenance mode, expressed in watts (W);
$t_{Maintenance}$ represents the time spent per week in maintenance mode, expressed in hours per week;
$P_{NoBattery}$ represents the average input power consumption of the battery charging system while in no-battery mode, expressed in watts;
$t_{NoBattery}$ represents the time spent per week in no battery mode, expressed in hours per week; and
365/7 represents the adjustment for converting weekly energy consumption to annual energy consumption.

6.2.2.1 E_{24}, $P_{Maintenance}$, $P_{NoBattery}$

From the engineering analysis in chapter 5, DOE calculated 24-hour energy consumption, maintenance mode input power, and no-battery mode input power value pairs for each representative product class at each candidate standard level CSL. Table 6.2 gives these values.

Table 6.2. Energy Consumption Characteristics by Representative Product Class and Efficiency Level

Representative Product Class	Characteristic	Efficiency Level				
		CSL 0	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**
Class A (0 to ≤ 3 V)	E24 (Wh)	55.0	22.0	14.0	10.0	7.0
	PMaintenance (W)	2.4	1.0	0.7	0.5	0.3
	PNoBattery (W)	0.9	0.5	0.5	0.3	0.2
Class B (3 < to ≤ 9 Volts(V))	E24 (Wh)	60.0	48.0	45.0	40.0	20.0
	PMaintenance (W)	2.0	1.8	1.7	0.9	0.7
	PNoBattery (W)	0.7	0.5	0.4	0.3	0.2
Class C (> 9V, Slow Charge)	E24 (Wh)	150.0	90.0	43.0	40.0	25.0
	PMaintenance (W)	9.4	3.8	2.4	1.7	1.0
	PNoBattery (W)	1.0	1.1	1.3	0.6	0.3
Class F (> 9V, Fast Charge)	E24 (Wh)	140.0	135.0	110.0	93.0	58.0
	PMaintenance (W)	14.2	5.0	4.2	2.7	1.7
	PNoBattery (W)	6.0	5.5	1.5	1.2	0.5

Based on these inputs, DOE calculated the following values for UEC for each representative product class and each CSL.

Table 6.3. Unit Energy Consumption by Representative Product Class and Efficiency Level (kilowatt hours per year (kWh/yr)

	Efficiency Level				
Representative Product Class	**CSL 0**	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**
Class A (0 to ≤ 3 V)	12.0	4.9	3.5	2.5	1.5
Class B (3 to ≤ 9 V)	13.2	11.3	10.6	6.6	4.3
Class C (> 9V, Slow Charge)	60.0	29.5	17.4	13.4	8.0
Class F (> 9V, Fast Charge)	66.9	48.0	37.5	30.1	18.6

6.3 External Power Supplies

6.3.1 External Power Supply Usage Profiles

For the determination analysis, DOE developed usage profiles for each of the three representative product classes of EPSs by considering how the associated applications are used. DOE developed usage patterns for each EPS application, as an expression of the total time (in hours) spent per week in active mode, no-load mode, and stowed/unplugged.

Considerable information was available on usage of EPS powered applications. DOE used the following sources to develop usage profiles for EPS applications:

Porter, Moorefield, Ostendorp. Final Field Research Report. October 2006. Ecos Consulting: Durango, CO.

Rosen and Meier. Energy Use of Consumer Electronics at the End of the 20th Century. 2000. Lawrence Berkeley National Laboratory: Berkeley, CA.

Roth, Ponoum, and Goldstein. US Residential Information Technology Energy Consumption in 2005 and 2010. May 2006. TIAX: Cambridge, MA

TIAX LLC. Assessment of Analyses Performed for the California Energy Efficiency Regulations for Consumer Electronics Products. Prepared by TIAX for CEA. 2 February 2006. TIAX LLC: Cambridge, MA.

Figure 6.2 and Table 6.4 show the usage profiles DOE developed for EPS applications.

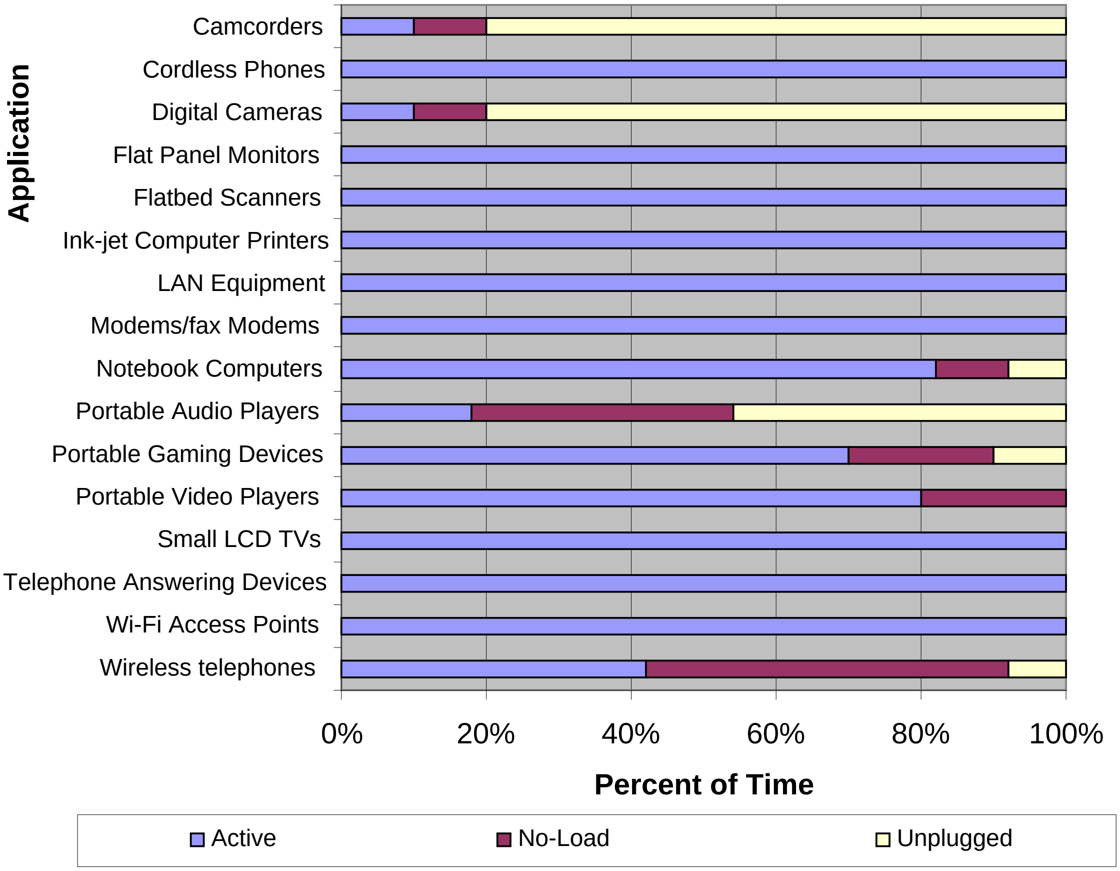

Figure 6.2. Usage Profiles for EPS Applications

Table 6.4. Usage Profiles for EPS Applications

Product Application	Usage Profile Percent Time Spent in Active Mode	Percent Time Spent in No-load Mode	Percent Time Spent Unplugged
Camcorders	10	10	80
Cordless Phones	100	0	0
Digital Cameras*	10	10	80
Flat Panel Monitors	100	0	0
Flatbed Scanners	100	0	0
Ink-Jet Computer Printers	100	0	0
LAN Equipment	100	0	0
Modems/Fax Modems	100	0	0
Notebook Computers	82	10	8
Portable Audio Players	18	36	46
Portable Gaming Devices	70	20	10
Portable Video Players	80	20	0
Small LCD TVs	100	0	0
Telephone Answering Devices	100	0	0
Wi-Fi Access Points	100	0	0
Wireless telephones	42	50	8

* Only those digital cameras and camcorders that used an EPS in combination with an integrated charger and battery designed to remain in the camera for charging were considered EPS applications.

6.3.2 External Power Supply Energy Consumption

EPS energy consumption is the sum of energy consumed in active mode (UEC_{active}) and in no-load mode (UEC_{NL}).

To calculate energy consumption for EPS, DOE first calculated UECs for each application, then calculated an average UEC for each representative product class based on shipment weighting in each representative product class. This is in contrast to BCs, for which DOE calculated UECs for each representative product class based on weighted average usage and consumption characteristics. . This was due primarily to the greater availability of data on the usage and energy consumption for EPS applications, as well as the fact that many applications spanned multiple representative product classes. In addition, DOE assumed the UEC of an EPS application to be a function of EPS nameplate output power and application usage, both of which vary considerably from application to application.

DOE calculated energy consumption for a given application and efficiency level using the following formulas:

$$UEC = UEC_{active} + UEC_{NL} \qquad \textbf{Eq. 6.2}$$

Where:

$$UEC_{active} = \frac{(1-\eta_{active})}{\eta_{active}} \times P_{out} \times D \times t_{active}$$

$$UEC_{NL} = P_{NL} * t_{NL}$$

and
η_{active} represents the active mode conversion efficiency of the EPS, expressed as percentage;
P_{out} represents the nameplate output power of the EPS, expressed in watts;
D represents the capacity factor of the EPS, based on the application, expressed as percentage;
t_{active} and t_{NL} represents the active mode time and no-load mode time, based on the usage profile previously discussed in this section, expressed in hours per year; and
P_{NL} represents the no-load input power, expressed in watts.

6.3.2.1 Active Mode Conversion Efficiency, No-Load Input Power

From the engineering analysis in chapter 5, DOE calculated active mode conversion efficiencies and no-load input power value pairs for each CSL. Table 6.5, taken from chapter 5, Table 5.7 gives these values.

Table 6.5 EPS Active Mode Conversion Efficiency and No-Load Input Power by Efficiency Level

		Efficiency Level						
		CSL 0	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL5**	**CSL 6**
Representative Product Class A (0 to < 4 W)	Active Mode Conversion Efficiency	30%	55%	58%	59%	65%	72%	75%
	No-Load Input Power (W)	2.00	0.80	0.50	0.50	0.40	0.30	0.20
Representative Product Class B (4 ≤ to ≤ 60 W)	Active Mode Conversion Efficiency	66%	71%	75%	76%	80%	85%	88%
	No-Load Input Power (W)	2.00	1.50	0.75	0.50	0.40	0.20	0.15
Representative Product Class F (>60 W)	Active Mode Conversion Efficiency	N/A*	78%	84%	85%	87%	89%	92%
	No-Load Input Power (W)	N/A*	2.00	0.75	0.50	0.40	0.31	0.15

*During the determination, DOE found that all EPSs from representative product class F were already switch mode, therefore no values were calculated for CSL 0.

6.3.2.2 Nameplate Output Power

Table 6.6 lists the average nameplate output power for each application as used in the determination. Where applications spanned two representative product classes, separate average nameplate output powers were estimated for each. DOE used data from the qualified product (QP) list for ENERGY STAR end-use products and matched these applications with their associated EPSs in the QP list for ENERGY STAR qualified EPSs.[1,2] For each application, DOE calculated the average nameplate output power of the associated EPSs. These estimates were verified by examining the distribution of EPS shipments across output powers in a report produced for the California Energy

Commission.[3] This report was also used to estimate the average nameplate output power for those applications not included in the ENERGY STAR product lists.

Table 6.6. Average EPS Nameplate Output Power by Applications

	Average Nameplate Output Power (W)		
Application	**Representative Product Class A <4W**	**Representative Product Class B 4-60W**	**Representative Product Class F >60W**
Camcorders	-	8	-
Cordless Phones	2.75	5	-
Digital Cameras	2.75	8	-
Flat Panel Monitors	-	40	70
Flatbed Scanners	-	20	-
Ink-Jet Computer Printers	-	25	-
LAN Equipment	-	12	-
Modems/Fax Modems	-	20	70
Notebook Computers	-	60	90
Portable Audio Players	2.75	6	-
Portable Gaming Devices	-	8	-
Portable Video Players	-	15	-
Small LCD TVs	-	45	70
Telephone Answering Devices	2.75	5	-
Wi-Fi Access Points	-	10	-
Wireless Telephones & PDAs	2.75	5	-

6.3.2.3 External Power Supply Capacity Factor

For the determination, DOE used capacity factors to account for the fact that nearly all EPS-powered applications draw only a fraction of the nameplate output power of their EPS at any given time. This is because by definition, active mode accounts for all the time an EPS is plugged into mains and attached to an application. Many applications have multiple energy-consuming states that may fall under active mode consumption. To account for the variety of energy consuming active mode states, and using the same sources as those used to develop overall usage profiles, DOE then subdivided active mode into four states, including a) high-power start-up or energy-intensive states, b) medium power normal mode states, c) lower power idle states while “on”, and, d) “off” states. To estimate capacity factor, DOE considered the output power (as a percentage of nameplate output power) and time spent in each state (as a percentage of active mode time). DOE then calculated capacity factor as the weighted average of all states. Table 6.7 shows the values used in the determination analysis. Where DOE could not determine capacity factor due to lack of information on either output power or time spent in each state, it used a default of 50 percent for capacity factor.

Table 6.7 External Power Supply Active Mode Capacity Factors

Camcorders

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Charging	80	25	20
	Battery Maintenance	18	75	13.5
		Total Time	100%	Sum Product
	Capacity Factor			33.5%

Cordless Phones

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Charging Handset	80	60	48
	Transmitting	69	5	4.8
	Standby	58	35	20.3
		Total Time	100	Sum Product
	Capacity Factor			73.1%

Digital Cameras

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Charging	80	25	20
	Battery Maintenance	18	75	13.5
		Total Time	100	Sum Product
	Capacity Factor			33.5%

Flat Panel Monitors

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Active	80	26	20.8
	Sleep	5	1	0.1
	Off	3	73	2.2
		Total Time	100	Sum Product
	Capacity Factor			23.1%

Flatbed Scanners

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Active	80	1	0.8
	Sleep	37	71	26.3
	Off	13	28	3.6
		Total Time	100%	Sum Product
	Capacity Factor			30.7%

Ink-Jet Computer Printers

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Printing	80	1	0.8
	Sleep	24	18	4.3
	Off	9	81	7.3
		Total Time	100	Sum Product
	Capacity Factor			12.4%

LAN Equipment				
EPS Mode	**Application State**	**Percent of Nameplate Output Power (A)**	**Percent of Time (B)**	**Product (A×B) (Percent)**
Active Mode	Active	80	100	80
		Total Time	100	Sum Product
	Capacity Factor			80%

Modems/Fax Modems				
EPS Mode	**Application State**	**Percent of Nameplate Output Power (A)**	**Percent of Time (B)**	**Product (A×B) (Percent)**
Active Mode	Active	80	100	80
		Total Time	100	Sum Product
	Capacity Factor			80%

Notebook Computers				
EPS Mode	**Application State**	**Percent of Nameplate Output Power (A)**	**Percent of Time (B)**	**Product (A×B) (Percent)**
Active Mode	High Power	80	13	10.4
	Low Power	33	14	4.6
	Sleep	3	11	0.3
	Off	3	62	1.9
		Total Time	100	Sum Product
	Capacity Factor			17.2%

Portable Audio Players				
EPS Mode	**Application State**	**Percent of Nameplate Output Power (A)**	**Percent of Time (B)**	**Product (A×B) (Percent)**
Active Mode	Active	80	4	3.2
	Sleep	59	7	4.1
	Off	34	89	30.3
		Total Time	100	Sum Product
	Capacity Factor			37.6%

Portable Gaming Devices

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Charging	80	50	40
	Battery Maintenance	20	50	10
		Total Time	100	Sum Product
	Capacity Factor			50%

Portable Video Players

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Charging	80	50	40
	Battery Maintenance	20	50	10
		Total Time	100	Sum Product
	Capacity Factor			50%

Small LCD TVs

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Active	80	17	13.6
	Off	3	83	2.5
		Total Time	100%	Sum Product
	Capacity Factor			16.1%

Telephone Answering Devices

EPS Mode	Application State	Percent of Nameplate Output Power (A)	Percent of Time (B)	Product (A×B) (Percent)
Active Mode	Play/Record	80	1	0.8
	Standby	71	99	70.3
		Total Time	100%	Sum Product
	Capacity Factor			71.1%

Wi-Fi Access Points				
EPS Mode	**Application State**	**Percent of Nameplate Output Power (A)**	**Percent of Time (B)**	**Product (A×B) (Percent)**
Active Mode	Active	80	100	80
		Total Time	100	Sum Product
	Capacity Factor			80%

Wireless Telephones				
EPS Mode	**Application State**	**Percent of Nameplate Output Power (A)**	**Percent of Time (B)**	**Product (A×B) (Percent)**
Active Mode	Charging Handset	80	20	16
	Transmitting	15	2	0.3
	Standby	6	78	4.7
		Total Time	100	Sum Product
	Capacity Factor			21%

6.3.2.4 Calculating Unit Energy Consumption by Application and Efficiency Level

Using the inputs and formula given above, DOE calculated a UEC for each combination of application, efficiency level, and representative product class. These values are given in

Table 6.8, Table 6.9, and Table 6.10. Using shipment weighting within each representative product class, DOE then calculated UECs for each representative product class at each efficiency level. These values are shown in the last row of the tables.

Table 6.8 Unit Energy Consumption of EPSs in Representative Product Class A (kWh/yr)

Application	Efficiency Level						
	CSL 0	**CSL 1**	**CSL 2**	**CSL 3**	**CSL 4**	**CSL 5**	**CSL 6**
Camcorders	-	-	-	-	-	-	-
Cordless Phones	40.47	14.19	12.56	12.05	9.34	6.75	5.78
Digital Cameras	3.61	1.35	1.01	0.99	0.78	0.57	0.44
Flat Panel Monitors	-	-	-	-	-	-	-
Flatbed Scanners	-	-	-	-	-	-	-
Ink-Jet Computer Printers	-	-	-	-	-	-	-
LAN Equipment	-	-	-	-	-	-	-
Medical Devices	39.48	14.02	12.04	11.59	9.00	6.52	5.49
Modems/Fax Modems	-	-	-	-	-	-	-
Notebook Computers	-	-	-	-	-	-	-
Portable Audio Players	10.05	3.84	2.74	2.69	2.13	1.57	1.17
Portable Gaming Devices	-	-	-	-	-	-	-
Portable Video Players	-	-	-	-	-	-	-
Small LCD TVs	-	-	-	-	-	-	-
Telephone Answering Devices	39.91	13.99	12.39	11.89	9.21	6.65	5.70
Wi-Fi Access Points	-	-	-	-	-	-	-
Wireless Telephones	13.72	5.24	3.73	3.67	2.90	2.14	1.58
Representative Product Class A UEC	**21.30**	**7.76**	**6.25**	**6.06**	**4.73**	**3.45**	**2.79**

Table 6.9 Unit Energy Consumption of EPSs in Representative Product Class B (kWh/yr)

Application	Efficiency Level						
	CSL 0	**CSL 1**	**CSL 2**	**CSL 3**	**CSL4**	**CSL 5**	**CSL 6**
Camcorders	3.56	2.75	1.83	1.54	1.23	0.79	0.61
Cordless Phones	16.25	12.88	10.51	9.96	7.88	5.57	4.30
Digital Cameras	2.94	2.26	1.43	1.17	0.93	0.58	0.45
Flat Panel Monitors	41.52	32.92	26.86	25.45	20.15	14.22	10.99
Flatbed Scanners	27.98	22.18	18.10	17.15	13.58	9.58	7.41
Ink-Jet Computer Printers	14.67	11.63	9.49	8.99	7.12	5.02	3.88
LAN Equipment	43.32	34.35	28.03	26.56	21.02	14.84	11.47
Medical Devices	55.49	43.85	34.95	32.74	25.93	18.16	14.02
Modems/Fax Modems	72.20	57.25	46.72	44.26	35.04	24.73	19.11
Notebook Computers	39.50	31.24	25.08	23.58	18.67	13.10	10.12
Portable Audio Players	8.11	6.16	3.53	2.68	2.14	1.25	0.95
Portable Gaming Devices	16.14	12.65	9.49	8.62	6.83	4.68	3.61
Portable Video Players	30.58	24.10	18.83	17.47	13.84	9.63	7.43
Small LCD TVs	32.49	25.76	21.02	19.92	15.77	11.13	8.60
Telephone Answering Devices	16.02	12.70	10.37	9.82	7.77	5.49	4.24
Wi-Fi Access Points	36.10	28.62	23.36	22.13	17.52	12.37	9.56
Wireless Telephones	10.75	8.15	4.57	3.41	2.72	1.56	1.18
Representative Product Class B UEC	**29.39**	**23.15**	**18.03**	**16.69**	**13.22**	**9.18**	**7.09**

Table 6.10 Unit Energy Consumption of EPSs in Representative Product Class F (kWh/yr)

Application	Efficiency Level						
	CSL 0	CSL 1	CSL 2	CSL 3	CSL 4	CSL 5	CSL 6
Camcorders		-	-	-	-	-	-
Cordless Phones		-	-	-	-	-	-
Digital Cameras		-	-	-	-	-	-
Flat Panel Monitors		39.78	26.86	24.89	21.07	17.43	12.26
Flatbed Scanners		-	-	-	-	-	-
Ink-Jet Computer Printers		-	-	-	-	-	-
LAN Equipment		-	-	-	-	-	-
Medical Devices		114.19	76.07	70.13	59.34	49.05	34.39
Modems/Fax Modems		138.36	93.44	86.57	73.30	60.63	42.66
Notebook Computers		32.75	21.59	19.83	16.77	13.86	9.69
Portable Audio Players		-	-	-	-	-	-
Portable Gaming Devices		-	-	-	-	-	-
Portable Video Players		-	-	-	-	-	-
Small LCD TVs		27.67	18.69	17.31	14.66	12.13	8.53
Telephone Answering Devices		-	-	-	-	-	-
Wi-Fi Access Points		-	-	-	-	-	-
Wireless Telephones		-	-	-	-	-	-
Representative Product Class C UEC		**40.63**	**27.04**	**24.92**	**21.09**	**17.43**	**12.21**

References

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[1] Environmental Protection Agency. *Qualified Product (QP) List for ENERGY STAR End-Use Products*. http://energystar.gov/ia/products/prod_lists/eup_prod_list.xls. Last Accessed December 17, 2007.

[2] Environmental Protection Agency. *Qualified Product (QP) List for ENERGY STAR Ac-Dc Qualified External Power Supplies*. http://www.energystar.gov/ia/products/prod_lists/eps_ac_dc_prod_list.pdf. Last accessed December 17, 2007.

[3] TIAX LLC. "Assessment of Analyses Performed for the California Energy Efficiency Regulations for Consumer Electronics Products." February 2006. TIAX LLC: Cambridge, MA.

CHAPTER 7. PRODUCT PRICE DETERMINATION

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7.1 Introduction

The purpose of the product price determination is to assess the impacts of the relationship between efficiency and manufacturer selling price (MSP) on end users. Therefore, during the determination analysis, DOE developed a retail (consumer) price for each candidate standard level (CSL) used in the life-cycle cost (LCC) and pay back period (PBP) analyses and the national impact analysis. DOE used MSP estimates (chapter 5) and studied the distribution value chain for battery chargers (BCs) and external power supplies (EPSs) moving from manufacturer to end user. With that information, DOE calculated a manufacturer-to-retail markup to convert MSP estimates to retail price estimates. DOE also developed a sales tax estimate, which it applied to the retail price estimates to arrive at end-user product prices.

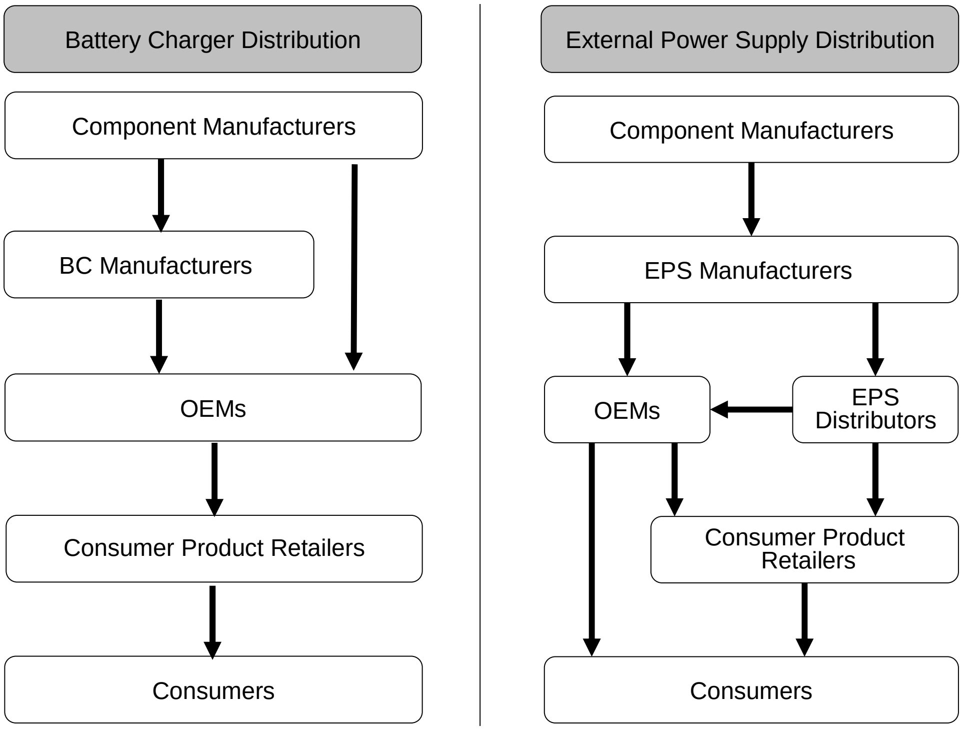

Figure 7.1. BC and EPS Product Distribution Networks

Figure 7.1 shows the distribution networks for BCs and EPSs discussed in chapter 3. DOE estimated MSPs in its engineering analysis. To estimate OEM and retailer markups, DOE used publicly available data on the gross margins of major publicly traded manufacturers and retailers.[1] Gross margin represents that portion of revenues that are over and above the cost of goods sold. The cost of goods sold includes variable and fixed costs directly linked to the product, such as material and labor. DOE used the following formula to derive markups from gross margins:

$$Markup = 1 + \frac{GrossMargin}{1 - GrossMargin}$$ **Eq.7.1**

7.2 Battery Charger Markups

Table 7.1 displays the retailers and their respective gross margins, which DOE used to estimate markups for the determination analysis. DOE chose these retailers because they represent significant distribution channels for BC-powered applications. For BCs, DOE did not derive separate original equipment manufacturer (OEM) markups, because it received information from manufacturers about the prices at which BCs are sold to retailers.

Table 7.1. Retailer Markups for Battery Chargers

Battery Voltage	Dominant Applications	Leading Retailers	Gross Margin (%)	Markup
Representative Product Class A				
0 to ≤ 3 V	Personal care products	Wal-Mart	24.21	1.32
		Target	32.74	1.49
		CVS	22.83	1.30
		Walgreens	28.35	1.40
Average Markup				**1.37**
Representative Product Class B				
>3 to ≤ 9 V	Universal battery chargers, digital cameras, kitchen and floor care appliances	Wal-Mart	24.21	1.32
		Target	32.74	1.49
		Best Buy	23.99	1.31
		Sears	28.37	1.40
		Bed Bath & Beyond	42.47	1.74
Average Markup				**1.45**
Representative Product Classes C and F				
> 9 V	Power tools	Home Depot	32.65	1.48
		Lowe’s	34.76	1.53
Average Markup				**1.51**

Note: Gross margins current as of December 21, 2007.

The sales tax represents state and local sales taxes and is a multiplicative factor that increases the end-user product price. DOE obtained information on state and local sales taxes from the Sales Tax Clearinghouse. The Clearinghouse was established in August 1999 to facilitate the calculation of sales and use taxes administered by the Nation's 7,000 taxing authorities at the State, county, and city levels.[2] DOE used a national, population-weighted average sales tax of 6.9 percent in its determination analysis.

Using the sales tax information and information on markups by OEMs and retailers, DOE calculated the total markup for representative BC product classes (Table 7.2).

Table 7.2. BC Manufacturer-to-Consumer Markups

	Battery Voltage			
	0 to ≤ 3 V	**>3 to ≤ 9 V**	**> 9 V Slow Charging**	**>9 V Fast Charging**
Retailer Markup	1.37	1.45	1.51	1.51
Sales Tax	1.069	1.069	1.069	1.069
Total Markup	*1.46*	*1.55*	*1.61*	*1.61*

Note: Total markup equals the product of the three markups. Multiplying the manufacturer selling price by the total markup yields the consumer purchase price.

Take, for example, low-voltage BCs, whose battery voltage is less than or equal to 3 volts. The manufacturer selling prices DOE used as inputs in its preliminary BC analysis represent the prices at which BCs are sold to retailers. DOE found that the principal retailers mark up products by 37 percent over their wholesale price, resulting in a markup of 1.37. The Sales Tax Clearinghouse reported a national average sales tax of 6.9 percent or 1.069. Multiplying these markups gives a total markup of 46 percent or 1.46 for low-voltage BCs. DOE used the same process to arrive at manufacturer-to-consumer markups for EPSs and other BCs.

7.3 External Power Supply Markups

Most EPSs are manufactured for an OEM and sold through a retailer to the consumer. DOE gathered gross margin data of major OEM manufacturers in each representative product class, in addition to gross margins for major retailers of those products (Table 7.3 and Table 7.4). Because the retail outlets for the dominant EPS product applications are similar, DOE used a single retailer markup for all EPSs. During work on its determination analysis, DOE did not adjust its gross margin figures to account for alternate distribution patterns for EPSs, such as direct sales from an OEM to a consumer.

Table 7.3. OEM Markups for External Power Supplies

Representative Product Classes A and B				
Nameplate Output Power	**Dominant Applications**	**Leading OEMs**	**Gross Margin (%)**	**Markup**
0 to < 4 W and ≥ 4 to ≤ 60 W	Telecommunications equipment	Nokia	32.73	1.49
		Motorola	27.22	1.37
Average Markup				**1.43**

Representative Product Class F				
Nameplate Output Power	**Dominant Applications**	**Leading OEMs**	**Gross Margin (%)**	**Markup**
> 60 W	Notebook computers	Dell, Inc.	18.71	1.23
		Hewlett Packard	24.36	1.32
		Apple, Inc.	33.97	1.51
Average Markup				**1.37**

Table 7.4. Retailer Markups for External Power Supplies

All Representative Product Classes				
Nameplate Output Power	**Dominant Applications**	**Leading Retailers**	**Gross Margin (%)**	**Markup**
All EPSs	Consumer electronics	Best Buy	24.00	1.32
		Circuit City	22.50	1.29
		Wal-Mart	24.21	1.32
Average Markup				**1.31**

Using the sales tax information and information on markups by OEMs and retailers, DOE calculated the total markup for representative EPS product classes (Table 7.5.

Table 7.5. EPS Manufacturer-to-Consumer Markups

	Nameplate Output Power		
	0 to < 4 W	**≥ 4 to ≤ 60 W**	**> 60 W**
OEM Markup	1.43	1.43	1.36
Retailer Markup	1.31	1.31	1.31
Sales Tax	1.069	1.069	1.069
Total Markup	*2.00*	*2.00*	*1.90*

Note: Total markup equals the product of the three markups. Multiplying the manufacturer selling price by the total markup yields the consumer purchase price.

References

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[1] Yahoo! Finance. . . . http://finance.yahoo.com. . . . Last accessed December 21, 2007.

[2] Further information on the Sales Tax Clearinghouse can be found at www.thestc.com.

CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

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8.1 Introduction

This chapter describes the methodology that the Department of Energy (DOE) used to analyze the economic impacts of possible energy efficiency standards on individual consumers. DOE performed this analysis for the determination analysis on the same representative units evaluated in the engineering analysis. The effect of standards on individual consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). This chapter describes the two metrics DOE used in the consumer analysis to determine the effect of potential standards on individual consumers:

- **Life-cycle cost** (LCC) is the total consumer expense over the life of an appliance, including purchase price 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.

- **Payback period** (PBP) measures the amount of time it takes customers to recover the assumed higher purchase price of more energy-efficient equipment through lower operating costs. It represents the number of years it would take the customer to recover the increased purchase price through decreased operating expenses.

DOE analyzed the net effect on consumers by calculating the LCC and PBP using data from the engineering analysis, the energy-use and end-use load characterization, and the product price determination.

8.2 Overview of LCC and PBP Inputs

For the determination analysis, DOE categorized inputs to the LCC and PBP analysis as follows: (1) inputs for establishing the purchase price, 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 cost*, or the costs incurred by the manufacturer to produce equipment meeting existing minimum efficiency standards;

- *standard-level manufacturer cost increases*, or the change in manufacturer cost associated with producing equipment to meet a particular standard level; and

- *markups and sales tax*, or the markups and sales tax associated with converting the manufacturer cost to a consumer equipment price (chapter 7).

The primary inputs for calculating the operating cost are:

- *equipment energy consumption*, the site energy use associated with operating the equipment;

- *equipment efficiency*, which dictates the equipment energy consumption associated with standard-level equipment (*i.e.*, equipment with efficiencies greater than baseline equipment);

- *energy prices*, the prices paid by consumers for energy (*i.e.*, electricity), determined using current energy prices based on data from DOE‘s Energy Information Administration (EIA);

- *energy price trends* , derived from the EIA *Annual Energy Outlook 2007* (*AEO2007*) to forecast energy prices into the future[a];

- *lifetime*, the age at which the equipment is retired from service; and

- *discount rate*, the rate at which DOE discounted future expenditures to establish their present value.

Figure 8.1 presents the flow diagram for the draft determination analysis LCC developed in 2007. The figure depicts, from left to right, LCC inputs in yellow boxes, interim calculated values in green boxes, and final output values (*i.e.*, LCC and PBP) in blue boxes. Table 8.1. lists the draft inputs DOE developed in 2007 for the determination analysis.

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[a] For the results presented in this chapter, DOE used the *AEO2007* reference case to forecast future energy prices.

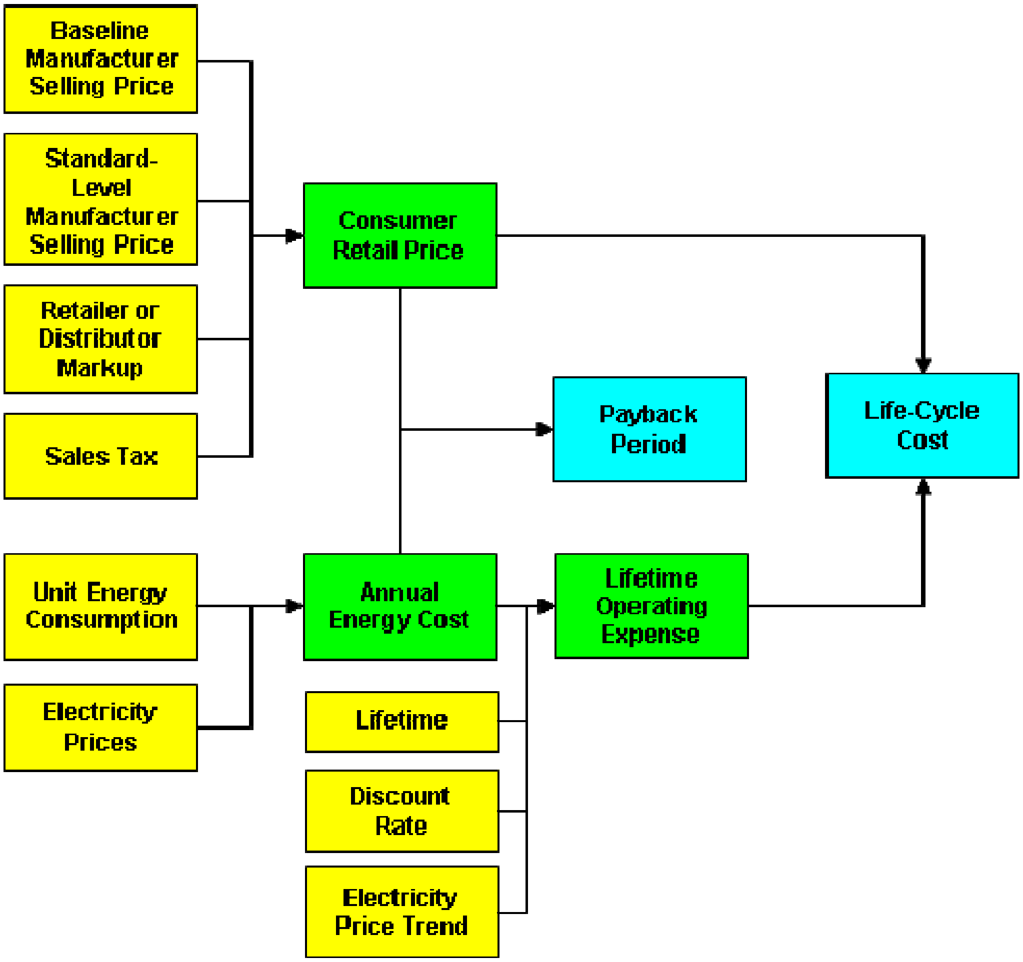

Figure 8.1. Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1. Draft Inputs to the Life-Cycle Cost and Payback Period Analysis

Input	**Description**	**Average or Typical Value**	**Sources**
Product Price	The retail price before tax (*i.e.*, bundled with a consumer product). Based on a manufacturer selling price marked up through the distribution chain.	Varies	Distributor catalogs, high-volume price estimates, manufacturer interviews.
Sales Tax	Used to convert the product price to a final consumer purchase price including sales tax.	6.9%	Weighted average of sales tax in 13 geographic regions and large states.
Unit Energy Consumption	The annual on-site electricity consumption associated with a BC or EPS.	Varies	Developed in section 6, Energy-use and End-use Load Characterization.
Electricity Prices	The national residential sector average price per kilowatt-hour (*i.e.*, $/kWh).	$0.097/kWh in 2005	Energy Information Administration (EIA), discussed in section 8.3.3.
Electricity Price Trends	Projects changes in the price of electricity over the analysis period. Includes a high and low scenario.	Varies	The Annual Energy Outlook from the EIA.
Product Lifetime	The total years in use after which the consumer retires the BC or EPS from service. The BC or EPS may be retired before the end of its useful life if the consumer product it operates is retired from service.	3 - 5 years	Discussed in section 8.3.5.
Discount Rate	The rate DOE estimates to be representative of BC and EPS consumers, used to discount future expenditures and establish their present value.	5.6%	Weighted average of residential financing methods, discussed in section 8.3.4.
Analysis Period	The time period over which DOE calculates the LCC.	Product lifetime	Discussed in section 8.3.5.

8.3 Life-Cycle Cost Inputs

When calculating the LCC, DOE discounted future operating costs to the time of purchase and summed them over the lifetime of the equipment, as shown in Equation 1:

$$LCC = IC + \sum_{t=1}^{N} \frac{OC_t}{(1+r)^t} \quad \textbf{Eq.8-1}$$

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 product in years,
OC = operating cost in dollars,
r = discount rate, and
t = year for which operating cost is being determined.

DOE conducted preliminary work on the LCC as part of its determination analysis directed by EPACT 2005. The text that follows discusses some of these inputs and methodologies that DOE was developing when the analysis was rescheduled.

DOE developed an LCC methodology based on the approach followed in other rulemakings, but tailored it for some unique aspects of BCs and EPSs. For example, while the equation above mentions “total installed cost” in its list of LCC input variables, DOE considers these costs to be just the equipment price, because BCEPS installation typically entails a consumer simply unpacking the BC or EPS from the box it was sold in and connecting the device to mains power and its associated product or battery. Because the cost of this “installation” (which may be considered temporary, as intermittently used devices might be unplugged for storage) is not quantifiable in dollar terms, DOE considers the installation cost to be zero.

The following sections discuss total installed cost, operating cost, lifetime, and discount rate.

8.3.1 Total Installed Cost Inputs

DOE defines the total installed cost using the following equation:

$$IC = EQP \quad \textbf{Eq.8-2}$$

where:

IC= total installed cost, expressed in dollars, and
EQP = equipment price *(i.e.,* purchase price for the equipment only), expressed in dollars.

The equipment price is based on how the consumer purchases the equipment. DOE defined markups and sales taxes for converting manufacturing costs into consumer equipment prices. For BCs and EPSs the cost of installation is zero; therefore, it is not included in the equation.

There are four inputs that determine total installed cost.

- Baseline Manufacturer Cost
- Standard-Level Manufacturer Cost
- Markups
- Sales Tax

The *baseline manufacturer cost* is the cost incurred by the manufacturer to produce equipment meeting existing minimum efficiency standards. *Standard-level manufacturer cost increases* are the change in manufacturer cost associated with producing equipment at a standard level. *Markups and sales tax* convert the manufacturer cost to a consumer equipment price. Thus, the total installed cost accounts for all factors contributing to the consumer equipment price. DOE calculated the total installed cost for baseline products based on the following equation:

$$\begin{aligned} IC_{BASE} &= EQP_{BASE} \\ &= COST_{MFG} \times MU_{OVERALL} \end{aligned} \qquad \textbf{Eq.8-3}$$

where:

IC_{BASE} = baseline total installed cost,
EQP_{BASE} = consumer equipment price for baseline models,
$COST_{MFG}$ = manufacturer cost for baseline models, and
$MU_{OVERALL}$ = overall markup (product of manufacturer markup, retailer or distributor markup, and sales tax).

DOE calculated the total installed cost for standard-level products based on the following equation:

$$\begin{aligned} IC_{STD} &= EQP_{STD} \\ &= \left(EQP_{BASE} + \Delta EQP_{STD}\right) \\ &= \left(IC_{BASE} + \Delta COST_{MFG}\right) \times MU_{OVERALL} \end{aligned} \qquad \textbf{Eq.8-4}$$

where:

IC_{STD} = standard-level total installed cost,
EQP_{STD} = consumer equipment price for standard-level models,
EQP_{BASE} = consumer equipment price for baseline models,
ΔEQP_{STD} = change in equipment price for standard-level models,
IC_{BASE} = baseline total installed cost, and
$\Delta COST_{MFG}$ = change in manufacturer cost for standard-level models.
$MU_{OVERALL}$ = overall markup (product of manufacturer markup, retailer or distributor markup, and sales tax).

DOE researched information about each of the above input variables that it used to calculate the total installed cost for external power supplies and battery chargers. DOE developed its manufacturer prices through manufacturer interviews, testing and teardowns, and researching distributor catalogues (chapter 5). OEM, distributor, and retailer markups came from manufacturer interviews and a review of publicly available company financial filings. Sales tax was based on a weighted average in 13 geographic regions and large states (Table 8.2).

Table 8.2. Sales Tax by Division and Large States

	State/Region	**Sales Tax (%)**
1	New England	4.8
2	Mid Atlantic	7.1
3	East North Central	15.5
4	West North Central	6.7
5	South Atlantic	13.0
6	East South Central	5.9
7	West South Central	3.6
8	Mountain	7.0
9	Pacific	4.0
10	New York State	6.4
11	California	12.2
12	Texas	7.9
13	Florida	6.0
	U.S. Average	6.9

8.3.2 Operating Cost Inputs

DOE defines the operating cost by the following equation:

$OC = EC$ **Eq.8-5**

where:

OC = operating cost, expressed in dollars, and
EC = energy expenditure associated with operating the equipment.

Although operating costs typically encompass repair and maintenance costs, DOE considered those costs (which are usually associated with larger products and appliances) to be zero in the draft LCC for the determination analysis. In making this decision, DOE recognized the reality of the marketplace, where the service life of a BC or EPS typically exceeds that of the consumer product with which it is designed to operate. Thus, a consumer would not incur repair or maintenance costs for a BC or EPS. Also, if a BC or EPS did fail, DOE expects that consumers would typically discard the device and purchase a replacement BC or EPS.

The inputs for determining the operating costs are listed below.

- Annual Energy Consumption
- Energy Prices
- Energy Trends
- Product Lifetime
- Discount Rate
- Effective Date of Standard

The *annual energy consumption* is the site energy use associated with operating the equipment. The annual energy consumption varies with the product efficiency. That is, the energy consumption associated with standard-level equipment (*i.e.*, equipment with efficiencies greater than baseline equipment) is less than the consumptions associated with baseline equipment. *Energy prices* are the prices paid by consumers for energy (*i.e.*, electricity). Multiplying the annual energy by the energy prices yields the annual energy cost. DOE used *energy price trends* to forecast energy prices into the future and, along with the product lifetime and discount rate, to establish the lifetime energy costs. The *product 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 baseline products based on the following equation:

$$\begin{aligned} OC_{BASE} &= EC_{BASE} \\ &= AEC_{BASE} \times PRICE_{ENERGY} \end{aligned} \qquad \textbf{Eq.8-6}$$

where:

OC_{BASE} = baseline operating cost,
EC_{BASE} = energy expenditure associated with operating the baseline equipment,
AEC_{BASE} = annual energy consumption for baseline equipment, and
$PRICE_{ENERGY}$ = energy price.

DOE calculated the operating cost for standard-level products based on the following equation:

$$\begin{aligned} OC_{STD} &= EC_{STD} \\ &= AEC_{STD} \times PRICE_{ENERGY} \\ &= \left(AEC_{BASE} - \Delta AEC_{STD}\right) \times PRICE_{ENERGY} \end{aligned} \qquad \textbf{Eq.8.7}$$

where:

OC_{STD} = standard-level operating cost,
EC_{STD} = energy expenditure associated with operating standard-level equipment,
AEC_{STD} = annual energy consumption for standard-level equipment,

$PRICE_{ENERGY}$ = energy price,
ΔAEC_{STD} = change in annual energy consumption caused by standard-level equipment, and
AEC_{BASE} = annual energy consumption for baseline equipment.

The following sections provide information about electricity prices, discount rate, and product lifetime that DOE used to calculate the operating costs for external power supplies and battery chargers. Annual energy consumption is discussed in chapter 6.

8.3.3 Electricity Prices

For residential consumers of BCs and EPSs, DOE used projections of national average electricity prices from EIA's *Annual Energy Outlook* (*AEO*) for the most recent year available. In other rulemakings, DOE has calculated a regionally-weighted average electricity price, based on inventories of products developed through EIA's Residential Energy Consumption Survey. This data allows the electricity price used in the LCC to be more accurate if products have different regional sales rates (*i.e.*, heaters in colder regions). However, the survey did not include questions on inventories of BCs and EPSs; therefore, DOE was unable to create a national installed-base-weighted average electricity price. Instead, DOE used the national average electricity price, as published by EIA.

To ascertain the sensitivity of the LCC to future electricity price trends as well as the reference case, DOE evaluated the LCC using both the low and high economic growth cases. Together, these three cases reflect the uncertainty in electricity prices over the analysis period. Figure 8.2 presents the residential electricity price trends (in constant 2007$), based on *AEO 2007* projections.

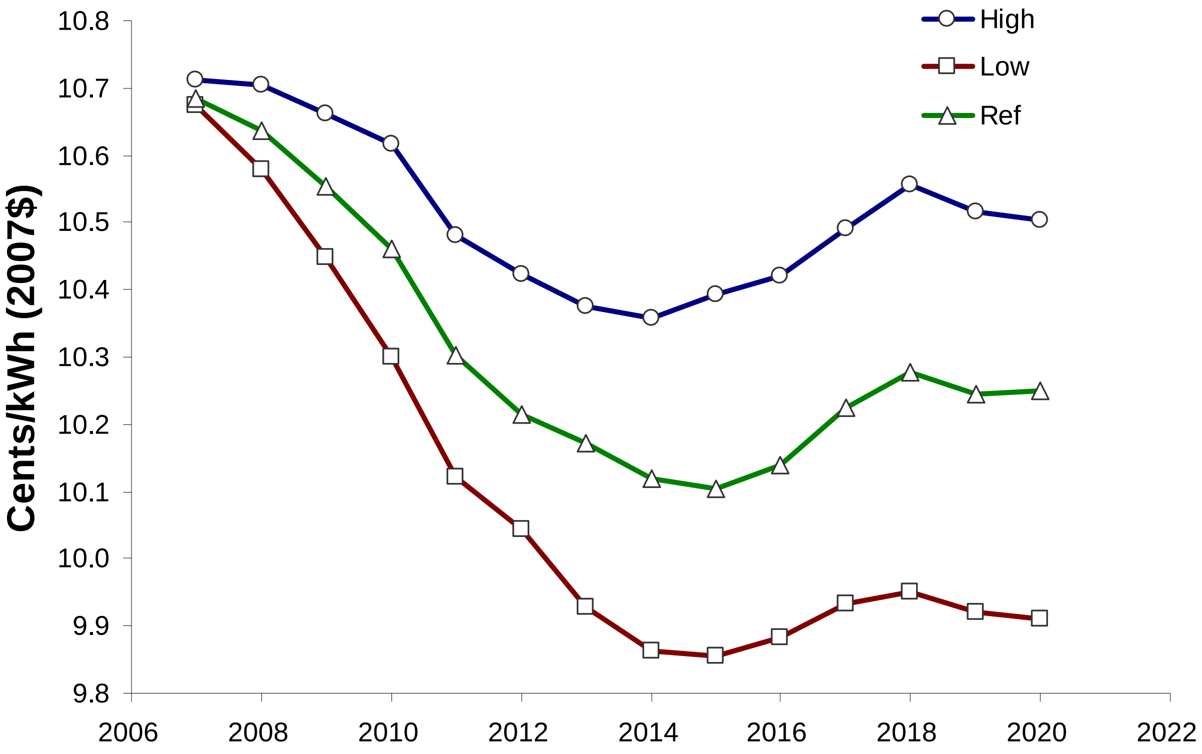

Figure 8.2. AEO 2007 Residential Electricity Price Trend Forecast

8.3.4 Life-Cycle Cost Discount Rates

Discounting reflects the current value of money spent or saved in the future. As discussed, calculating consumer LCC required DOE to use a discount rate to determine the present value of the money the consumer would spend to operate the BCs and EPSs over their lifetime. Because consumers can use a variety of financial means to purchase a BC or EPS, the discount rate should equal the average cost of capital to the consumer. DOE assumed these financial means, listed in Table 8.3, to be similar to the ones consumers use when purchasing and financing replacement appliances for the home.

DOE adapted the LCC discount rate derived in the home appliances rulemaking to its draft analysis. DOE's approach involved identifying all possible debt or asset classes that consumers might use to purchase replacement equipment, including household assets that might be affected indirectly.

DOE estimated the shares of the various debt and equity classes in the typical U.S. household portfolio using the Federal Reserve's *Survey of Consumer Finances* (*SCF*) data for 1989, 1992, 1995, 1998, 2001, and 2004. DOE also used *SCF* data to determine rates of return for each class. DOE then calculated an average rate weighted by the share of each class of debt or equity, equal to 5.6 percent, to represent a household discount rate, shown in Table 8.3.

Table 8.3. Shares and Interest or Return Rates Used for Household Debt and Equity Types

Type	Average Share of Household Debt Plus Equity* (%)	Mean Real Effective Discount Rate** (%)
Home Equity Loans	3.6	4.0
Credit Cards	2.0	11.0
Other Installment Loans	1.7	6.0
Other Residential Loans	4.9	4.6
Other Line of Credit	0.5	8.7
Checking Accounts	4.5	0.0
Savings and Money Market Accounts	15.7	2.3
Certificates of Deposit	9.0	2.4
Savings Bonds	1.5	3.5
Bonds	10.0	4.2
Stocks	29.1	8.8
Mutual Funds	17.5	7.0
Total/Weighted-Average Discount Rate	100	**5.6**

* Not including primary mortgage or retirement accounts.

** Adjusted for inflation and, for home equity loans, loan interest tax deduction.

8.3.5 BC and EPS Operational Lifetimes

Lifetime data are important for determining life-cycle costs and payback periods. In the NIA, lifetime data allow for an estimate of the total stock of EPSs being used. Because BCs and EPSs are often made specifically for use with particular consumer products, their lifetimes relate directly to the lifetimes of those products. DOE assumed that once the consumer product has reached the end of its useful life, the user typically discards the associated BC or EPS. Therefore, for each group of BCs and EPSs, DOE gathered lifetime values for consumer product applications and combined them with shipment estimates to derive a shipment-weighted average lifetime representative of the group. Average lifetimes for BC and EPS applications are shown in Table 8.4 and Table 8.6.

DOE estimated lifetimes for categories that include multiple applications by examining the lifetimes of popular applications within them. For example, DOE examined the lifetimes of shavers, beard trimmers, hand-held massagers, and heating pads and used their relative shipments to derive the lifetime of personal care products. With shipments data and these application lifetimes, DOE calculated the shipment-weighted average lifetime of each representative product class of BCs and EPSs. These values are shown in 1. Appliance Magazine. . *30th Annual Portrait of the U.S. Appliance Industry.* . September 2007.

2. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. . *FY2005 Preliminary Priority-Setting Summary Report and Actions Proposed. . Appendix A: FY2005 Technical Support Document. . Table A9-1:*

Background Data on Battery Chargers and Power Supplies. Cited henceforth as *DOE FY05 Rulemaking Appendix A9*.

Table 8.5 and Table 8.7.

Table 8.4. Average Lifetimes for Battery Charger Applications

Representative Product Class	Application	Lifetime (Years)	Source
A	Personal Care Products	3	Appliance Magazine[1]
B	Kitchen Products	6	Appliance Magazine[1]
	Floor Care Products	6	Appliance Magazine[1]
	Universal Battery Chargers	4	DOE estimate
	Digital Cameras	6	DOE FY05 Rulemaking Appendix A9[2]
	Camcorders	6	DOE FY05 Rulemaking Appendix A9[2]
C	DIY Power Tools	5	DOE estimate
F	Pro Power Tools	5	DOE estimate

1. Appliance Magazine. . *30th Annual Portrait of the U.S. Appliance Industry*. . September 2007.
2. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. . *FY2005 Preliminary Priority-Setting Summary Report and Actions Proposed. . Appendix A: FY2005 Technical Support Document. . Table A9-1: Background Data on Battery Chargers and Power Supplies*. Cited henceforth as *DOE FY05 Rulemaking Appendix A9*.

Table 8.5. Shipment-Weighted Average Lifetimes for Battery Chargers

	Battery Voltage			
	0 to ≤ 3 V	**>3 to ≤ 9 V**	**> 9 V Slow Charging**	**>9 V Fast Charging**
Lifetime	3 years	5 years	5 years	5 years

Table 8.6. Average Lifetimes for External Power Supply Applications

Application	**Lifetime (Years)**	**Source**
Ink-Jet Computer Printers	5	DOE FY05 Rulemaking Appendix A9
Notebook Computers	4	DOE FY05 Rulemaking Appendix A9
Modems/Fax Modems	4	DOE FY05 Rulemaking Appendix A9
LAN Equipment	4	DOE FY05 Rulemaking Appendix A9
Wi-Fi Access Points	4	DOE FY05 Rulemaking Appendix A9
Flat Panel Monitors	4	DOE FY05 Rulemaking Appendix A9
Flatbed Scanners	4	Estimated based on average computer peripheral lifetime
Portable Video Players	4	Estimated based on TV/VCR/DVD combined lifetime of 6 years, adjusting for increased wear and tear
Cordless Phones	6	DOE FY05 Rulemaking Appendix A9
Wireless Telephones	2	DOE FY05 Rulemaking Appendix A9
Telephone Answering Devices	6	DOE FY05 Rulemaking Appendix A9
Digital Cameras	6	DOE FY05 Rulemaking Appendix A9
Portable Gaming Devices	2	Estimated based on fast turnover of gaming operating systems and software, as well as greater wear and tear relative to stationary gaming systems.
Small LCD TVs	6	DOE FY05 Rulemaking Appendix A9
Portable Audio Players	6	DOE estimate
Camcorders	6	DOE FY05 Rulemaking Appendix A9

Table 8.7. Shipment-Weighted Average Lifetimes for External Power Supplies

	Nameplate Output Power		
	0 to < 4 W	**≥ 4 to ≤ 60 W**	**> 60 W**
Lifetime	4 years	5 years	4 years

References

1. Appliance Magazine. . *30th Annual Portrait of the U.S. Appliance Industry.* . September 2007.

2. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. . *FY2005 Preliminary Priority-Setting Summary Report and Actions Proposed.* . *Appendix A: FY2005 Technical Support Document.* . *Table A9-1: Background Data on Battery Chargers and Power Supplies*. . (Last accessed March 3, 2006.) www.eere.energy.gov/buildings/appliance_standards/pdfs/fy05_priority_setting_app_a.pdf.

CHAPTER 9. SHIPMENTS ANALYSIS

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9.1 Current Year Shipments

In its work on the determination analysis, DOE estimated that 70 million battery chargers and 397 million external power supplies were sold in the United States in 2007. DOE divided total shipments into the BC and EPS representative product classes described in chapter 3.

9.1.1 Battery Charger Shipments

Based on its analysis and input from manufacturers, DOE divided BC applications into three representative product classes, grouped by battery voltage. Because of the prevalence of fast chargers for professional power tool applications, the analysis of the high-voltage product class C further focused on two representative units differing in charge rate. Table 9.1 shows the distribution of BC shipments by representative product class.

Table 9.1. Battery Charger Shipments by Representative Product Class in 2007

Representative Product Class	**Dominant Applications**	**Total Shipments (millions)**
Class A (0 to ≤ 3 V)	Personal Care Products	5.1
Classes B (>3 to ≤ 9 V)	Kitchen Products Floor Care Products Universal BCs Digital Cameras Camcorders	41.7
Class C (> 9 V)	Power Tools	22.8
All Groups	All Applications	69.6

Table 9.2 shows the distribution of BC shipments by candidate standard level (CSL) used in the determination analysis. To divide the shipments of BCs among the CSLs (discussed in chapter 5 of the Draft Technical Report), DOE began with a large dataset published by the California Energy Commission, counting the number of models that met each CSL.[1] However, DOE included in the count only those BCs with a battery voltage close to those of the representative units. As a result, the sample sizes are relatively small.

Table 9.2. Distribution of BC Shipments Across Efficiency Levels by Representative Product Class in 2007

CSL	**Efficiency Level**	**Class A (0 to ≤ 3 V) (percent)**	**Class B (>3 to ≤ 9 V) (percent)**	**Class C (>9 V) (percent)**
CSL0	Baseline	60	45	65
CSL1	Slightly Improved	20	13	10
CSL2	CEC Tier 1/ENERGY STAR	13	26	10
CSL3	Beyond Standard	0	10	15
CSL4	Best-in-Market Technology	7	6	0
All Levels		100	100	100

Product class A had a representative unit with a battery voltage of 1.2 volts, but DOE included in the count all units with a battery voltage between 0 volts and 3 volts to ensure an adequate sample size. Similarly, the representative unit for product class B had a battery voltage of 4.8 volts, but DOE included in the count all units with a battery voltage between 3.6 volts and 6 volts. For product class C, DOE included all BCs with a battery voltage between 18 volts and 19.2 volts. DOE did not differentiate between fast and slow models when counting BCs in this class.

The final count used to distribute BCs among the CSLs included 15 units for representative product class A, 62 for product class B, and 20 for product class C. Table 9.3 shows how representative units from the dataset were distributed among the CSLs for representative product class B.

Table 9.3. Distribution of BCs in Representative Product Class B by CSL

CSL	**Efficiency Level**	**Number of Units, 3.6 to 6 V**	**Percent of Total**
CSL0	Base Line	*33*	45
CSL1	Slightly Improved	*8*	13
CSL2	CEC Tier 1/ENERGY STAR	*22*	26
CSL3	Beyond Standard	*6*	10
CSL4	Best-in-Market	*7*	6
All Levels		*62*	*100*

Because shipments data for the individual BCs in the dataset were not available, the BC models in the dataset that DOE included in the count were not weighted by their shipments. Thus, the base case distribution in Table 9.3 is only a rough representation of the population of BCs in the market.

9.1.2 External Power Supply Shipments

DOE divided EPSs into three representative product classes based on nameplate output power. However, many applications using an EPS spanned two product classes. DOE referred to prior work by the California Energy Commission on consumer electronic products for guidance on fitting applications into the three representative product classes.[2]

Table 9.4 shows the distribution of EPS application shipments across product classes; Table 9.5 shows the total EPS shipments in each product class.

Table 9.4. Distribution of EPS Application Shipments Across Representative Product Classes in 2007 (as a Percentage of Total Shipments)

Application	Class A 0 to < 4 W (percent)	Class B ≥ 4 to ≤ 60 W (percent)	Class F > 60 W (percent	All Classes (percent)
Ink-Jet Computer Printers	0	100	0	100
Notebook Computers	0	15	85	100
Modems/Fax Modems	0	92	8	100
LAN Equipment	0	100	0	100
Wi-Fi Access Points	0	100	0	100
Flat Panel Monitors	0	100	0	100
Flatbed Scanners	0	100	0	100
Medical Devices	10	87	3	100
Portable Video Players	0	100	0	100
Cordless Telephones	75	25	0	100
Cellular Telephones	50	50	0	100
Telephone Answering Devices	50	50	0	100
Digital Cameras	25	75	0	100
Portable Gaming Devices	0	100	0	100
Small LCD Tvs	0	70	30	100
Portable Audio Players	40	60	0	100
Camcorders	0	100	0	100

Table 9.5. External Power Supply Shipments by Representative Product Class in 2007

Representative Product Class	Shipments (millions)
Class A (0 to < 4 W)	112.2
Class B (≥ 4 to ≤ 60 W)	249.5
Class F (> 60 W)	35.5

During work on the determination analysis, DOE found limited information on the distribution of shipments by efficiency level. The Darnell Group forecasted that in 2007, 21 percent of EPSs on the market would use line-frequency technology and the remaining EPSs would use switched-mode technology.[3] However, during the Scoping Workshop in January 2007, some stakeholders noted that this figure was too high.[4] For simplicity, DOE assumed that line-frequency EPSs made up 20 percent of 2007 shipments (79.4 million of 397.2 million total EPSs). Although some of the available line-frequency power supplies met CSL2, the specific number of shipments was unknown. DOE estimated that the number is likely to be very small. To simplify matters, DOE assumed that all line-frequency power supplies fell into CSL0, and divided the remaining 80 percent among the higher CSLs.

Information gathered during work on the engineering analysis suggested that as output power increases, line-frequency power supplies become less common. DOE assumed product class F contained no line-frequency supplies. DOE also assumed that half of all line-frequency power supplies are in product class A (39.7 million of 112.2 million EPSs) and half in product class B (39.7 million of 249.5 million EPSs). Thus, 35 percent of total shipments in product class A fell in CSL0. In product class B, 16 percent of total shipments fell in CSL0.

Before CEC Tier 1 became a mandatory standard in California, a 2004 study completed by Pacific Gas and Electric estimated that 40 percent of the market already met the qualifications, which corresponded to CSL2.[5] DOE assumed this 40 percent was distributed evenly across representative product classes.[a] In product class A, if 35 percent of EPSs are in CSL0 and 40 percent meet CSL2 or better, then the remaining 25 percent meet CSL1. Applying this logic to representative product classes B and F, CSL1 comprises 44 and 60 percent of EPSs in each class, respectively (Table 9.6).

Table 9.6. Distribution of External Power Supply Shipments by Efficiency – Part 1

CSL	**Efficiency Level**	**Group A (0 to < 4 W) (percent)**	**Group B (≥ 4 to ≤ 60 W) (percent)**	**Group F (> 60 W) (percent)**
CSL0	Baseline Line Frequency	35	16	0
CSL1	Baseline SMPS	25	44	60
CSL2	CEC 1	40	40	40
CSL3	CEC 2			
CSL4	> CEC 2			
CSL5	Market Best			
CSL6	Max Tech			
All Levels		100	100	100

The study further estimated that 25 percent of the 2004 EPS market was at least as efficient as CEC Tier 2 Standards, corresponding to CSL3. With this information, DOE calculated the percentage of EPSs in CSL2 as 15 percent - the remainder of the original 40 percent meeting CEC Tier 1 or better (Table 9.7). DOE assumed that no products on the market met the max-tech efficiency level (CSL6).

Table 9.7. Distribution of External Power Supply Shipments by Efficiency – Part 2

CSL	**Efficiency Level**	**Group A 0 to < 4 W (percent)**	**Group B ≥ 4 to ≤ 60 W (percent)**	**Group F > 60 W (percent)**
CSL0	Baseline Line Frequency	35	16	0
CSL1	Baseline SMPS	25	44	60
CSL2	CEC 1	15	15	15
CSL3	CEC 2	25	25	25
CSL4	> CEC 2			
CSL5	Market Best			
CSL6	Max Tech	0	0	0
Total		100	100	100

To divide the final 25 percent of shipments among CSL3, CSL4, and CSL5, DOE used the ENERGY STAR list of qualified EPS units.[6] DOE examined a subset of EPSs

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[a] The CEC Tier 1 standard that California adopted is slightly more stringent than that suggested by the literature above. This should not have a significant impact on the percentage of the market that already met the standard.

whose nameplate output power matched that of the representative units (developed in the engineering analysis) in each representative product class. Units selected met or exceeded CSL3 active mode efficiency. The list included 10 units at 2.75 watts, 39 units at 18 watts, and 16 units at 120 watts, which were then divided among CSL3, CSL4, and CSL5. Table 9.8 shows the categorization of units at 2.75 watts by active mode efficiency. DOE applied the same technique to representative product classes B and F. Because shipments data for the individual EPSs in the data set were not available DOE did not weight the EPSs in CSL3, CSL4, and CSL5 by their shipments. Thus, the distribution in those CSLs may not have accurately represented the population of EPSs shipped to the market.

Table 9.8. Distribution of 2.75-Watt External Power Supply Models by Efficiency

CSL	Name	Number of Units, 2.75 W	Percent of Total
CSL3	CEC 2	*5*	*50*
CSL4	> CEC 2	*4*	*40*
CSL5	Market Best	*1*	*10*
CSL6	Max Tech	*0*	*0*
Total		*10*	*100*

This last piece of information provides the entire distribution of shipments across efficiency levels that DOE used in its determination analysis.

Table 9.9. Final Distribution of Shipments by Efficiency for External Power Supplies

CSL	Name	Group A 0 to < 4 W (percent)	Group B ≥ 4 to ≤ 60 W (percent)	Group F > 60 W (percent)
CSL0	Baseline Line Frequency	*35*	*16*	*0*
CSL1	Baseline SMPS	*25*	*44*	*60*
CSL2	CEC 1	*15*	*15*	*15*
CSL3	CEC 2	*12*	*6*	*9*
CSL4	> CEC 2	*10*	*18*	*5*
CSL5	Market Best	*3*	*1*	*11*
CSL6	Max Tech	*0*	*0*	*0*

9.2 Base Case Shipments Forecasts

9.2.1 Total Annual Shipments

To evaluate the various impacts of standards, DOE developed a base case shipments forecast against which to compare the standards case shipments forecasts developed for each CSL. For the determination analysis, DOE designed the base case forecasts based on what it anticipated would happen to energy consumption and energy costs over time if federal energy conservation standards were not adopted. In determining the base case forecasts, DOE considered historical shipments, the mix of BC and EPS efficiencies currently sold, and how that mix might change over time if new standards are not adopted.

The base case shipments model tracked the aging and replacement of BCs and EPSs given product lifetimes (chapter 8) and projected future BC and EPS sales growth. Shipments growth rates for many applications using BCs and EPSs have been historically high. This has been especially true for higher-wattage EPS applications. Also, as applications incorporate more features, output powers have risen to accommodate them. For example, compared to a basic cellular telephone, cellular telephones that incorporate a digital camera and PDA functionality require a higher-capacity battery and therefore an EPS with a higher output power to charge it.

In the determination analysis, DOE used the constant annual growth rates in Table 9.10 as reference values. These growth rates considered historic shipments of BCs and EPSs, market saturation of those products, and U.S. population growth. High saturation of consumer products would tend to slow growth in BC and EPS shipments. DOE considered population growth, which was projected to average 0.79 percent per year during the analysis period (2014 to 2039) to be the lower bound of its considered growth rates.[7]

Because recent improvements in battery charging systems such as shorter charge times helped increase demand for BCs, DOE estimated growth rates to be 4 percent per year for each BC product class. Because of a high saturation of cellular telephones and their dominance in the 0 to 4 watt EPS category, DOE estimated growth to be only 2 percent per year over the analysis period for this product class. EPSs with higher output have been growing more quickly in recent years, with the highest output category experiencing the fastest growth and the least saturation. DOE estimated that EPSs between 4 and 60 watts would grow 3 percent per year and EPSs above 60 watts would grow 4 percent per year between 2014 and 2039.

Table 9.10. Base Case Shipments Growth Rates for BCs and EPSs

Battery Chargers	**Compound Annual Growth Rate (percent)**
All Representative Product Classes	4

External Power Supplies	**Compound Annual Growth Rate (percent)**
Representative Product Class A (0 to < 4 W)	2
Representative Product Class B (≥ 4 and ≤ 60 W)	3
Representative Product Class F (> 60 W)	4

9.2.2 Natural Progression of Efficiency Over Time

To provide an upper and lower bound for estimated energy savings in the NIA, DOE considered two possibilities for the natural market state of efficiencies over time.

Natural in this case referred to improvements in efficiency that might take place independent of a federal standard. These two market states, static and dynamic, presented situations in which the BC and EPS markets would experience either no improvement in efficiency (static) or progressive improvements in efficiency (dynamic).

To simplify calculations, DOE assumed that the natural market state could be either static or dynamic, but that the market could not change states within the period of analysis. That is, markets could not change from static to dynamic or from dynamic to static.

The static market state represented the case in which there would be no progression toward higher efficiency. Because the efficiency of BCs or EPSs would remain unchanged outside a standard, scenarios with a static market state represented cases in which a standard would have the most impact in generating energy savings and thus provided an upper bound for energy savings. As reflected in the National Energy Savings model, a static natural market state was represented by an unchanging distribution of efficiencies over time. Table 9.11 gives the static scenario for group A EPSs in the base case (no standard) as calculated for the NES in the determination analysis. Although only EPS tables are provided as examples, the same model would apply to BCs; however, DOE did not complete equivalent tables for BCs for the determination analysis.

Table 9.11. Static Scenario for Group A EPSs in the Base Case

	Distribution of Shipments Across Efficiency Levels (percent)						
Year	**CSL0**	**CSL1**	**CSL2**	**CSL3**	**CSL4**	**CSL5**	**CSL6**
2007	35	25	15	12	10	3	0
2008	35	25	15	12	10	3	0
2009	35	25	15	12	10	3	0
2010	35	25	15	12	10	3	0
2011	35	25	15	12	10	3	0
2012	35	25	15	12	10	3	0
2013	35	25	15	12	10	3	0
2014	35	25	15	12	10	3	0
2015	35	25	15	12	10	3	0
2016	35	25	15	12	10	3	0
2017	35	25	15	12	10	3	0
2018	35	25	15	12	10	3	0
2019	35	25	15	12	10	3	0
2020	35	25	15	12	10	3	0
2021	35	25	15	12	10	3	0
2022	35	25	15	12	10	3	0
2023	35	25	15	12	10	3	0
2024	35	25	15	12	10	3	0
2025	35	25	15	12	10	3	0
2026	35	25	15	12	10	3	0
2027	35	25	15	12	10	3	0
2028	35	25	15	12	10	3	0
2029	35	25	15	12	10	3	0
2030	35	25	15	12	10	3	0
2031	35	25	15	12	10	3	0
2032	35	25	15	12	10	3	0
2033	35	25	15	12	10	3	0
2034	35	25	15	12	10	3	0
2035	35	25	15	12	10	3	0
2036	35	25	15	12	10	3	0
2037	35	25	15	12	10	3	0
2038	35	25	15	12	10	3	0

The dynamic market state represented the case in which the BC and EPS market would progress toward higher efficiency regardless of the presence of a standard. Because the efficiencies of BCs and EPSs would improve naturally, scenarios with a dynamic market state represented cases in which a standard would have the least impact on generating energy savings, and thus provided the lower bound for energy savings.

During its work on the determination analysis, DOE assumed that a dynamic market state would progress toward CSL5 (Best-in-Market Technology), with 100 percent of production in CSL5 in the last year of the analysis period. To reflect the assumption of diminishing returns on efficiency improvements, the time for each subsequent progression step was increased, *i.e.*, while the progression from CSL0 to CSL1 would take only 3 years, the progression from CSL1 to CSL2 would take 4 years, the progression from CSL2 to CSL3 would take 6 years, etc. Table 9.12 gives the dynamic scenario for class A EPSs in the base case (no standard) as calculated for the NES in the determination analysis.

Table 9.12. Dynamic Scenario for Group A EPSs in the Base Case

	Distribution of Shipments Across Efficiency Levels (percent)						
Year	CSL0	CSL1	CSL2	CSL3	CSL4	CSL5	CSL6
2007	35	25	15	12	10	3	0
2008	23	33	17	13	10	5	0
2009	12	40	18	13	11	6	0
2010	0	48	20	14	11	8	0
2011	0	36	29	14	11	9	0
2012	0	24	39	15	12	11	0
2013	0	12	48	16	12	12	0
2014	0	0	58	17	12	14	0
2015	0	0	48	25	13	15	0
2016	0	0	38	33	13	16	0
2017	0	0	29	41	13	17	0
2018	0	0	19	50	14	18	0
2019	0	0	10	58	14	19	0
2020	0	0	0	66	15	20	0
2021	0	0	0	58	22	21	0
2022	0	0	0	49	29	21	0
2023	0	0	0	41	36	22	0
2024	0	0	0	33	44	23	0
2025	0	0	0	25	51	24	0
2026	0	0	0	16	58	25	0
2027	0	0	0	8	66	26	0
2028	0	0	0	0	73	27	0
2029	0	0	0	0	66	34	0
2030	0	0	0	0	59	42	0
2031	0	0	0	0	51	49	0
2032	0	0	0	0	44	56	0
2033	0	0	0	0	37	63	0
2034	0	0	0	0	29	71	0
2035	0	0	0	0	22	78	0
2036	0	0	0	0	15	85	0
2037	0	0	0	0	7	93	0
2038	0	0	0	0	0	100	0

9.3 Standards Case Shipments Forecasts

After calculating the volume of shipments and distribution across efficiency levels in the base case, DOE considered the market response to the standard with respect to (1) the total volume of shipments, and (2) the distribution of those shipments across efficiency levels.

9.3.1 Impact of Standards on Total Annual Shipments

For the determination analysis, DOE made the simplifying assumption that the aggregate demand for BCs and EPSs would be the same in the standards case as in the base case. This assumption was based on two factors. First, the cost of BCs and EPSs would not increase much relative to the cost of the application; therefore, the increased manufacturing cost would not materially affect consumer demand. Second, the substitution options for BCs and EPSs are limited due to the design considerations and functionality of BCs and EPSs. That is, designers cannot easily substitute another power supply technology when size or the ability to operate without mains power are important attributes of the product. Therefore, DOE assumed that standards would have no impact on the volume of shipments of BCs and EPSs, and the shipment growth rate as calculated in section 9.2.1 could be used for both base and standards cases.

9.3.2 Impact of Standards on Distribution of Shipments Across Efficiency Levels

To account for the change in distribution across efficiencies due to a standard, DOE considered two possibilities for how manufacturers would adapt production: roll-up and shift. Note that these two responses occur between the year immediately preceding the standard and the year the standard takes effect, and are intended to reflect the immediate need of the market to comply with the increased efficiency required by the standard.

9.3.2.1 Roll-Up Response

In the roll-up scenario, DOE assumed that manufacturers would stop producing units that did not meet the standard but would maintain total production levels by producing more of those units that just met the standard. Looking at the overall distribution of efficiencies in the marketplace, those units that did not meet the standard would be “rolled up” to the minimum efficiency level set by the standard, while units already meeting the standard would remain unchanged. This response gives a lower bound on energy savings, because the roll-up response represents the minimum possible improvement in energy efficiency.

Table 9.13 gives an example of a roll-up response to a standard set at CSL2 for EPSs in representative product class A. In the year before the effective date of the standard (2013), units are produced at all efficiency levels. The year the standard takes effect (2014), units at CSL0 and CSL1 no longer meet the efficiency required by the standard. As a result, the units produced at those levels are rolled up to CSL2. Thus:

- the 35 percent of the market at CSL0 and the 25 percent of the market at CSL1 are rolled up and added to the 15 percent of the market at CSL2; and
- the portions of the market at CSL3, CSL4, and CSL5 are unaffected and are carried down with no changes.

Table 9.13. Example of a Roll-Up Response

	Distribution of Shipments Across Efficiency Levels (percent)					
Year	**CSL0**	**CSL1**	**CSL2**	**CSL3**	**CSL4**	**CSL5**
2013	35	25	15	12	10	3
2014	0	0	75	12	10	3

9.3.2.2 Shift Response

In the shift scenario, DOE assumed that manufacturers would respond to a standard by improving those units that did not meet the standard, but would also improve units that already met the standard. In the shift scenario, the distribution of products across efficiency levels remains the same, but the *base level of existing production* is shifted to the standard level, and higher levels are shifted the same number of levels, with a cap at the best-in-market level (CSL5). This response gives an upper bound on energy savings.

Table 9.14 gives an example of a shift response to a standard (with an effective start date of 2014) set at CSL2 for EPSs in Representative Product Class A. In the year before the standard (2013), units are produced at all efficiency levels. The year the standard takes effect (2014), units at CSL0 and CSL1 no longer meet the efficiency required by the standard. As a result, the entire distribution moves, so that the portion of the market at the lowest efficiency level (CSL0) shifts up to the minimum level required by the standard (CSL2), while the portions of the market at all other levels shift the same number of levels. No units exceed CSL5. Thus:

- the 35 percent of the market at CSL0 shifts up to CSL2;
- the 25 percent of the market at CSL1 shifts up to CSL3;
- the 15 percent of the market at CSL2 shifts up to CSL4;
- the 12 percent of the market at CSL3 shifts up to CSL5; and
- the 10 percent of the market at CSL4 shifts up to CSL5 (due to the cap); while
- the 3 percent of the market at CSL5 is unaffected.

Table 9.14. Example of a Shift Response

	Distribution of Shipments Across Efficiency Levels (percent)					
Year	**CSL0**	**CSL1**	**CSL2**	**CSL3**	**CSL4**	**CSL5**
2013	35	25	15	12	10	3
2014	0	0	35	25	15	25

9.3.3 Adjusting Dynamic Progression Rates Following the Standard

In those scenarios with a dynamic market state, DOE assumed that units would continue to improve in efficiency following the market's initial response to the standard. However, DOE chose not to consider efficiency levels beyond the available best-in-market technologies, because such levels would be speculative. Therefore, DOE adjusted the progression rate following the market response. Efficiency would progress toward 100 percent distribution at CSL5, limiting potential energy savings to bounds based on practical technologies, rather than the max-tech technologies at CSL6. Figure 9.1 provides a visual representation of an adjusted progression rate in the standards case.

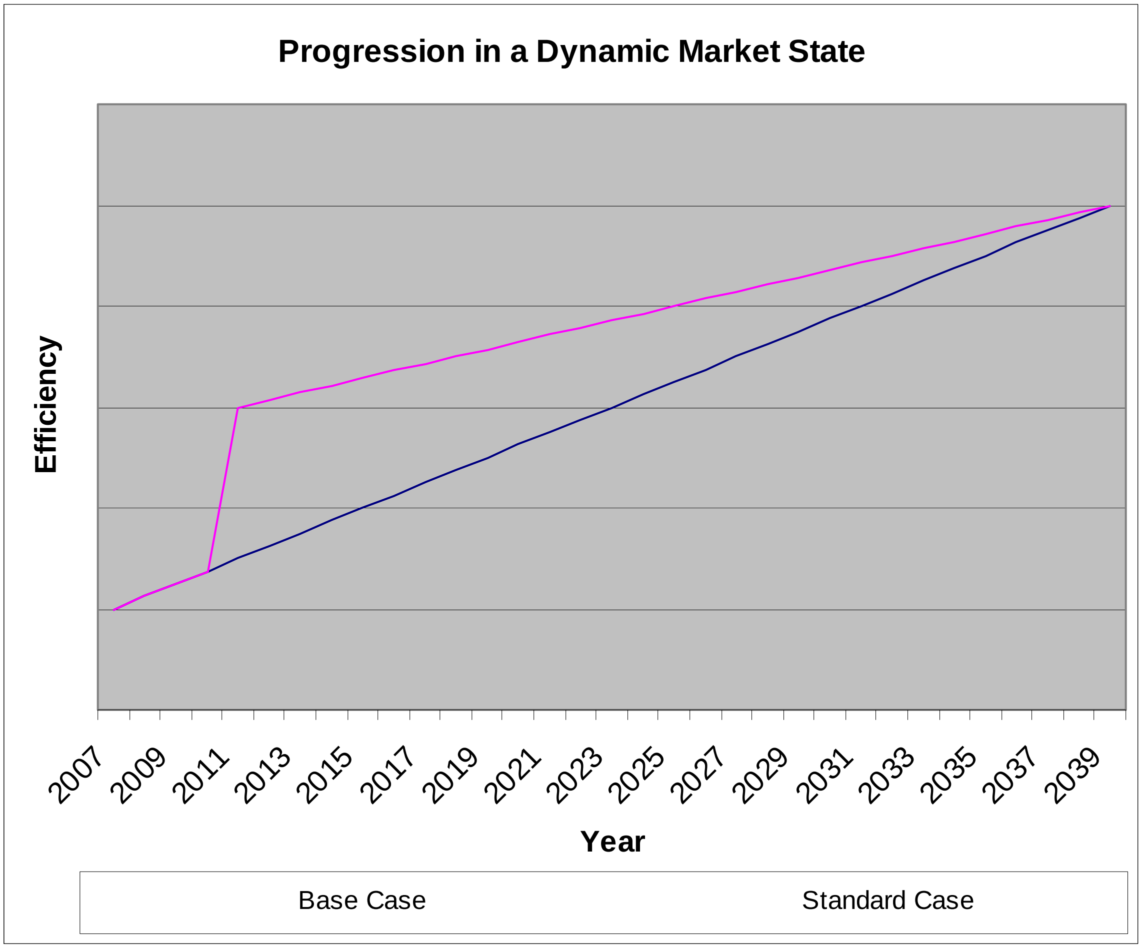

Figure 9.1. Progression in a Dynamic Market State

Tables 16 to 24 give an example of how the dynamic progression in the base case would eventually catch up with the accelerated progression in the standards case. By the end of the analysis period, however, the distributions in the base case eventually catch up to the standards case.

Tables 16 to 24 are further examples of the roll-up and shift responses to standards in the context of a dynamic market state. For all tables except the first, which represents the base case, DOE used the standard level of CSL3. These tables reflect actual tables DOE calculated for the determination analysis.

Table 9.15. List of Following Roll-Up and Shift Tables

EPS Representative Product Class	Base Case	Roll-Up Response to Standard	Shift Response to Standard
A	Table 9.16	Table 9.17	Table 9.18
B	Table 9.19	Table 9.20	Table 9.21
F	Table 9.22	Table 9.23	Table 9.24

Table 9.16. EPS Representative Product Class A, Dynamic Natural Progression, Base Case

	Percent of Market at Each Efficiency Level					
Year	**CSL0**	**CSL1**	**CSL2**	**CSL3**	**CSL4**	**CSL5**
2007	35	25	15	12	10	3
2008	23	33	17	13	10	5
2009	12	40	18	13	11	6
2010	0	48	20	14	11	8
2011	0	36	29	14	11	9
2012	0	24	39	15	12	11
2013	0	12	48	16	12	12
2014	0	0	58	17	12	14
2015	0	0	48	25	13	15
2016	0	0	38	33	13	16
2017	0	0	29	41	13	17
2018	0	0	19	50	14	18
2019	0	0	10	58	14	19
2020	0	0	0	66	15	20
2021	0	0	0	58	22	21
2022	0	0	0	49	29	21
2023	0	0	0	41	36	22
2024	0	0	0	33	44	23
2025	0	0	0	25	51	24
2026	0	0	0	16	58	25
2027	0	0	0	8	66	26
2028	0	0	0	0	73	27
2029	0	0	0	0	66	34
2030	0	0	0	0	59	42
2031	0	0	0	0	51	49
2032	0	0	0	0	44	56
2033	0	0	0	0	37	63
2034	0	0	0	0	29	71
2035	0	0	0	0	22	78
2036	0	0	0	0	15	85
2037	0	0	0	0	7	93
2038	0	0	0	0	0	100

Table 9.17. EPS Representative Product Class A, Dynamic Natural Progression, Standard at CSL3, Roll-Up Response

	Percent of Market at Each Efficiency Level					
Year	**CSL0**	**CSL1**	**CSL2**	**CSL3**	**CSL4**	**CSL5**
2007	35	25	15	12	10	3
2008	23	33	17	13	10	5
2009	12	40	18	13	11	6
2010	0	48	20	14	11	8
2011	0	36	29	14	11	9
2012	0	24	39	15	12	11
2013	0	12	48	16	12	12
2014	0	0	0	74	12	14
2015	0	0	0	68	17	15
2016	0	0	0	62	23	16
2017	0	0	0	56	28	17
2018	0	0	0	50	33	18
2019	0	0	0	43	38	19
2020	0	0	0	37	43	20
2021	0	0	0	32	45	22
2022	0	0	0	28	47	25
2023	0	0	0	23	49	28
2024	0	0	0	19	51	30
2025	0	0	0	14	53	33
2026	0	0	0	9	55	36
2027	0	0	0	5	57	39
2028	0	0	0	0	59	41
2029	0	0	0	0	53	47
2030	0	0	0	0	47	53
2031	0	0	0	0	41	59
2032	0	0	0	0	35	65
2033	0	0	0	0	29	71
2034	0	0	0	0	24	77
2035	0	0	0	0	18	82
2036	0	0	0	0	12	88
2037	0	0	0	0	6	94
2038	0	0	0	0	0	100

Table 9.18. EPS Representative Product Class A, Dynamic Natural Progression, Standard at CSL3, Shift Response

	Percent of Market at Each Efficiency Level					
Year	CSL0	CSL1	CSL2	CSL3	CSL4	CSL5
2007	35	25	15	12	10	3
2008	23	33	17	13	10	5
2009	12	40	18	13	11	6
2010	0	48	20	14	11	8
2011	0	36	29	14	11	9
2012	0	24	39	15	12	11
2013	0	12	48	16	12	12
2014	0	0	0	12	48	40
2015	0	0	0	11	45	44
2016	0	0	0	10	42	48
2017	0	0	0	9	39	52
2018	0	0	0	8	36	56
2019	0	0	0	7	33	60
2020	0	0	0	6	30	64
2021	0	0	0	5	29	66
2022	0	0	0	4	28	68
2023	0	0	0	4	27	70
2024	0	0	0	3	25	72
2025	0	0	0	2	24	73
2026	0	0	0	1	23	75
2027	0	0	0	1	22	77
2028	0	0	0	0	21	79
2029	0	0	0	0	19	81
2030	0	0	0	0	17	83
2031	0	0	0	0	15	85
2032	0	0	0	0	13	87
2033	0	0	0	0	10	90
2034	0	0	0	0	8	92
2035	0	0	0	0	6	94
2036	0	0	0	0	4	96
2037	0	0	0	0	2	98
2038	0	0	0	0	0	100

Table 9.19. EPS Representative Product Class B, Dynamic Natural Progression, Base Case

	Percent of Market at Each Efficiency Level					
Year	**CSL0**	**CSL1**	**CSL2**	**CSL3**	**CSL4**	**CSL5**
2007	15	45	15	6	18	1
2008	10	43	20	8	16	4
2009	5	40	25	9	14	7
2010	0	38	30	11	12	10
2011	0	28	36	13	12	12
2012	0	19	41	15	12	13
2013	0	9	47	18	11	15
2014	0	0	53	20	11	16
2015	0	0	44	27	12	17
2016	0	0	35	34	13	18
2017	0	0	26	41	14	19
2018	0	0	18	49	14	20
2019	0	0	9	56	15	21
2020	0	0	0	63	16	22
2021	0	0	0	55	23	23
2022	0	0	0	47	29	24
2023	0	0	0	39	36	25
2024	0	0	0	31	43	26
2025	0	0	0	23	50	27
2026	0	0	0	16	57	28
2027	0	0	0	8	64	29
2028	0	0	0	0	71	30
2029	0	0	0	0	63	37
2030	0	0	0	0	56	44
2031	0	0	0	0	49	51
2032	0	0	0	0	42	58
2033	0	0	0	0	35	65
2034	0	0	0	0	28	72
2035	0	0	0	0	21	79
2036	0	0	0	0	14	86
2037	0	0	0	0	7	93
2038	0	0	0	0	0	100

Table 9.20. EPS Representative Product Class B, Dynamic Natural Progression, Standard at CSL3, Roll-Up Response

	Percent of Market at Each Efficiency Level					
Year	CSL0	CSL1	CSL2	CSL3	CSL4	CSL5
2007	15	45	15	6	18	1
2008	10	43	20	8	16	4
2009	5	40	25	9	14	7
2010	0	38	30	11	12	10
2011	0	28	36	13	12	12
2012	0	19	41	15	12	13
2013	0	9	47	18	11	15
2014	0	0	0	73	11	16
2015	0	0	0	67	16	17
2016	0	0	0	61	22	18
2017	0	0	0	55	27	19
2018	0	0	0	49	32	20
2019	0	0	0	42	37	21
2020	0	0	0	36	42	22
2021	0	0	0	32	44	24
2022	0	0	0	27	46	27
2023	0	0	0	23	48	30
2024	0	0	0	18	50	32
2025	0	0	0	14	52	35
2026	0	0	0	9	54	37
2027	0	0	0	5	55	40
2028	0	0	0	0	57	43
2029	0	0	0	0	52	48
2030	0	0	0	0	46	54
2031	0	0	0	0	40	60
2032	0	0	0	0	34	66
2033	0	0	0	0	29	71
2034	0	0	0	0	23	77
2035	0	0	0	0	17	83
2036	0	0	0	0	11	89
2037	0	0	0	0	6	94
2038	0	0	0	0	0	100

Table 9.21. EPS Representative Product Class B, Dynamic Natural Progression, Standard at CSL3, Shift Response

	Percent of Market at Each Efficiency Level					
Year	CSL0	CSL1	CSL2	CSL3	CSL4	CSL5
2007	15	45	15	6	18	1
2008	10	43	20	8	16	4
2009	5	40	25	9	14	7
2010	0	38	30	11	12	10
2011	0	28	36	13	12	12
2012	0	19	41	15	12	13
2013	0	9	47	18	11	15
2014	0	0	0	9	47	44
2015	0	0	0	9	44	48
2016	0	0	0	8	41	52
2017	0	0	0	7	38	55
2018	0	0	0	6	34	59
2019	0	0	0	5	31	63
2020	0	0	0	5	28	67
2021	0	0	0	4	27	69
2022	0	0	0	4	26	71
2023	0	0	0	3	25	72
2024	0	0	0	2	23	74
2025	0	0	0	2	22	76
2026	0	0	0	1	21	78
2027	0	0	0	1	20	79
2028	0	0	0	0	19	81
2029	0	0	0	0	17	83
2030	0	0	0	0	15	85
2031	0	0	0	0	13	87
2032	0	0	0	0	11	89
2033	0	0	0	0	9	91
2034	0	0	0	0	8	93
2035	0	0	0	0	6	94
2036	0	0	0	0	4	96
2037	0	0	0	0	2	98
2038	0	0	0	0	0	100

Table 9.22. EPS Representative Product Class F, Dynamic Natural Progression, Base Case

Year	Percent of Market at Each Efficiency Level					
	CSL0	CSL1	CSL2	CSL3	CSL4	CSL5
2007	0	60	15	9	5	11
2008	0	50	23	10	6	12
2009	0	40	30	11	6	13
2010	0	30	38	12	7	14
2011	0	23	40	15	8	14
2012	0	15	43	18	8	15
2013	0	8	46	22	9	16
2014	0	0	49	25	10	17
2015	0	0	41	31	11	18
2016	0	0	33	37	12	19
2017	0	0	24	43	13	19
2018	0	0	16	49	15	20
2019	0	0	8	55	16	21
2020	0	0	0	61	17	22
2021	0	0	0	53	24	23
2022	0	0	0	46	30	24
2023	0	0	0	38	37	25
2024	0	0	0	31	43	26
2025	0	0	0	23	50	27
2026	0	0	0	15	57	28
2027	0	0	0	8	63	29
2028	0	0	0	0	70	30
2029	0	0	0	0	63	37
2030	0	0	0	0	56	44
2031	0	0	0	0	49	51
2032	0	0	0	0	42	58
2033	0	0	0	0	35	65
2034	0	0	0	0	28	72
2035	0	0	0	0	21	79
2036	0	0	0	0	14	86
2037	0	0	0	0	7	93
2038	0	0	0	0	0	100

Table 9.23. EPS Representative Product Class F, Dynamic Natural Progression, Standard at CSL3, Roll-Up Response

	Percent of Market at Each Efficiency Level					
Year	**CSL0**	**CSL1**	**CSL2**	**CSL3**	**CSL4**	**CSL5**
2007	0	60	15	9	5	11
2008	0	50	23	10	6	12
2009	0	40	30	11	6	13
2010	0	30	38	12	7	14
2011	0	23	40	15	8	14
2012	0	15	43	18	8	15
2013	0	8	46	22	9	16
2014	0	0	0	74	10	17
2015	0	0	0	67	15	18
2016	0	0	0	61	20	19
2017	0	0	0	55	26	19
2018	0	0	0	49	31	20
2019	0	0	0	43	36	21
2020	0	0	0	37	42	22
2021	0	0	0	32	44	24
2022	0	0	0	28	46	27
2023	0	0	0	23	48	30
2024	0	0	0	18	50	32
2025	0	0	0	14	52	35
2026	0	0	0	9	54	37
2027	0	0	0	5	56	40
2028	0	0	0	0	58	43
2029	0	0	0	0	52	48
2030	0	0	0	0	46	54
2031	0	0	0	0	40	60
2032	0	0	0	0	35	66
2033	0	0	0	0	29	71
2034	0	0	0	0	23	77
2035	0	0	0	0	17	83
2036	0	0	0	0	12	89
2037	0	0	0	0	6	94
2038	0	0	0	0	0	100

Table 9.24. EPS Representative Product Class F, Dynamic Natural Progression, Standard at CSL3, Shift Response

	Percent of Market at Each Efficiency Level					
Year	**CSL0**	**CSL1**	**CSL2**	**CSL3**	**CSL4**	**CSL5**
2007	0	60	15	9	5	11
2008	0	50	23	10	6	12
2009	0	40	30	11	6	13
2010	0	30	38	12	7	14
2011	0	23	40	15	8	14
2012	0	15	43	18	8	15
2013	0	8	46	22	9	16
2014	0	0	0	8	46	47
2015	0	0	0	7	43	50
2016	0	0	0	6	40	54
2017	0	0	0	6	36	58
2018	0	0	0	5	33	62
2019	0	0	0	4	30	66
2020	0	0	0	4	27	70
2021	0	0	0	3	26	71
2022	0	0	0	3	24	73
2023	0	0	0	2	23	75
2024	0	0	0	2	22	76
2025	0	0	0	1	21	78
2026	0	0	0	1	20	80
2027	0	0	0	0	18	81
2028	0	0	0	0	17	83
2029	0	0	0	0	15	85
2030	0	0	0	0	14	86
2031	0	0	0	0	12	88
2032	0	0	0	0	10	90
2033	0	0	0	0	9	91
2034	0	0	0	0	7	93
2035	0	0	0	0	5	95
2036	0	0	0	0	3	97
2037	0	0	0	0	2	98
2038	0	0	0	0	0	100

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CHAPTER 10. NATIONAL IMPACT ANALYSIS

LIST OF FIGURES

LIST OF TABLES

10.1 Introduction

For the determination analysis, DOE intended to use the national impact analysis to measure the affects of Federal energy conservation standards by comparing projected U.S. energy consumption with and without new energy conservation standards. Aggregate impacts combined projections of unit energy consumption of new battery chargers and external power supplies, annual equipment shipments, and the price of purchased equipment. Approaches to determining unit energy consumption are described in chapter 6, methods for deriving base case shipment forecasts are discussed in chapter 9, and approaches to determining retail prices for products are described in chapter 7.

The national impact analysis consisted of four calculations:

- *Unit energy savings* (UES), which measured the change in unit energy consumption due to the impact of the standard (section 10.2);
- *National inventory*, which measured the total number of units affected by the standard (section 10.3);
- *National energy savings* (NES), which combined unit energy savings and the national inventory to obtain the aggregate energy savings generated by the standard (section 10.4); and
- *Net present value*, which calculated the net present savings and costs of a standard by comparing the present value of energy savings from national energy savings with the present value of the increased consumer purchase costs associated with the standard (section 10.5).

10.2 Unit Energy Savings

The unit energy savings is the difference between the unit energy consumption (UEC) in the standard case and the UEC in the base case. Thus, the UES represents the reduced energy consumption of a single unit due to the higher efficiency generated by a standard. Once calculated, the UES would then be multiplied by the national inventory of units to calculate national energy savings.

For each representative product class, DOE calculated the shipment-weighted average UEC of products in that class sold in a given year. Chapter 6 provides the UEC of products at each candidate standard level (CSL); chapter 9 provides the proportion of total shipments at each CSL. DOE calculated weighted-average UECs for each year in the evaluation period in both the standards case and the base case. DOE then calculated UES by taking the difference between the two cases (Figure 10.1).

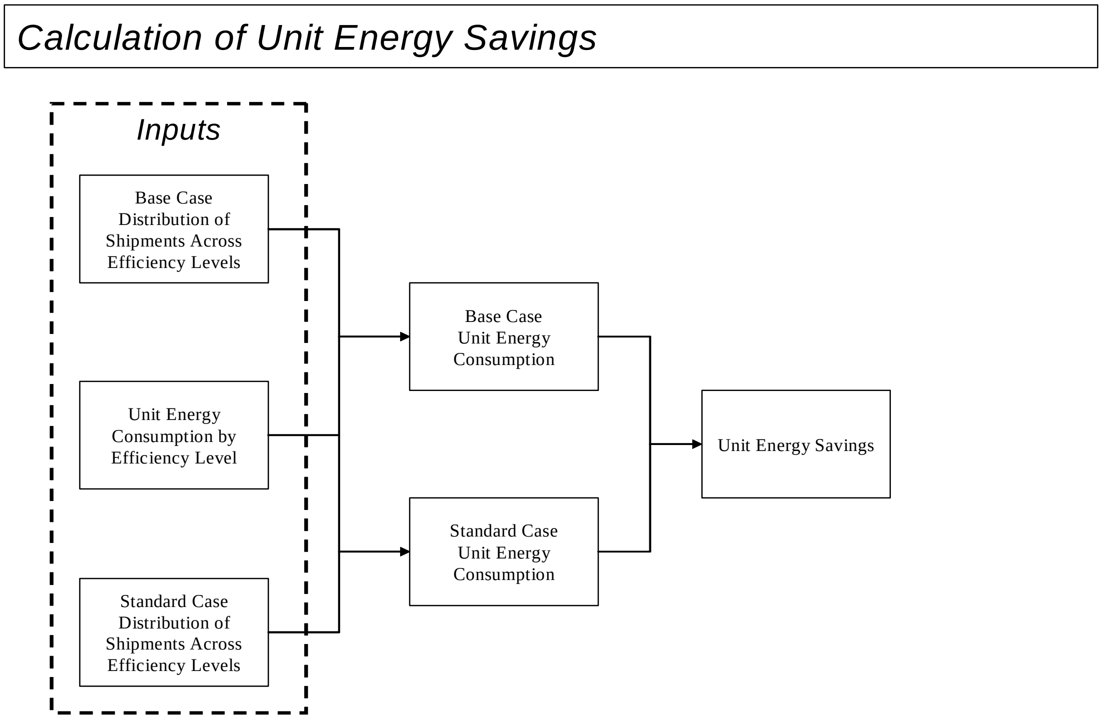

Figure 10.1. Flow Diagram of the Calculation of UES

10.3 National Inventory

DOE used the national inventory to represent the installed base of BCs and EPSs that a standard would affect. Because the BCs and EPSs remain in use for several years, the national inventory represents the stock of BCs or EPSs in service for any given year of the analysis period. It is important to track the date of manufacture, or vintage, of products in the installed base because the energy efficiency and price of products sold changes over time. DOE used the following inputs to calculate the national inventory for the determination analysis:

- **Start-Year Shipments**

  The values for start-year shipments by representative product class, estimated in chapter 9 of the draft technical report.

- **Shipment Growth Rate**

  The values for shipment growth rate by representative product class, estimated in chapter 9 of the draft technical report.

- **Lifetime by Representative Product Class**

  The values for lifetime by product class, drawn from chapter 8 of the draft technical report.

Table 10.1 shows how the national inventory model tracks the number of products by vintage in the installed base for a given year. In 2014, 100 units are sold and enter the installed base. In this example, the product has an average lifetime of 3 years. Therefore, the units sold in 2014 are retired in 2017. The shipment growth rate is 5 percent, so 105 units are sold in 2015. These units are added to the 100 units that remain in the installed base from the year before. In 2015, 205 units are in the installed base. This process of adding to and subtracting from the installed base is carried forward throughout the analysis period (Figure 10.2).

Table 10.1 Sample National Inventory Table

Vintage	**Year of Analysis**						
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
2014	100	100	100	-	-	-	-
2015	-	105	105	105	-	-	-
2016	-	-	110	110	110	-	-
2017	-	-	-	116	116	116	-
2018	-	-	-	-	122	122	122
2019	-	-	-	-	-	128	128
2020	-	-	-	-	-	-	134
Total	100	205	315	331	348	366	384

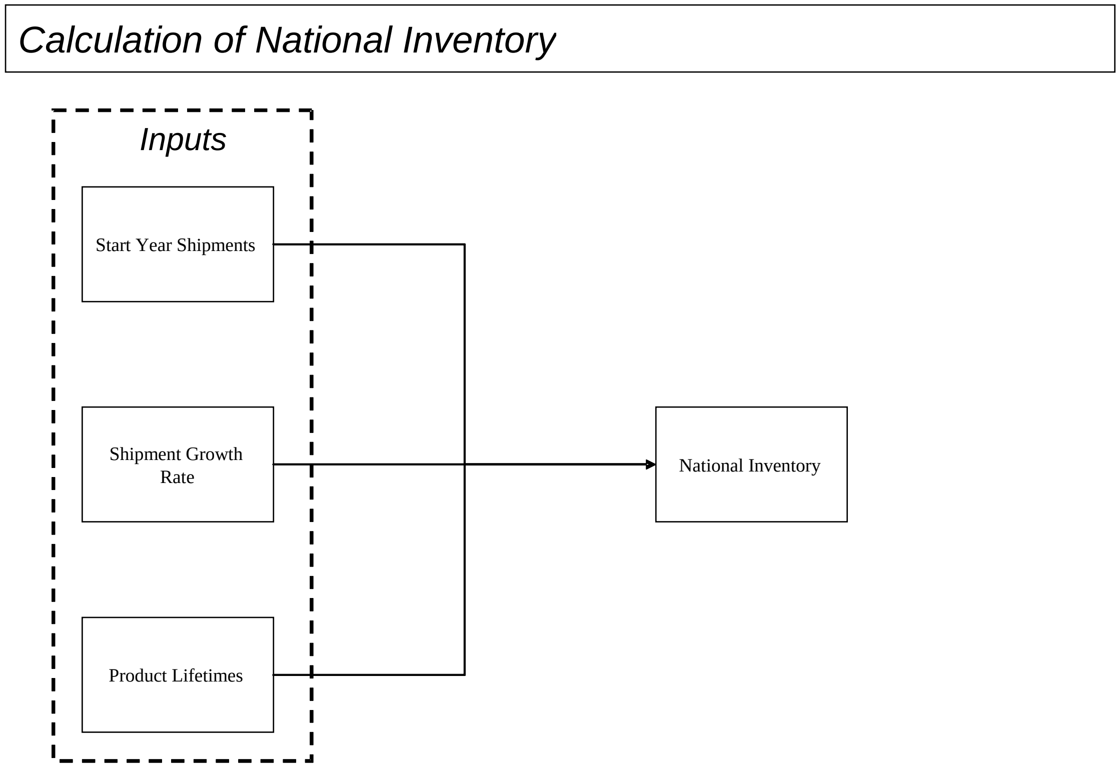

Figure 10.2. Flow Chart of the Calculation of National Inventory

10.4 National Energy Savings

Using the calculated national inventory and unit energy savings for each year of the analysis, DOE then calculated national energy savings by multiplying the two inputs together, depicted in Figure 10.3.

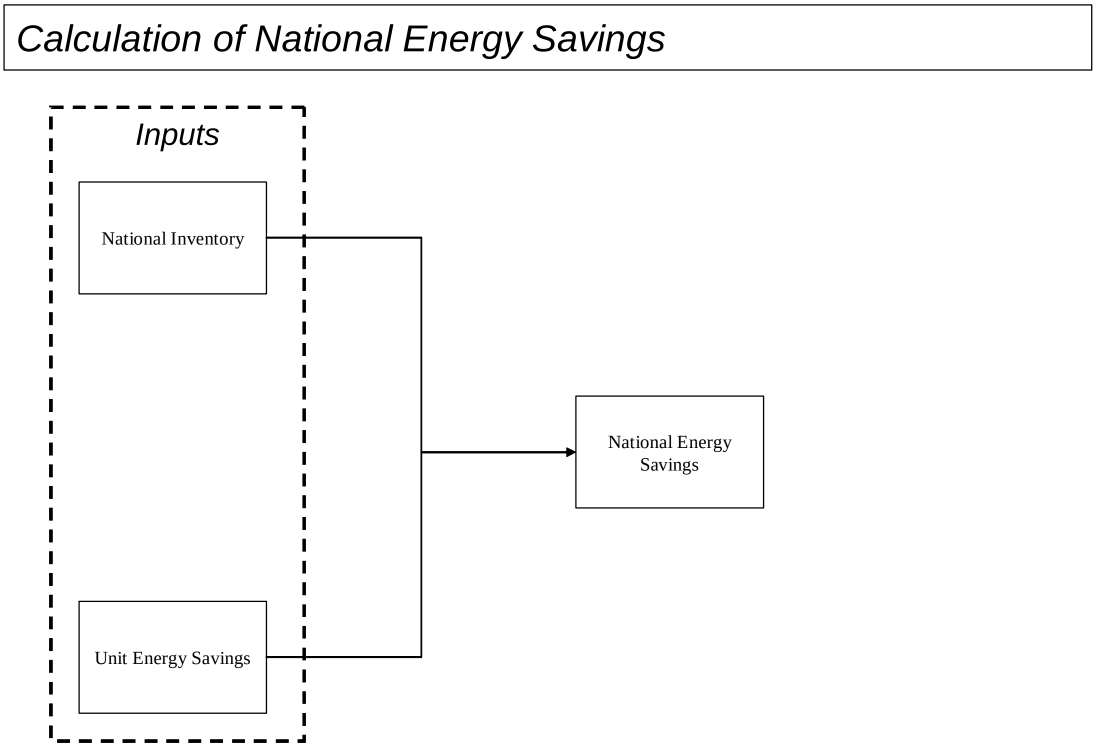

Figure 10.3. Flow Chart of the Calculation of NES

10.5 National Net Present Value

The national NPV of energy conservation standards for the determination analysis is the difference between electricity cost savings and equipment cost increases. DOE calculated electricity cost savings for each year by multiplying energy savings by forecasted electricity prices. DOE assumed that consumers paying residential electricity rates would receive 80 percent of the total energy savings, and that the commercial sector would receive the remainder. DOE calculated equipment cost increases for each year by taking the incremental price increase per unit (from chapter 8) between a base case and a standards case scenario and multiplying the difference by the national inventory. For each year, DOE took the difference between the savings and cost to calculate the net savings (if positive) or net cost (if negative).

After calculating the net savings and costs, DOE discounted these annual values to the present time and summed them to obtain the national net present value, displayed in Figure 10.4.

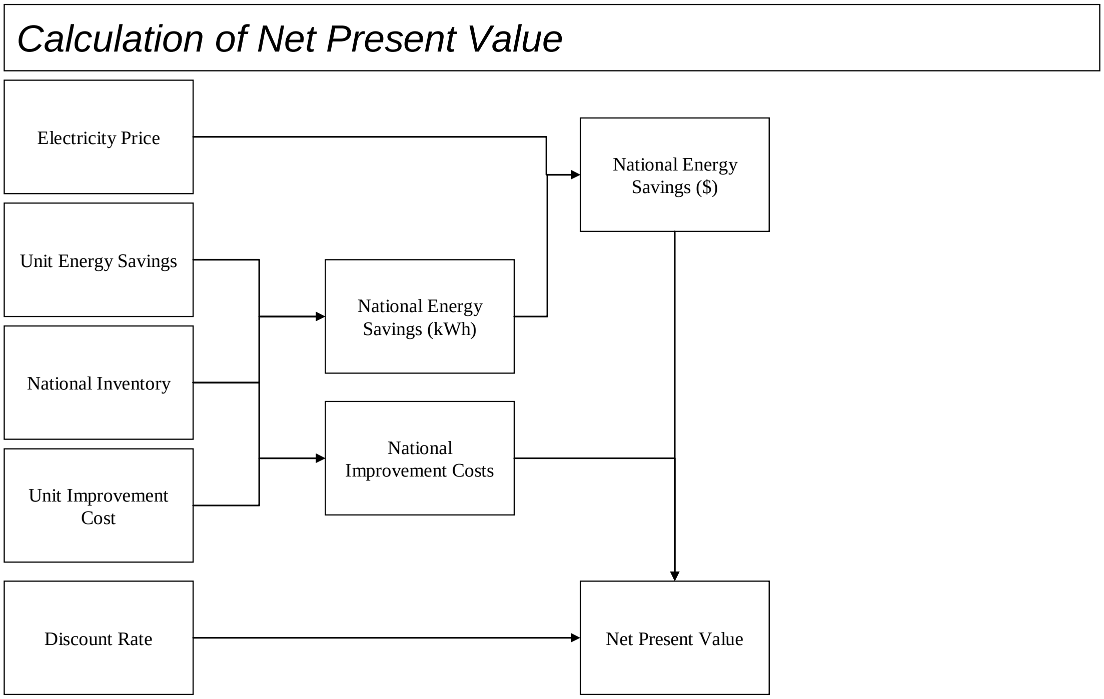

Figure 10.4. Flow Chart of the Calculation of NPV