Energy Research and Development Division
FINAL PROJECT REPORT

RESEARCH FINDINGS ON STANDARDS FOR BATTERY CHARGER SYSTEMS AND INTERNAL POWER SUPPLIES

Prepared for: California Energy Commission
Prepared by: Ecos Consulting

OCTOBER 2006
CEC-500-2013-082

PREPARED BY:

Primary Author(s):
Chris Calwell
Suzanne Foster Porter

Ecos Consulting
Durango, CO 81301

Contract Number: 500-04-030

Prepared for:

California Energy Commission

Brad Meister
Contract Manager

Virginia Lew
Office Manager
Energy Efficiency Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

ACKNOWLEDGMENTS

The following team members contributed to the success of this project:

- Peter May-Ostendorp, Ecos Consulting
- Laura Moorefield, Ecos Consulting
- Kim Herb, Ecos Consulting
- Donna George, Ecos Consulting

- Vicki Calwell, Calwell Communications

- Brian Fortenbery, EPRI Solutions
- Haresh Kamath, EPRI Solutions
- Baskar Vairomohan, EPRI Solutions
- Tom Geist, EPRI Solutions

- Jarred Metoyer, RLW Analytics
- Rima Gupta, RLW Analytics
- Stacia Okura, RLW Analytics
- Matt Brost, RLW Analytics

- Jonathan Koomey, Analytics Press

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Research Findings on Standards for Battery Charger Systems and Internal Power Supplies is the final report for the Energy Efficient Battery Chargers and Secondary Power Supplies project (contract number 500-04-030) conducted by Ecos Consulting. The information from this project contributes to Energy Research and Development Division's Building End-Use Energy Efficiency Program

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

This report summarizes the final results of research regarding the energy efficiency of power supplies and battery chargers and the electronic devices that employ them to convert power and store it for later use. The research was conducted in 2005–2006 by Ecos Consulting, EPRI Solutions, and RLW Analytics. This work included the development of standardized test procedures for measuring the efficiency of internal power supplies and battery chargers, innovative field research into residential plug load energy consumption, and new research into the energy savings attributable to power factor correction in power supplies at the point of load. The research findings confirmed that residential electronics consume the greatest amount of energy in the active, rather than the standby mode. Field research and subsequent analysis indicated that entertainment and information technology products represented the great majority of residential plug load consumption and savings opportunities. The test procedures and measured data are intended to support efforts by policy makers to adopt voluntary or mandatory efficiency specifications for electronic products.

Keywords: power supply, battery charger, miscellaneous energy, plug loads, usage patterns, duty cycle, consumer electronics, energy efficiency, external power supply, internal power supply, residential, power factor, personal computer, test procedure, field measurement, standards, energy policy

Please cite this report as follows:

Calwell, C., and S.F. Porter (Ecos Consulting). 2006. *Research Findings on Standards for Battery Charger Systems and Internal Power Supplies.* California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2013-082.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

Recent studies showed that consumer electronics and miscellaneous plug loads account for about 10–15 percent of residential electricity consumption, and the overall energy use of these products is expected to grow (Energy Information Administration 2001; Ecos Consulting 2004; Roth, Ponoum et al. 2006). Policy makers needed information on the efficiency of power supplies and battery chargers, the "common denominator" technologies found in most electronic plug loads, before proposing voluntary and mandatory efficiency specifications to curb plug load energy use. Detailed information on consumer electronics usage patterns had been difficult to obtain, in part because of the difficulty and expense of collecting consumption data for plug loads in the field.

Project Purpose

This goal of this research was to support the creation of a policy to reduce plug load energy use by developing test procedures to measure residential plug load energy use and conducting detailed technical energy efficiency investigations of power supplies and battery chargers.

The specific project objectives included:

- Conducting a field measurement of residential plug load energy consumption in a representative sample of California homes to determine if plug loads represent more than 10 percent of residential electricity use and to identify which devices dominate in that category.
- Developing draft test procedures for measuring the efficiency of self-contained, internal, non-redundant power supplies and a range of battery charging systems through consultation with industry and other stakeholders.
- Assessing the dependence of external power supply efficiency on output voltage and current to determine whether future efficiency specifications for these products should include terms beyond nameplate wattage.
- Determining which technologies are typically used in battery charging systems and how component and system design changes would affect overall efficiency.
- Characterizing the battery charger market to inform policy recommendations by identifying distribution channels, product scope, and other features in order.

Project Results

There were three main project research areas: field measurement, power supplies, and battery chargers.

The key results in the field measurement research area were:

- Miscellaneous plug-load devices consumed 12–16 billion kilowatt-hours (kWh) of electricity per year in California or roughly 15–19 percent of the electricity used by all California homes.
- Entertainment electronics, such as televisions and set top boxes, constituted the largest share of that miscellaneous energy use; information technology electronics constituted the second largest share of miscellaneous energy use.
- The active mode of operation used the greatest proportion of total residential plug load energy, accounting for 61–78 percent of total energy consumption.

The key results in the power supply research area were:

- A finalized test procedure for internal power supplies was developed. A draft version of the test revealed that a subset of internal power supplies, those with self-contained, non-redundant designs, were amenable to testing, promotion, and inclusion in energy efficiency labeling efforts.
- Output voltage and current had sufficient impact on external power supply efficiency to justify considering these factors when crafting future revisions to California external power supply efficiency standards. Output power also had an impact on external power supply efficiency and a separate report was prepared on this topic.
- Correcting the power factor in a computer power supply can yield 12–21 percent additional energy savings over simply improving power supply efficiency. A separate report provided details on this analysis.
- A number of domestic and international outreach activities facilitated significant stakeholder involvement.

The key results in the battery charger research area were:

- Two drafts of a battery charger system energy efficiency test procedure were prepared.
- Efficiency measurements were conducted for more than 60 battery chargers.
- A separate report detailed battery charger market trends and growth expectations, energy savings potential, and cost-benefit analyses.
- A separate report was developed to examine the efficiency of battery charger technologies and opportunities for efficiency improvement. This work confirmed that highly efficient existing technologies could sharply reduce power consumption in all three operating modes of battery chargers—active, maintenance, and no-battery.
- Changes to battery charger system design and component choices could greatly improve battery charger system efficiencies.

- A number of domestic and international outreach activities facilitated significant stakeholder involvement.

This research established the need for measures to improve plug load energy efficiency by quantifying the significant energy draw of plug load in homes, which represented 15–19 percent of all residential energy use. More detailed data on plug load power use and efficiency improvement opportunities helped position the Energy Commission and electric utilities to pursue policies, programs, and other market interventions to reduce plug load energy use in the residential sector. Specifically, the information can lead to policies that encourage industry to find the most cost-effective and technically sound solutions.

The team focused policy recommendations on internal power supplies and battery chargers:

- Mandatory battery charger system minimum efficiency standards should be pursued in the near-term. The 24-hour active maintenance efficiency metric coupled with a separate no-battery mode power provision would likely be acceptable to the battery charger industry.
- The researchers did not recommend that the California Energy Commission take any action on mandatory internal power supply efficiency for any product categories at this time because the test procedure itself was still undergoing final revisions and the voluntary initiatives to encourage greater power supply efficiency in computers (www.80Plus.org) were just getting underway.

Benefits to California

The short-term direct benefits of this research to California included:

- The residential plug load field measurement research allowed policy makers and utilities to determine policy and program priorities for plug loads.
- The work with Brand Electronics to refine its existing plug load meter design will yield significant technology benefits to future California plug load studies.
- The internal power supply test procedure development contributed to the technical approach of 80 PLUS, a utility-funded desktop computer energy efficiency program.
- ENERGY STAR® elected to incorporate a power supply efficiency requirement into its labeling program for computers based on these research results.
- The battery charger technical research enabled policy makers at the California Energy Commission to pursue a mandatory minimum efficiency standard for battery charger systems.
- Disseminating project findings at a variety of industry meetings, utility forums and via the project websites informed stakeholders about the research findings from this project. This outreach benefitted the Energy Commission’s policy making activities.

- The research team created a draft "efficiency philosophy" checklist to aid in a long-term approach to electronics efficiency at the request of industry stakeholders.
- The research team's websites (www.efficientpowersupplies.org and www.efficientproducts.org) began publicizing efficiency differences to increase competition among manufacturers of energy efficient electronic products.

Chapter 1: Introduction

1.1 Background and Overview

In the last decade, the energy efficiency community has turned increasing attention to the efficiency of consumer electronics, office electronics, and other miscellaneous plug load devices. This group of "miscellaneous" or "other" residential energy use has traditionally been a relatively small percentage of residential electric demand, which has been long dominated by water heating, refrigeration, large appliances, and lighting. Now that state and federal efficiency standards have locked in substantial efficiency improvements in these dominant residential end uses, miscellaneous energy use represents an ever-growing share of total residential energy use. This growth in reflected in the "All other" in Figure 1, which shows past DOE energy use figures and Department of Energy (DOE) projections of future use (Energy Information Administration 2006).

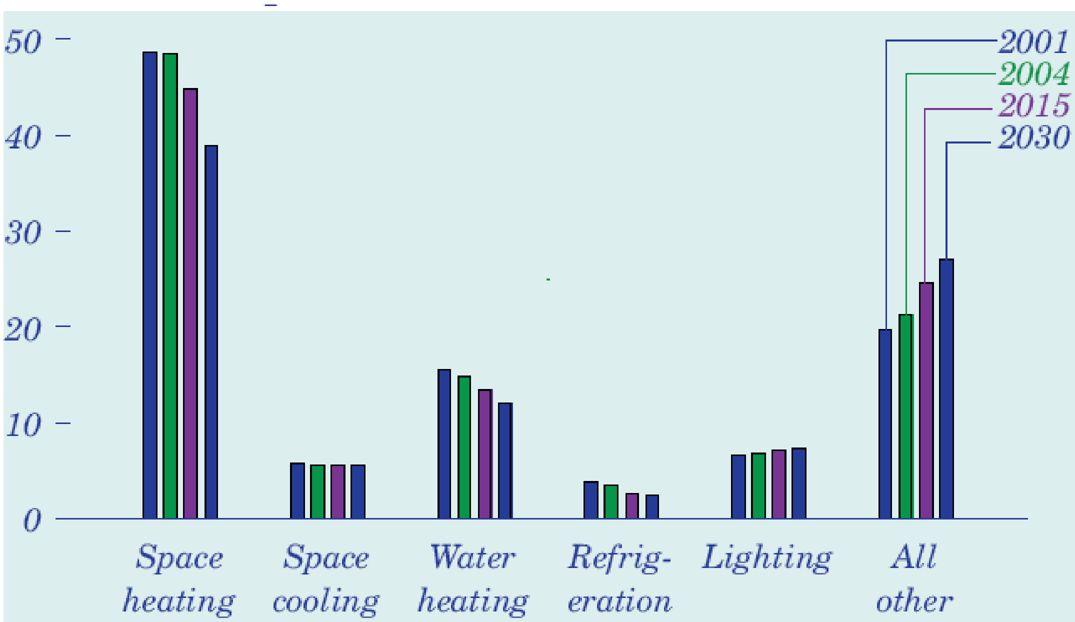

Figure 1: Delivered residential energy consumption by end use, 2001, 2004, 2015, and 2030 (million Btu per household)

In agreement with other estimates (Energy Information Administration 2001; Ecos Consulting 2004; Roth, Ponoum et al. 2006) , DOE's projections in Figure 1 show that consumer electronics and miscellaneous plug loads constitute approximately 10 percent–15 percent of residential electricity consumption and the overall energy use of these products is expected to grow. Lawrence Berkeley National Laboratory (LBNL) initiated much of the U.S. work on miscellaneous residential energy use, drawing particular attention to standby power consumption. Its studies in the mid to late 1990s revealed standby power consumption of various residential products to be a significant portion of energy use in the residential sector. (Rosen and Meier 2000; Ross and Meier 2000). LBNL's most recent findings on the topic (Brown et al. 2006) indicate that plug loads can represent an extremely high percentage of the net energy consumption of highly efficient houses, since on-site generation and careful attention to home design are often sufficient to offset the majority of space heating, cooling, and water heating loads.

In 2004 and 2005, Ecos Consulting and others began to quantify the energy use of not only standby and low power modes, but also active mode (Ecos Consulting 2004 Ostendorp et al. 2005, Foster 2005, Foster et al. 2004). This previous research contained detailed lab measurements of power use in active and standby mode, as well as market data on annual sales, but usually relied on assumptions about device usage patterns to create annual energy use and savings estimates. Detailed information on usage patterns of these products was simply unavailable, in part because of the difficulty and expense of collecting consumption data for plug loads in the field.

At the same time, many researchers believed that the relatively low power factor[1] and high total harmonic distortion (THD)[2] of electronic products like computers and monitors imposed additional costs on the utility distribution system. Some believed that utilities could compensate for these power quality problems within their transmission and distribution networks with additional corrective equipment, while others believed that all distortion and reactive power at the point of load resulted in additional need for generation at the power plant. Research was needed to document the extent to which low power factor and high THD increased electric consumption and, conversely, the value of correcting power factor at the point of load to prevent those additional losses.

Power supplies and battery chargers represent the "common denominator" technologies found in most electronic plug loads. Therefore, federal and state government agencies aiming to reduce plug load consumption have sought information on the efficiency of those components within electronic devices as a prelude to measuring products and proposing efficiency levels for voluntary and mandatory efficiency specifications. Gaining this information was not possible without standardized test procedures. Ecos Consulting and EPRI Solutions developed such a procedure for single voltage external power supplies (EPS) under a previous contract, but internal power supplies (typically multi-voltage) and battery chargers (including all modes of operation) had been largely unaddressed prior to the research discussed in this report.

---

[1] Power factor is defined as the ratio of the real power to the apparent power and is a number between 0 to 1 inclusive.

[2] Total harmonic distortion for a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental.

1.2 Project Objectives

The objectives of this project were to measure the energy impact of miscellaneous plug load energy use in the residential sector and conduct detailed technical energy efficiency investigations of power supplies and battery chargers. Specifically, this work included the following activities:

- Conduct a field measurement of residential plug load energy consumption in a representative sample of California homes to validate previous energy use estimates. Examine and report on usage patterns of individual products, as well as measure product power use by mode and count the incidence of products in homes. Place outlet meters on products to log power use in one-minute intervals over the course of one week. Determine if plug loads represent more than 10 percent of residential electricity use and which devices dominate in the residential electricity use category.
- Develop a draft test procedure in consultation with industry and other stakeholders for measuring the efficiency of self-contained, internal, non-redundant power supplies. Identify manufacturer and stakeholder buying cycles and perspectives and consider them in the technical investigation. Measure the efficiency of an assortment of internal power supplies to assess savings potential. Make the resulting data available to utilities and policy makers considering strategies for promoting efficient computers.
- Assess the dependence of EPS efficiency on output voltage and current to determine whether future efficiency specifications for these products should include additional terms beyond nameplate wattage.
- Measure distribution wiring losses associated with the operation of computer power supplies with low power factor and high THD and compare those to computer power supplies with power factor correction (PFC). Assess additional statewide energy consumption and savings potential from correcting power factor at the point of load. Determine if additional savings from PFC are significant enough to include power factor requirements in future policies regarding efficient electronics.
- Develop a draft test procedure in consultation with industry and other stakeholders for measuring battery charger efficiency and measure the efficiency of a wide range of battery charging systems. Assess energy use and savings potential.
- Determine which technologies are typically used in battery charging systems and how component and system design changes would affect overall efficiency. Document these findings in a technical primer understandable by a lay audience, illustrating how manufacturers might improve the energy efficiency of conventional battery charging systems. Conduct cost-benefit analysis associated with moving to new technologies.

- Characterize the battery charger market. Identify distribution channels, product scope, and other factors to inform policy recommendations.
- Disseminate project findings at a variety of industry meetings and utility forums and via websites. Coordinate and leverage efforts with other national and international activities. Create energy and environmental policy recommendations for the Energy Commission that are based on technical findings and results.

1.3 Report Organization

Although many detailed reports on specific investigations were delivered to the Energy Commission over the course of this project, this report summarizes the entire body of work completed under contract 500-04-030. First, in Section 2, the approach taken in this project is reviewed. Then, results of the plug load residential field measurement, the power supply investigations, and the battery charger investigations are summarized in Section 3. Finally, recommendations, conclusions, and direct benefits to California are outlined in Section 4. Following Section 4 are references and other supporting materials.

Chapter 2:
Project Approach and Methods

Under this contract, Ecos Consulting and EPRI Solutions extended past work on external power supply efficiency to internal power supplies, battery chargers, and the electronic products that contain them. Methods used included a combination of market research, laboratory measurements, industry outreach, field measurements in homes, retail store measurements, data analysis, presentations, and written reports.

2.1 Plug Load Field Measurement

The team's approach to field measurements of electronic products that contain battery chargers and power supplies was built on long-established protocols at RLW Analytics for conducting field measurement of energy use in heating, ventilating, and air conditioning (HVAC) equipment, lighting, and appliances. Sampling and recruiting strategies for electronic devices were similar to those used in these established protocols, though scope and budget limitations necessitated short measurement periods (one week) and cost-sharing with a related field research project underway at LBNL. Brand Electronics developed custom plug load meters for the project. These meters met the project's goals for data storage, precision, sampling frequency, and form factor, but in the end presented challenges associated with software and data transfer. Meters were placed on 12–35 individual products in each of the selected homes, left for a week to capture readings once per minute, and then retrieved for a manual data download and subsequent analysis. Devices metered included such as televisions (TVs), cell phones, and computers. The team ultimately needed to create additional software to filter erroneous values (introduced during the serial data transfer process) from the raw data, adding significantly to the time and cost required to complete the project.

To validate the field measurement, the team originally planned to compare results to power data for a subset of electronic products collected from consumers via a website. Templates for uploading these data were made available via email and on a website (www.efficientproducts.org). Outreach, which was conducted by email, phone, and at the 2006 American Council for an Energy Efficient Economy (ACEEE) Summer Study Conference focused on energy conscious consumers who worked in the energy efficiency field. Despite these outreach efforts, no data were obtained for comparison against field measurement. Instead, field measurements were compared to already published research conducted by LBNL, DOE, and others. A large opportunity exists to obtain a significant amount of energy use data from consumers via a website interface. However, optimizing the opportunity would require a larger budget with incentives for participation or complimentary power meters for consumer use.

2.2 Power Supply Tests

The power supply effort began with a re-examination of EPS data, including hundreds of newly compliant ENERGY STAR®–labeled models, to understand the extent to which measured efficiencies depend on nameplate output voltage and current, rather than simply nameplate output power. Statistical correlations were developed in Excel among various power supply attributes, leading to a series of charts documenting compliance as function of output voltage and current. Ecos conducted a series of new laboratory measurements on medical EPS as well, to assess whether that category faced particular challenges in complying with efficiency specifications.

EPRI Solutions began its internal power supply test procedure development with the foundation already established for EPS—dividing measured output power by measured input power under a variety of load conditions. Intel had previously stipulated loading conditions for common sizes of desktop computer power supplies in its *Personal Computer (PC) Design Guide Specifications* on www.formfactors.org. However, a method was needed to automate and standardize the determination of those loading conditions across a wider range of power supply types and sizes. Laboratory tests and comments from industry and government stakeholders led to the creation of a new methodology for proportionally allocating loads to each of multiple voltage rails in relation to their rated outputs.

Once the internal power supply test procedure was largely complete, EPRI Solutions was able to employ it to assess expected energy savings from upgrading desktop PC power supplies to more efficient models. However, the real-world savings from such changes depend on a variety of other factors, including power quality and I^2R losses[3] in power cables and distribution wiring of various lengths. EPRI therefore established controlled laboratory conditions for analyzing each of those factors separately and in combination. This strategy allowed the project team, for the first time, to demonstrate and quantify an energy efficiency benefit associated with correcting power factor and distortion power in power supplies—an effect amplified in large office buildings with long runs of distribution wiring.

2.3 Battery Charger Tests

The foundation for the battery charger test procedure development work began with a series of product measurements of all operating modes funded by Pacific Gas and Electric Company (PG&E) and conducted in 2003 and 2004. The Energy Foundation and Natural Resources Defense Council (NRDC) funded an initial set of meetings with industry in 2003 regarding standardized test procedures for measuring battery charger system efficiency. The new research conducted in this project built on those efforts to craft a more holistic approach to measuring efficiency, focusing less on individual modes of operation and more on the overall functional efficiency of converting, storing, and retrieving energy during a defined period of time. This simplified the test procedure considerably, given the difficulty of determining when charge mode ends and battery maintenance mode begins for many battery charging systems.

[3] I^2R is the product of the electric current squared and the resistance.

The team then developed a battery charger technical primer that followed closely in the footsteps of a predecessor created by EPRI Solutions and Ecos Consulting for power supplies under a previous contract. EPRI researchers disassembled commonly available battery charger designs to understand which components were most commonly employed and measured the losses associated with each stage of circuitry. From that point, it was relatively straightforward to swap conventional components with more efficient ones and measure the resulting energy savings, while also generalizing design approaches that could be used with a broader range of charging circuitry. Results of this work was documented in the primer, and circulated to a variety of manufacturers and researchers, whose input was essential to honing the final results.

The team approached the outreach process in a manner similar to that used under previous contracts, employing a combination of websites (www.efficientpowersupplies.org and www.efficientproducts.org), industry conferences (Applied Power Electronics Conference [APEC] and Battery Power 2006), and market transformation community conferences (ACEEE Summer Study and Energy Efficiency in Domestic Appliances and Lighting Conference). This approach allowed technical findings to be informed by policy and programmatic considerations, while also exposing market transformation stakeholders to the constraints and priorities faced by manufacturers.

Chapter 3:
Project Outcomes and Results

This section details project results and is organized into three main sections: plug load field measurement, power supply results, and battery charger results.

3.1 Plug Load Field Measurement

The plug load field measurement project enabled Ecos Consulting and RLW Analytics to characterize the energy impacts associated with miscellaneous plug load energy use in the residential sector. Products were time-series metered for one week to understand not only their energy use, but also their usage patterns. Figure 2 visually illustrates findings from one of the homes incorporated in the study.

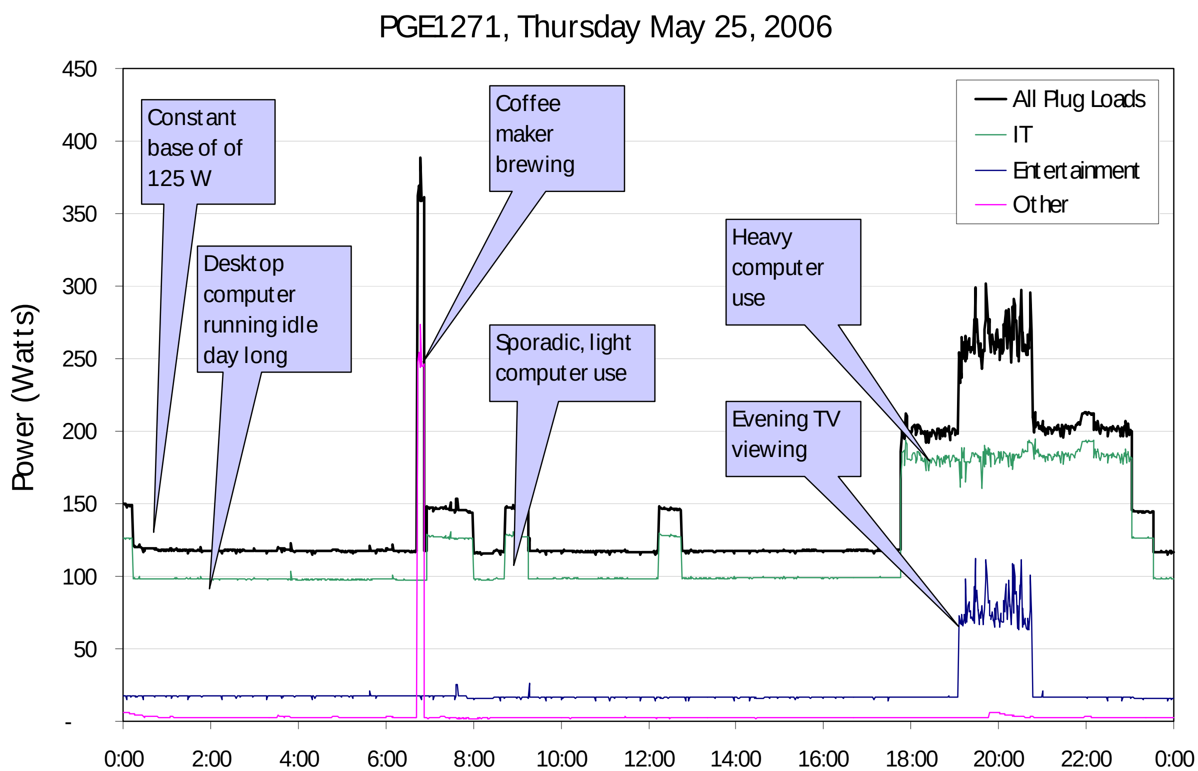

Figure 2: Sample plug load field measurements from one home[4]

3.1.1 Miscellaneous Plug Load Use Statewide and Nationwide

The overall data from 50 homes metered indicate that these miscellaneous plug-load devices currently consume 12–16 billion kilowatt-hours (kWh) of electricity per year in California alone

[4] Note that this home is atypical of the sample population in one key way: its IT energy use is significantly higher than its entertainment energy use.

or roughly 15 percent–19 percent of the electricity used by all California homes. This is enough energy to power about 2 million homes in California annually. On the national scale, these products account for anywhere from 114–146 billion kWh per year or between 3 percent–4 percent of *all* electricity used in the country. This is enough energy to fully power *all* of the homes in California and Washington *combined* or enough to provide electricity to the entire state of Michigan across *all* sectors.

Table 1 illustrates specific findings, showing the total amount of electricity use by miscellaneous plug loads for both California and the United States. The lower estimate presented in the table represents time-series metered results only, whereas the high estimate includes an extrapolation of the energy use of a small number of products that were merely counted in house surveys and not time-series metered.

Table 1: Estimated California and national electricity consumption of miscellaneous plug loads

	Low Estimate	High Estimate
Estimated CA Statewide Electricity Consumption (billion kWh/yr)	12.5	16.0
Percent of CA Statewide Residential Electricity Consumption	15%	19%
Percent of CA Statewide Total Electricity Consumption	5%	6%
Equivalent Number of CA Households Operated for One Year Based on Electricity Use (millions)	1.8	2.3
Estimated National Electricity Consumption (billion kWh/yr)	114.4	146.5
Percent of National Residential Electricity Consumption	9%	12%
Percent of National Total Electricity Consumption	3%	4%
Equivalent Number of U.S. Households Operated for One Year Based on Electricity Use (millions)	10.7	13.8

3.1.2 Miscellaneous Plug Load Energy Use by Category

The measured data indicate that entertainment electronics constitute over half of the energy used by miscellaneous and electronic plug loads, double that of any other product category (Figure 3). Information technology (IT) products constitute the second highest miscellaneous energy use, constituting approximately one-third of the total. The energy use in these two product categories is high because a large number of products per household draw a continual standby load and these products, which have high levels of power consumption during active operation, are used frequently by consumers. Categories with near-zero energy use do not appear in Figure 3.

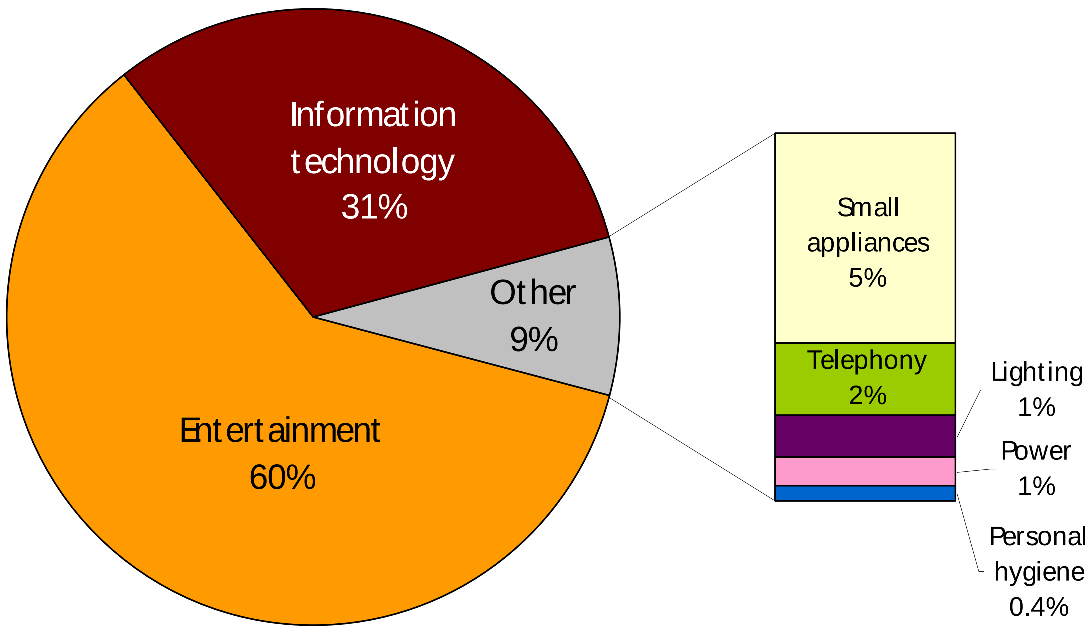

Figure 3: Share of California residential miscellaneous plug load energy use by product category

3.1.3 Energy Consumption by Operating Mode

The results of this research also clarified which operating modes are most important to the overall energy consumption, showing that the vast majority of energy use for the products examined occurs when the products are switched on. They may be performing their intended function or may be idling ready to perform that function, but they are not in their lowest power consuming mode or "standby." This finding corroborates earlier research by Ecos and others which had only been able to estimate the impact of the active mode (because of lack of usage pattern data), but had nonetheless identified active mode energy efficiency in consumer electronics, IT equipment, and other devices containing power supplies as a high priority for policy makers.

Specifically, the data indicate that the average California home uses 650–833 kWh per year, or 61 percent–78 percent of the energy consumption of all miscellaneous plug loads, solely in the active mode of operation (Figure 4). The figure expresses some of the uncertainty in quantifying the active mode exactly, due to the large number of products measured—set top boxes (STBs), for example—that consume the same amount of power regardless of whether they are "on" or "off." The figures denotes energy use that could not be ascribed to either active or standby/low power modes as "Indeterminate Modes."

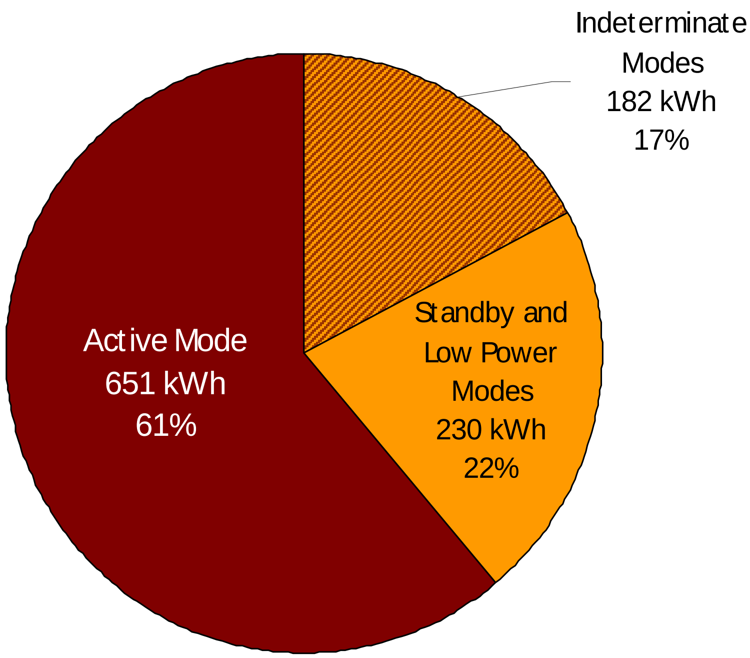

Figure 4: Average California household energy use of miscellaneous plug loads by operational mode (kWh figures indicate annual average use per California home)

This research shows that over half of the energy used by these products is consumed when they are turned on. However, these devices consume a relatively large base load of 54 watts through standby power consumption. It is as if every household is leaving a standard incandescent light bulb turned on all of the time, equating to more than 640 megawatts (MW) of constant load across California just to supply standby power to miscellaneous plug loads. This is consistent with previous studies by LBNL estimating an average standby power consumption of approximately 77–87 watts for plug loads, white goods, and hard-wired infrastructure and controls (Lawrence Berkeley National Laboratory 2004). The additional loads of white goods and hard-wired infrastructure represent about 13 watts, yielding a standby power consumption estimate only slightly higher than the 54 watts found here.

3.2 Power Supplies

The main outcomes of the power supply portion of this project were as follows:

- A finalized internal power supply test procedure.
- Efficiency measurements for 20 internal power supplies.
- A report analysis of efficiency elements related to PFC for PC power supplies.
- A report detailing how output voltage and current affects external power supply efficiency.

- Stakeholder involvement through a number of outreach activities, domestic and international.

These outcomes are summarized in turn below.

3.2.1 Internal Power Supply Product Technical Activities

Testing

Input from the research community and manufacturers at the January 2006 internal power supply test procedure workshop indicated that standardized energy efficiency testing of internal power supplies (see examples in Figure 5) is readily achievable for only certain categories of products that meet the following criteria:

- The power supplies must be separate or readily separable from the main circuit board of the device they are powering.
- The power supply nameplate output current and voltage ratings must be either printed on their housings or readily available from their manufacturers.
- The power supplies must have standard output connectors to facilitate measurement with reference loads under laboratory conditions.

These three tests are met by a few categories of internal power supplies, particularly those employed in most desktop, workstation, and server computers (Power Supply A, Figure 5). Many types of internal power supplies used in set-top boxes, slot machines, computer monitors, automated teller machines (ATMs), and other types of computer-related hardware may also meet these criteria. Most internal power supplies found in televisions, imaging equipment, and audio-video equipment, and many types of high-power battery charger systems will likely not meet these criteria (Power Supply B, Figure 5).

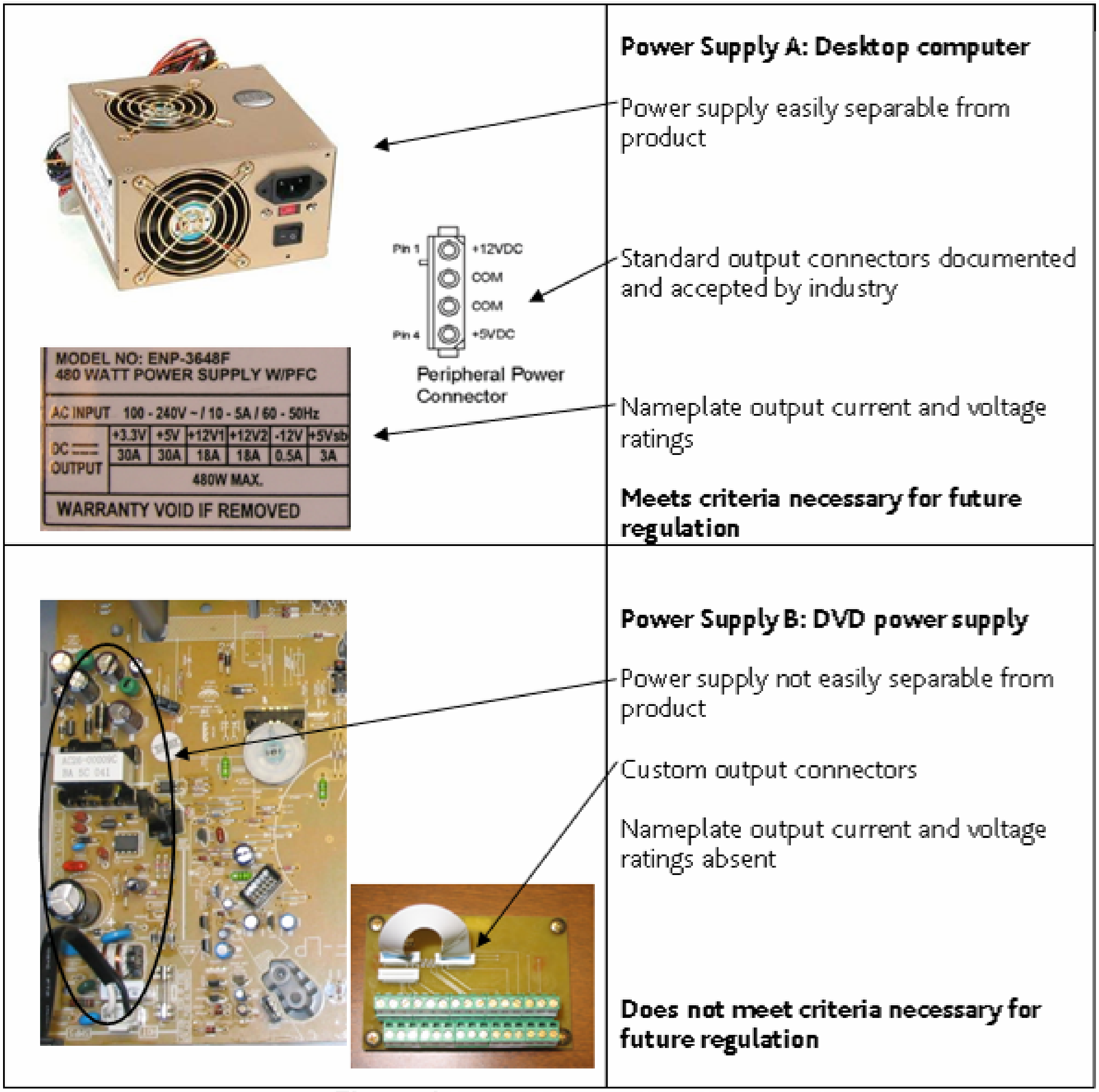

Figure 5: Internal power supply examples

A total of 20 power supplies were tested (Figure 6) during the test procedure development process described in Section 2.2. Power Supply Tests. All 20 were non-PC power supplies, 15 were separable power supplies, and 5 were non-separable power supplies.

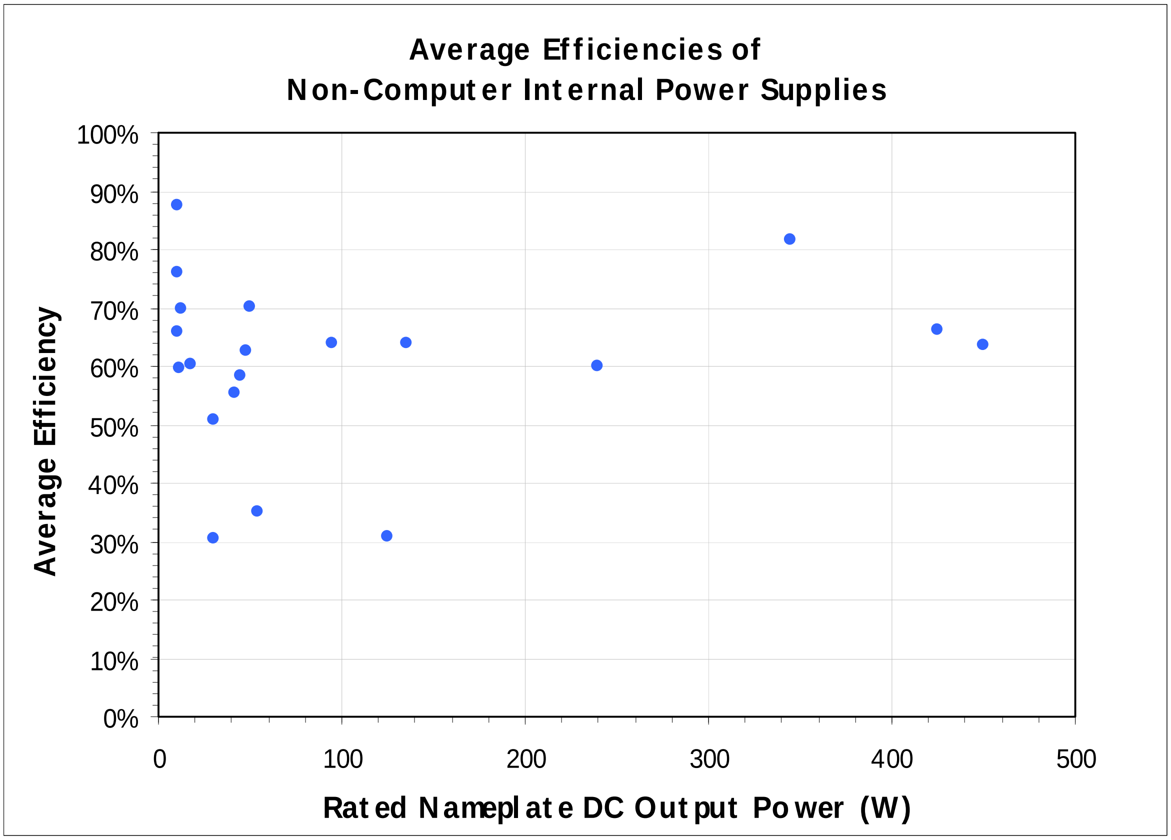

Figure 6: Average efficiencies of non-PC internal power supplies tested

Power Factor Correction Analysis

While efforts are underway to improve power supply efficiency through standardized test methods, voluntary labeling programs, and mandatory efficiency standards, parallel discussions are addressing whether or not to include PFC in the high efficiency designs. Power factor is a measure of the efficiency with which a load uses the current supplied to it. The power supplies in question draw more current than required for the direct current (DC) load on their output because of harmonics that are inherent in the power supply current, due to the power supply design. However, this problem can be corrected using PFC circuitry at the front end of the power supply—an approach required in Europe and Japan for high wattage devices. Through PFC, the total current flowing in the building wiring is reduced, and this in turn can reduce the heating of the wires that causes energy loss from that current.

EPRI Solutions assessed the energy-saving benefit of improved efficiency in computer power supplies, using the approach described in Section 2.2 Power Supply Tests. EPRI Solutions then extended that analysis to consider any additional energy savings resulting from PFC in the computer itself and in the building wiring that distributes power to the computer. The resulting impacts were tallied per computer, for the state of California as a whole, and for the United States.

The analysis showed that the use of high efficiency computer power supplies with PFC will result in three effects:

- **Direct savings from using a more efficient power supply**. This is the original intent of using 80 PLUS[5] power supplies and is the most significant effect.
- **Indirect savings in wiring due to lower current requirement of more efficient power supply**. This is a side effect of high efficiency loads, and while it is relatively small, it is still real and measurable (and has usually been ignored in past analyses).
- **Indirect savings in wiring due to power factor correction.** This is a known and measurable effect of PFC loads, larger than the indirect savings from higher efficiency and a significant added savings of energy.

Figure 7 shows some of those results, indicating the rising significance of cable and PFC savings as building distribution wiring becomes longer. PFC adds another 12 percent–21 percent to the resulting energy savings, based on the cable lengths typically found in residential and commercial buildings (40 feet and 100 feet, respectively). The results indicate that additional savings from PFC could be nearly 300 million kWh per year in California and as high as 2.4 billion kWh per year for the entire country.

5 80 PLUS is a utility-funded energy efficiency program offering financial incentives to computer manufacturers that install power supplies with a minimum efficiency of 80% and power factor correction. See www.80plus.org.

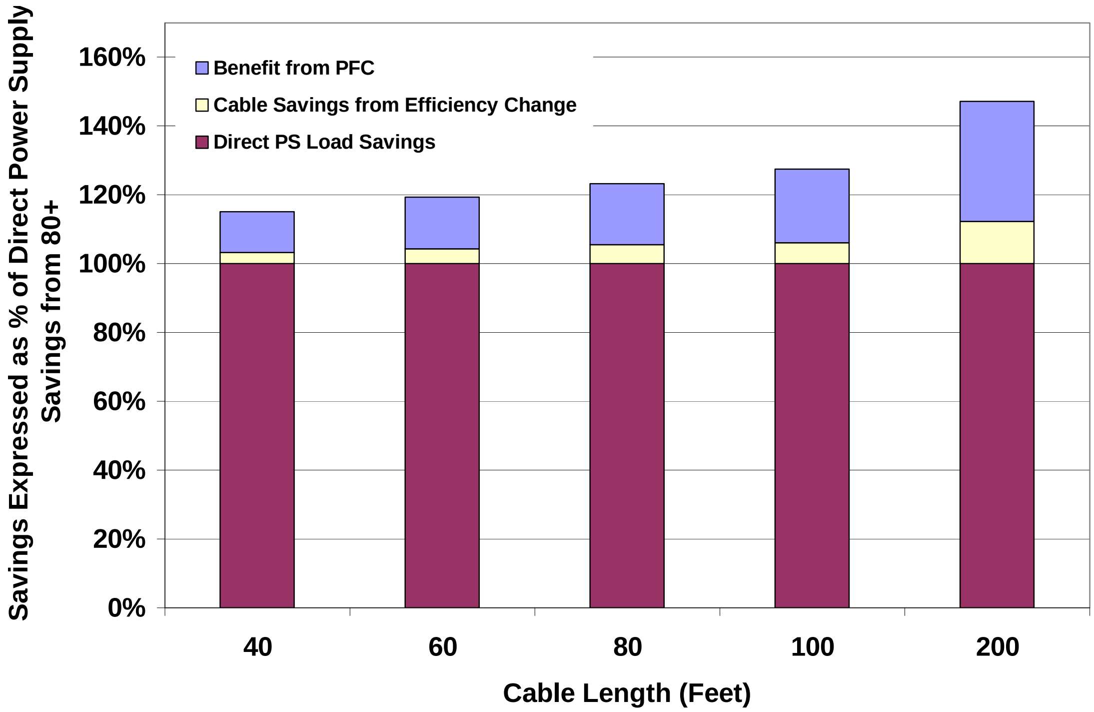

Figure 7: Effect of building wire length on energy savings associated with PFC

Additionally, some non-energy benefits associated with PFC could help avoid problems generated by excessive harmonics in the power system:

- Heating effects in phase conductors as well as neutrals.
- Heating in 3-phase, dry-type transformers.
- Harmonic voltage related heating in other equipment, such as motors.
- Harmonic voltage stress on system capacitors and equipment capacitors.
- Resonance with power-factor-correction capacitors.
- Voltage distortion at the point of common coupling.
- Release of kilo volt-amps (kava) in the power system (a positive effect).

3.2.2 External Power Supply Technical Activities

Ecos Consulting examined in detail the efficiency of 21 new EPS in 2005. These units were selected and purchased to meet the following objectives:

- Reflect EPS currently employed in popular consumer electronics, such as MP3 players and digital cameras.

- Augment Ecos Consul ting's database of nearly 500 EPS efficiency tests from past work with the Public Interest Energy Research (PIER) program by adding unusual voltage and current combinations.

Ecos examined several combinations of variables/factors to determine possible trends or relationships between these variables and average EPS efficiency, searching for combinations of variables that better explained variation in EPS efficiency than rated power alone. The most significant variables were found to be rated output current and rated output voltage.

Regression analysis indicated that a model incorporating rated output current and voltage yielded slightly higher statistical significance and better fit to these data. The model offers a promising structure for future revisions to efficiency specifications, as opposed to than simply raising the stringency of the existing ENERGY STAR®/Energy Commission specification. Key findings were as follows:

- All other factors being equal, EPSs with higher rated output current tend to achieve higher levels of efficiency.
- Similarly, all other factors being equal, EPSs with higher rated output voltage tend to achieve higher levels of efficiency.
- Using rated output current and voltage combined into a two-variable regression model allows more accurate prediction of average efficiency of an EPS than does using output power alone.
- Epps with high rated output current but low rated output voltage (products plotted in the lower right-hand corner in Figure 8 below, which shows rated output voltage, current, and efficiency of Epps, tend to have slightly lower average efficiency than do designs with similar output power achieved through a higher output voltage and lower output current. However the number of data points represented is very small, so this pattern is difficult to validate with statistical significance.

Policy implications are as follows:

- More stringent future power supply efficiency specifications can yield additional energy savings, as long as voltage and current are taken into account.
- As shown in Figure 8, numerous power supplies with a wide range of voltage and current ratings comply with the current ENERGY STAR® specification and forthcoming Energy Commission EPS standard. The highlighted regions that appear to contain no highly efficient, ENERGY STAR®/Energy Commission–compliant units are the products with very high current and low voltage and the products with very high voltage and low current. Both are rare in the data set, accounting for perhaps 8–10 of the hundreds of units tested. This is not surprising, because high power products tend to

employ standard ranges of output voltage and current to keep power supply designs manageable in size, complexity, and cost.

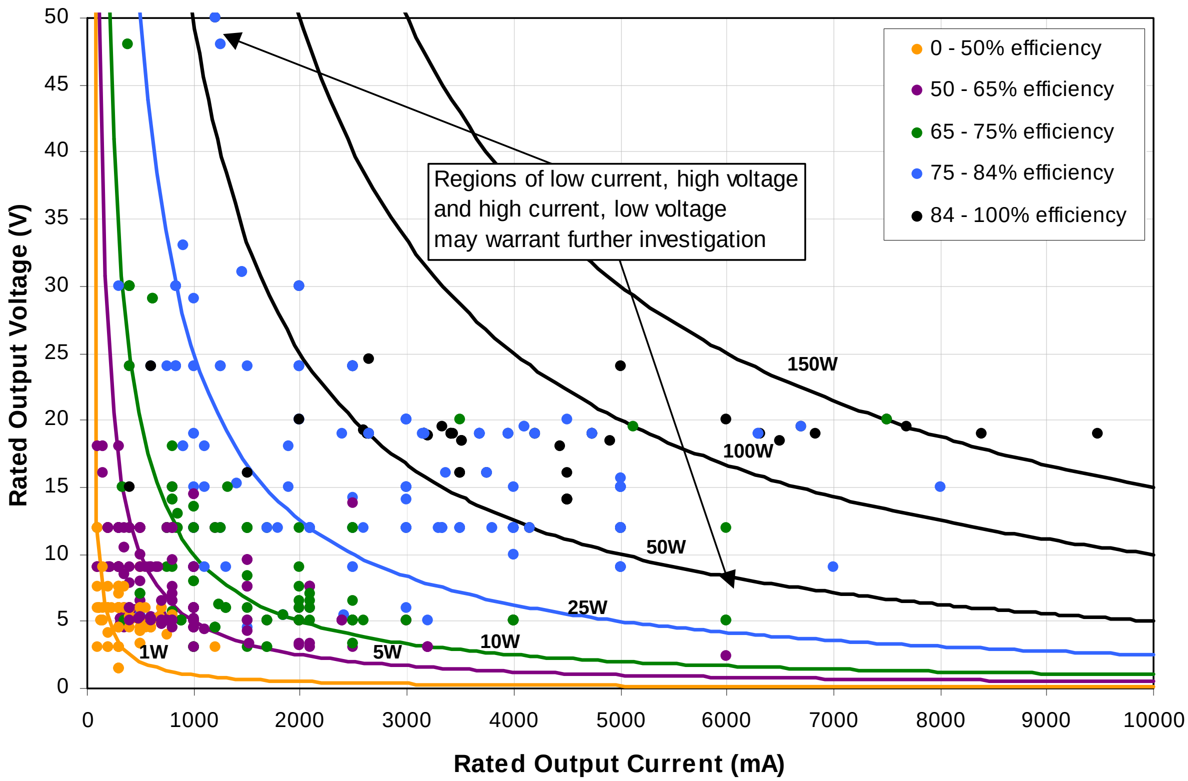

Figure 8: Rated output voltage, current, and efficiency of Epps

3.2.3 Power Supply Industry Outreach

Outreach to receive input from and disseminate information to stakeholders was a key element of this project. The following power supply outreach activities were conducted for the project:

- A workshop was held with stakeholders to receive input on the internal power supply test procedure on February 14, 2006, in Phoenix, Arizona, at ON Semiconductor's headquarters. Thirty-six attendees—representing government agencies, utilities, the power supply industry, and the electronics industry—reviewed the technical details of the internal power supply draft test procedure and provided comment on its approach and scope. Workshop notes with full detail on dialog were delivered as part of this project.
- Ecos Consulting and EPRI Solutions gave a presentation to on the test procedure and power factor analysis at the 2006 APEC meeting in Dallas. The power supply industry representatives attending gave an exciting level of attention to highly efficient power

conversion technologies, many of which have been designed specifically to meet the challenges of upcoming Energy Commission and ENERGY STAR® specifications for external power supplies, and the 80 PLUS and ENERGY STAR® specifications for internal computer power supplies.

- A website on this topic, www.efficientpowersupplies.org, was reorganized and redesigned to give a look more similar to its sister site, www.efficientproducts.org. Drafts of the internal power supply test procedure, workshop materials, power supply related policy updates, and other relevant content were posted on the site throughout the contract period.
- Ecos Consulting attended a number of meetings in the United Kingdom in June 2006, including the PEIG (Power Electronics Industry Group) seminar, a TV workshop, an STB workshop, and the Energy Efficiency in Domestic Appliances and Lighting (EEDAL) Conference. Attending these meetings allowed Ecos' policy recommendations to be informed by the international arena. Activities included coordinating with international players on a variety of important research and policy steps, including test procedure development, data collection, policy approaches, and policy timing and levels.

3.3 Battery Chargers

The main outcomes of the battery charger portion of this project were:

- Two drafts of a battery charger system energy efficiency test procedure.
- Efficiency measurements of more than 60 battery chargers.
- Reports detailing battery charger market trends and growth expectations, energy savings potential, and cost-benefit analyses.
- A technical report examining efficiency of battery charger technologies and opportunities for efficiency improvement.
- Stakeholder involvement through a number of outreach activities, domestic and international.

These outcomes are summarized in turn below.

3.3.1 Test Procedure and Laboratory Testing of Battery Charger Systems

To address battery charger systems as a single policy initiative and to enable fair comparison among products, Ecos and EPRI began developing a standard test procedure and efficiency metric. Another battery charger test procedure had been developed by the U.S. EPA ENERGY STAR® program (ENERGY STAR® 2005). However, the project team's research suggests that the ENERGY STAR® test procedure was not well-suited for the wide scope of battery charger systems under consideration in the scope of the current project.

The basic approach for the test procedure is to consider alternating current (AC) energy needed to put into the charger to charge the battery and maintain it over time and compare that to the DC energy extractable from the battery during discharge (Figure 9). When Ecos/EPRI initiated development of the battery charger system test procedure in 2003, the team attempted to test charge, maintenance, and no-battery modes separately (Foster, McAllister et al. 2003). This approach presents technicians with the challenge of using observation to definitively determining the exact moment when a battery charger transitions from charge mode to maintenance mode. The challenge is complicated by the chargers that maintain a steady-state power level throughout the charge and maintenance cycle, such that no transition ever takes place. (See for example the handheld radio battery charger system in Figure 12.) Consequently, with stakeholder input, the team changed the approach to combine charge and maintenance mode in a 24-hour test.

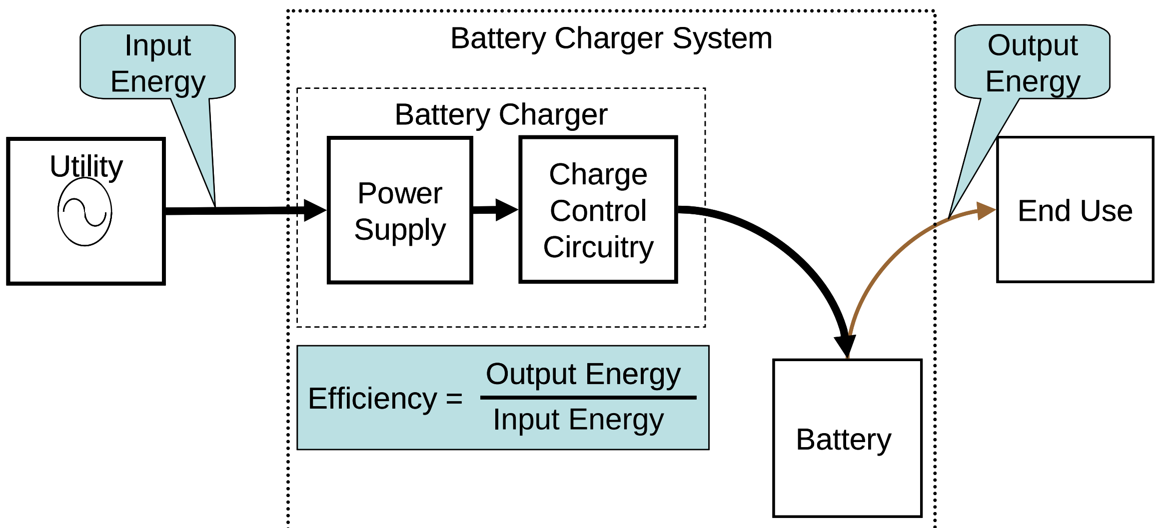

Figure 9: Battery charger configuration and efficiency metric

The 24-hour period chosen ensured that the battery charger completed its charge sequence and entered into maintenance mode, but was not so long that it placed an undue cost burden on manufacturers. Ecos/EPRI retained the battery discharge test and the no-battery test from the 2003 preliminary draft and refined the document with stakeholder input to ensure repeatability through standardization of environmental conditions and specific battery chemistry test provisions (such as rest periods between tests), among other details. In summary, the major provisions of the current Draft 2 (Porter, Kamet et al. 2006) include:

- Battery discharge test to determine the extractable energy from the battery (measured in watt-hours).
- 24-hour charge and maintenance test to determine the energy needed to return the battery to a full state of charge (measured in watt-hours).

- No-battery mode test to measure of the power use of the charger without the battery installed (measured in watts).

Table 2 summarizes the 24-hour charge and maintenance efficiency and no-battery mode power of 195 battery charger systems that were measured according to the Draft 2 standard test procedure. With partner EPRI Solutions, the team collected efficiency data using the newly developed procedure on 62 products (Glosser, Kamet et al. 2006). To ensure small random error relative to the overall differences, selected samples were tested with the same procedure multiple times very early in the research. Variations in efficiency results were within a few percent, and so the majority of the samples were tested only once. Testing as many different samples as possible to understand the range of efficiency in the marketplace allowed Ecos and EPRI to more clearly determine the energy saving opportunity associated with battery chargers. As the test procedure is refined further, a more detailed examination of error will need to be conducted.

These data are coupled with other efficiency data from Cadmus Group collected as part of the U.S. EPA ENERGY STAR® program to create a battery charger efficiency database. Data from Cadmus were collected according to the ENERGY STAR® test procedure. Where active mode data were collected, a previous version of the Ecos/EPRI draft was employed. Although the database contains a large number of products, it lacks data for large-scale battery charger products (between 100 watts input and 2000 watts input). More data for these products in particular will need to be collected to create a specific efficiency standard.

Table 2: Battery charger laboratory data from Ecos/EPRI and Cadmus tests

Product Category	Count	Devices Tested in Charge Mode	Typical Chemistry	Efficiency Range on a 24-Hour Charge/ Maintenance Cycle	Average Efficiency on a 24-Hour Charge Cycle	No-Battery Mode Range (watts)	Average No-Battery Mode (watts)
AA Battery Charger	45	7	NiMH	2% - 16%	11%	0.2 - 3.1	1.1
Auto Battery	1	1	LA	NA	25%	NA	1.9
Camcorder	1	1	Li-Ion	NA	54%	NA	0.00
Camera	2	2	Li-Ion	13% - 56%	35%	0.0 - 1.2	0.6
Cordless Phone	5	5	NiCd/NiMH	3% - 7%	4%	1.0 - 3.1	0.04
DVD Player	1	1	Li-Ion	NA	42%	NA	1.4
Egress Lighting	1	1	LA	NA	30%	NA	1.5
Forklift	2	2	LA	28% - 40%	34%	13.4 - 50.3	31.9
Golf Cart	2	1	LA	NA	47%	NA	205.6
Laptop	3	3	Li-Ion	59% - 69%	64%	0.5 - 3.3	1.9
Lighting	1	1	LA	NA	34%	NA	1.0
Mixer, Cordless	1	1	NiCd	NA	7%	NA	0.5
Oral Care	3	3	NiCd	4% - 11%	7%	0.6 - 1.7	1.2
Power Tool	86	33	NiCd	4% - 54%	18%	0.00 - 11.0	2.5
Handheld Radio	1	1	NiMH	NA	2%	NA	0.8
RV Battery Charger	4	4	LA	22% - 28%	25%	26.3 - 69.7	49.3
Shaver	9	4	NiCd	4% - 13%	8%	0.00 - 0.7	0.3
Sweeper, Automatic	12	5	NiCd	11% - 26%	19%	0.00 - 3.5	0.9
Toys	4	2	NiCd	4% - 19%	12%	0.7 - 1.3	1.0
Wheelchair/Scooter	2	2	LA	26% - 33%	29%	16.3 - 49.1	40.5
Wireless Telephone	9	9	Li-Ion	24% - 64%	39%	0.0 - 0.9	0.1
Total	195	89					

Source: (Porter, Herb et al. 2006) and (Cadmus Group 2005)

3.3.2 Battery Charger System Market Analysis

More than 1 billion AC-powered battery chargers are in use in the United States, and about 300 million new units are sold each year. Sales of devices with battery charging circuitry are on the rise as mobility capabilities increase. From 1999–2004, demand for secondary (rechargeable) batteries in portable devices grew 8.9 percent annually, and devices in mobile applications (other than automotive) grew 4.3 percent annually.

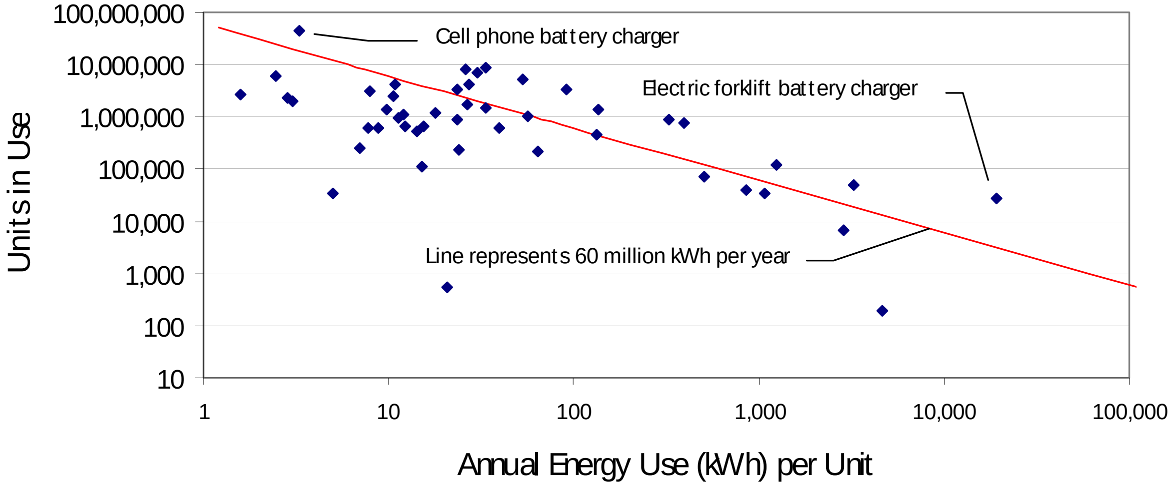

Figure 10: Battery charger stock and unit energy use

Figure 10 shows the types of battery chargers in use in 2006 and their annual energy use. As shown, products with battery charging systems tend toward one of two categories. Products in the first category (e.g., cell phones) consume a relatively small amount of energy per unit, but have tens of millions of units in use in California. The second category, which includes forklifts, has comparatively modest sales, but the energy use per unit is high (for fork lifts, nearly 20,000 kWh per year). Of course, many products with relatively small individual energy use fall between these two groups. Yet, the combined annual energy use of the products that fall between the two extremes is quite large, approximately 3.5 billion kWh per year in California.

Battery chargers currently consume approximately 42 billion kWh per year nationally (**Figure 11**) and 4.6 billion kWh per year in California, or about 14 percent of the total energy use of electronic devices. Highly efficient existing technologies could sharply reduce power consumption in all three operating modes of battery chargers—active, maintenance, and no-battery. The resulting annual energy savings would be approximately 18 billion kWh nationwide (Table 3), or almost 2 billion kWh per year in California.

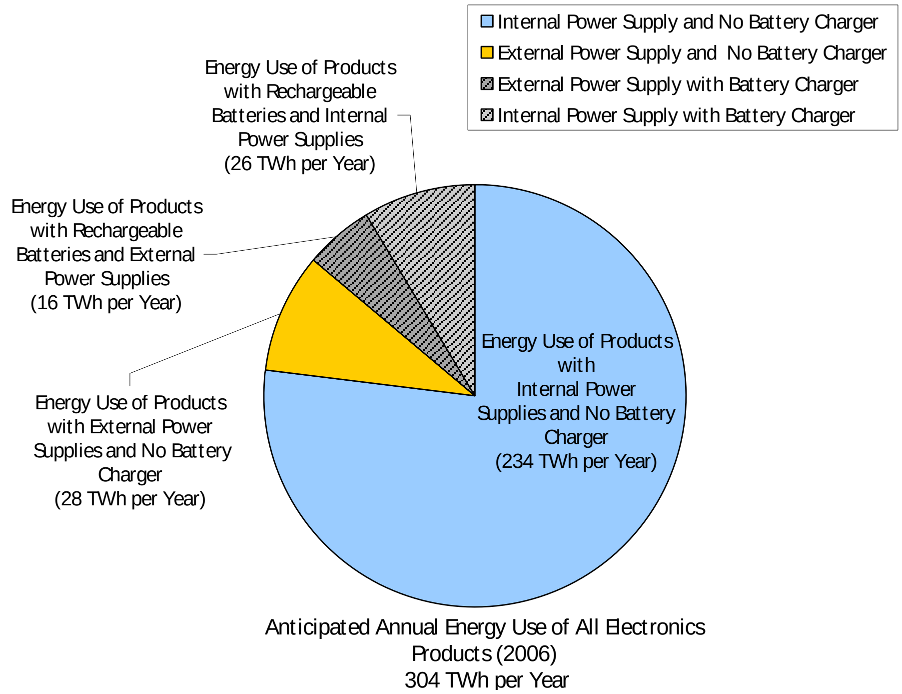

Figure 11: Annual U.S. energy use by electronic products with and without battery chargers

Table 3: National market summary for battery chargers

Device	Units in Use (Millions)	Total Annual Energy Use (TWh per year)	Annual Energy Savings from Improved External Power Supplies (TWh per year)	Annual Savings from Improved Battery Charging Systems (TWh per year)	Total Annual Savings Nationwide (TWh per year)
Cordless Phones	277.6	7.2	0.8	1.7	2.6
Stand Alone Battery Chargers (Marine)	7.3	2.7	NA	1.9	1.9
Forklifts	0.2	7.7	NA	1.7	1.7
Uninterruptible Power Supply (Standby)	47.1	2.5	NA	1.7	1.7
Golf Cart Chargers	1.1	4.3	NA	1.6	1.6
Recreational Vehicle Chargers	6.7	2.3	NA	1.6	1.6
Personal Electric Vehicle Chargers	12.3	1.7	NA	1.1	1.1
Other	694.6	13.4	1.4	4.9	6.3
Total	1047	41.9	2.3	16.3	18.5

Some areas of the market are already actively using the most efficient battery charging technologies. However, in markets where low price is the primary driver, the energy efficiency of the overall system tends to be low. In markets where portability and battery life are key and consumers are driven by the quality, portability, and runtime of devices, chargers tend to be more energy efficient. The growing popularity of small, high-performance portable devices has driven down the cost of energy efficient charging strategies. In most cases, these technologies yield greater savings in lifetime energy use than their incremental cost.

3.3.3 Battery Charger Technical Primer Results

The key finding from developing the technical primer is that significant opportunities exist to improve the efficiencies of battery charger systems in use today. At present, inefficiencies in the charger and battery often cause chargers to consume more electricity than do the product they power. Millions of battery charger systems are in operation worldwide; therefore substantial energy savings are achievable by reducing or eliminating these inefficiencies.

Figure 12 illustrates the charge, maintenance and no-battery mode levels for two common products—a handheld radio and a cell phone—of similar battery energy capacity. The battery charger system associated with the handheld radio, shown by the blue line, has these characteristics:

- An inefficient power supply (average efficiency 43 percent).
- A nickel metal hydride (NiMH) battery with a high rate of self-discharge (i.e., the battery tends to lose stored energy if allowed to sit for a long time without maintenance current from the charge).
- Indistinguishable charge and maintenance modes because the battery charging circuitry feeds the battery the same amount of current regardless of the state of charge of the battery. This simple "charging solution," commonly found coupled with batteries with high self-discharge rates (NiMH and nickel cadmium [NiCd]), tends to overheat the battery and shorten the overall lifetime, but is less expensive to manufacture than more sophisticated charging circuitry.
- A significant power draw (2.8 watts) when no battery is installed.

The cell phone battery charger system, shown by the yellow-green, has these characteristics:

- A relatively efficient power supply (average efficiency 73 percent).
- A lithium-ion (Li-Ion) battery with a low self-discharge rate (0.3 watts) so little battery maintenance is required.
- A feature (not found in all Li-Ion battery charger circuitry) that intelligently turns off power drawn from the wall once the battery is fully charged and when no battery is installed. Thus, little power is drawn in the battery maintenance mode after the battery is fully charged and when the phone is disconnected from the charger.

Because of the design choices, the cell phone charger is clearly more efficient than the handheld radio charger. Specifically, the cell phone charger achieves about 48 percent efficiency (determined by comparing the total energy extractable from the battery to the AC energy consumed over a 24-hour period) and uses less than 0.1 watts in no-battery mode. In contrast, handheld radio battery charger has only about 2 percent efficiency and consumes 0.8 watts in no-battery mode. The significant efficiency difference between these two systems suggests a large energy savings opportunity for the total battery charger market. However, without a test procedure to measure a range of battery charger systems in a consistent and repeatable manner, it is difficult to determine with any precision the true energy savings opportunity.

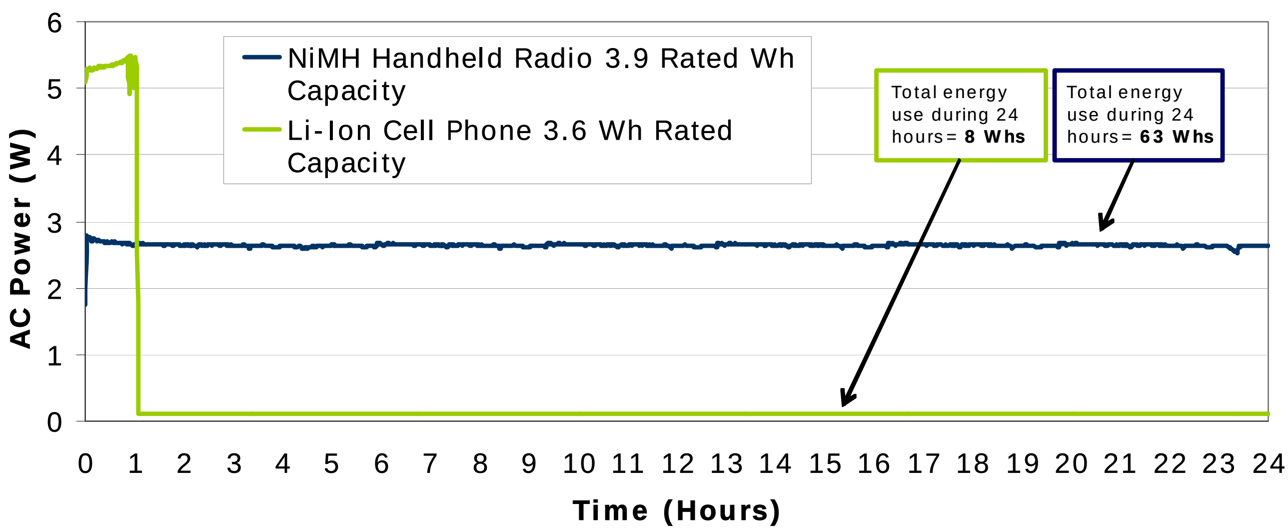

Figure 12: Measurements of two battery-powered products with similar battery energy capacity

More generally, use of the following components or methods can lead to higher efficiency in battery charger systems:

- Higher voltage systems.
- Switch-mode power supplies.
- A design technique called synchronous rectification.
- Improved semiconductor switches.
- Lithium-ion batteries.
- Lower current rate for charge and discharge.

Table 4 summarizes the degree to which efficiency can be improved for today's various charger topologies.

Table 4: Potential for efficiency improvements in charger topologies

Topology	Typical Efficiency Range (%)	Estimated Improved Efficiency Range
Linear	10%–30%	20%–40%
Switch Mode	40%–60%	50%–70%
Ferroresonant	25%–50%	45%–55%
SCR	30%–55%	45%–60%

In conclusion, many common battery charger systems have measured efficiencies of less than 15 percent. However, comparable systems with overall efficiencies of 65 percent or greater are technically feasible, and the technical path to higher efficiency is clear. These results suggest that the technology is ready for policies that will encourage and accelerate the market adoption of the technologies and practices that can reduce battery charger energy consumption cost-effectively, while preserving the essential convenience of these products that has made them popular.

3.3.4 Battery Charger Stakeholder Outreach

Outreach to receive input from and disseminate information to stakeholders was a key element of this project. The following battery charger outreach activities were conducted for the project:

- On November 17, 2005, at the PG&E Pacific Energy Center in San Francisco, California, a workshop was held with stakeholders to receive input on the battery charger system test procedure. Forty workshop attendees, including energy efficiency advocates, utility representatives, battery charger manufacturers, researchers, manufacturer's associations, and staff members from the California Energy Commission, participated in an engaging technical discussion about the battery charger test procedure. Workshop notes with full detail on dialog were delivered as part of this project.
- Ecos Consulting and EPRI Solutions attended two Battery Power Products and Technology Conferences, one in Vancouver in August 2005 and the other in Chicago in April 2006. Contacts were made for the stakeholder list and research results and recommendations were shared with battery charger stakeholders.
- A website on this topic, www.efficientproducts.org, was augmented to include detailed information on battery charger system efficiency. Drafts of the battery charger system test procedure, workshop materials, battery charger related policy updates, and other relevant content were posted on the site throughout the contract period.

- Ecos Consulting attended ACEEE Summer Study to present a peer-reviewed paper on battery charger technical findings and policy recommendations. At this conference, the team was able to share results with energy efficiency and environmental advocates, international policy makers, and electric utilities.

Chapter 4: Conclusions and Recommendations

4.1 Conclusions

A number of conclusions can be drawn from the team's research:

- The residential plug load field research revealed that miscellaneous plug-load devices currently consume 12–16 billion kWh of electricity per year in California alone or roughly 15 percent–19 percent of the electricity used by all California homes. Entertainment electronics, such as TVs and STBs, constitute the largest share of that miscellaneous energy use; IT electronics constitute the second largest share of miscellaneous energy use. Fully 61 percent–78 percent of the energy consumption of all miscellaneous plug loads is solely in the active mode of operation.
- The draft test procedure for internal power supplies revealed that a subset of that product family—self-contained, non-redundant designs—were amenable to testing, promotion, and inclusion in energy efficiency labeling efforts. Indeed ENERGY STAR® has now included power supply efficiency in its computer specification (scheduled to take effect in late July 2007), and electric utilities throughout North America are promoting highly efficient desktop computer power supplies through the 80 PLUS program.
- The impact of output voltage and current on EPS efficiency is significant enough to justify considering output voltage and current instead of output power only when crafting future revisions to California EPS efficiency standards.
- Correcting power factor in a computer power supply can yield 12 percent–21 percent additional energy savings over simply improving power supply efficiency. Savings tend toward the high end of that range in large commercial buildings where computers are used in large numbers.
- It is technically feasible to create a standard battery charger system test method. Testing conducted with the draft standard test procedure developed in this project revealed enormous differences in the measured energy efficiency of battery charging systems. Annually, battery charger systems currently consume approximately 42 billion kWh nationally and 4.6 billion kWh in California, or about 14 percent of the total energy use of electronic devices. Highly efficient existing technologies could sharply reduce power consumption in all three operating modes of battery chargers—active, maintenance, and no-battery. The resulting annual energy savings would be approximately 18 billion kWh nationwide or almost 2 billion kWh in California.

- The battery charger technical primer developed revealed that changes to battery charger system design and component choices could greatly improve battery charger system efficiencies. At a time when many common battery charger systems have measured efficiencies of less than 15 percent, comparable systems with overall efficiencies of 65 percent or greater are technically feasible.

4.2 Recommendations

From these conclusions, Ecos and EPRI Solutions have a number of recommendations, including policy and technical transfer recommendations as well as recommendations for future research.

4.2.1 Policy Recommendations

Voluntary and mandatory energy efficiency policy coverage of devices with external power supplies is extensive, but the majority of energy use occurs in the larger, more powerful devices that tend to rely on internal power supplies. As a result, a sequential four-step policy approach is recommended to capture energy savings from electronic products:

- Voluntary labeling programs and mandatory energy efficiency standards to increase the efficiency of AC-DC and AC-AC power conversion in active and no-load modes in nearly all external power supplies (largely complete).
- Voluntary labeling programs and mandatory energy efficiency standards to increase the efficiency of nearly all battery charger types in all modes of operation (partially underway).
- Further research and market initiatives to understand and improve the efficiency of DC-DC power conversion processes within all electronic products (started in Q4 2006 under contract 500-06-007).
- Product-by-product, voluntary labeling and utility incentive programs to increase the whole-product efficiency in all modes of operation of electronic devices containing internal power supplies (partially underway).

Significantly, each of these steps builds on the preceding one to expand total achievable energy savings. For example, it is difficult to store low-voltage DC energy efficiently in a battery without first converting it efficiently from line voltage AC. Likewise, improvements in power supply efficiency, battery charger efficiency, and DC-DC conversion are three of the most promising ways to improve whole-product efficiency. They therefore represent technological stepping stones toward the overall goal of making the entire product more efficient.

Because the focus of this research is internal power supplies and battery chargers, the team created specific policy recommendations for these two products. Based on the technical and market research conducted under this contract, Ecos/EPRI recommend that mandatory battery charger system minimum efficiency standards be pursued in the near-term, but suggest delaying internal power supply minimum efficiency standards until the market is better positioned to respond.

Battery Charger Standards

It is possible to plot the 24-hour efficiency metric and the no-battery power for each battery charger in the Ecos/EPRI data set against the measured capacity of the battery (Figure 13 and 14**Error! Reference source not found.**). On average, battery charger systems are 22 percent fficient over a 24-hour period in charge and maintenance modes; the least efficient unit tested is 2 percent efficient and the most efficient is 69 percent. This variation among all products measured is accompanied by variations for specific measured capacities. For example, for batteries with measured capacities of roughly 2.5 watt-hours, efficiencies vary from less than 5 percent to greater than 60 percent. In no-battery mode (Figure 14), several battery charger systems use as much as 6 watts and yet other products use nearly 0 watts.

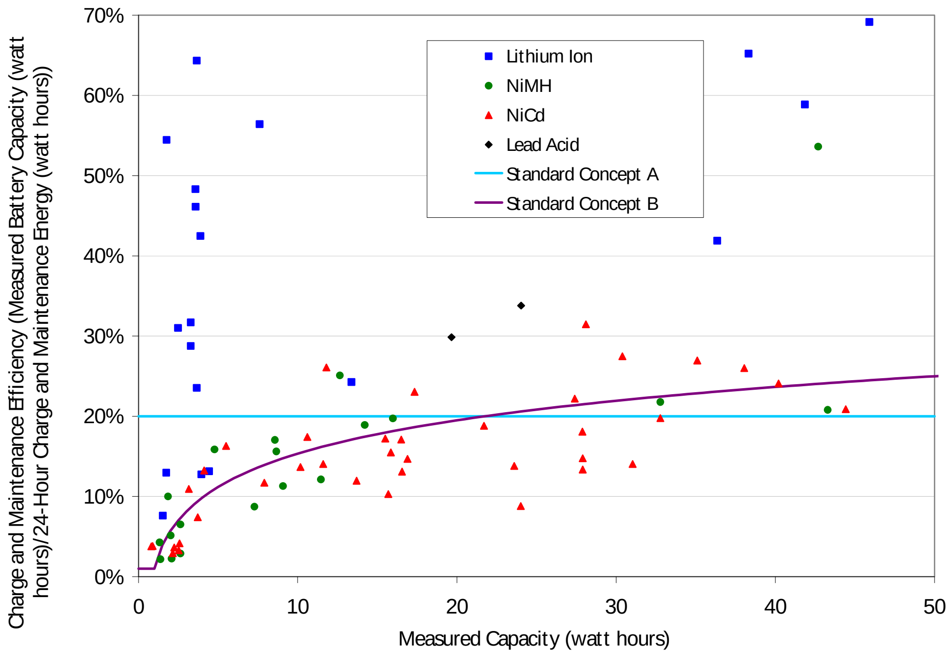

Figure 13: Active and battery maintenance standard concept

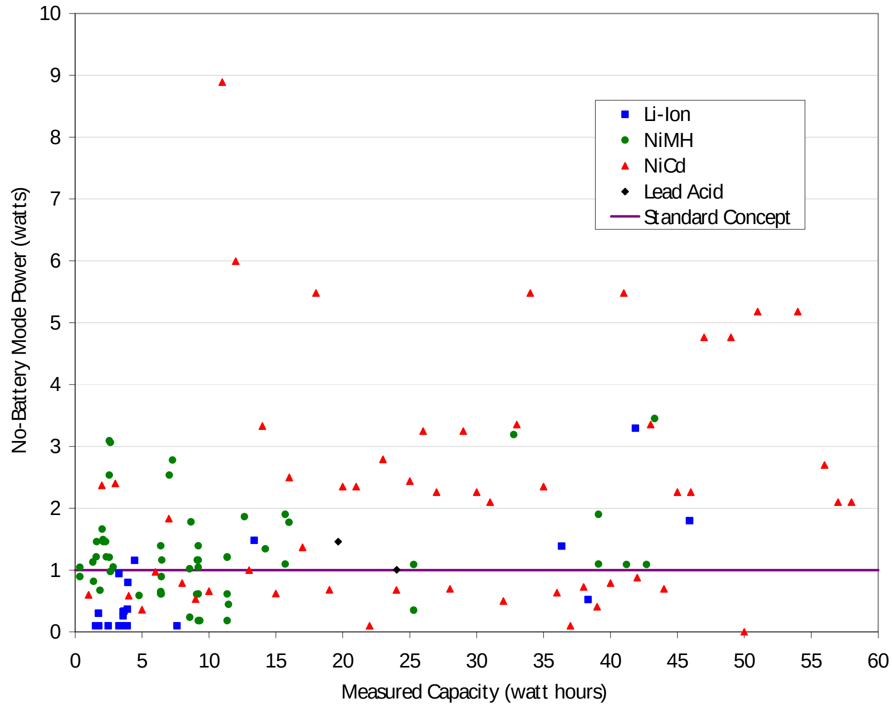

Figure 14: No-battery mode power standard concept

A line drawn through the data for both active/maintenance efficiency and no-battery mode power would indicate which products would be considered efficient according to a standard. For active mode, it might be possible to create one level of efficiency across all battery energy capacities (standard concept A, Figure 13), or there may be a need to base the standard on different energy capacities (standard concept B, Figure 13). A minimum efficiency standard for the no-battery mode is not likely to be dependent on battery capacity. The standard concept lines drawn in Figure 13 and 14**Error! Reference source not found.** illustrate possibilities; collection of more product data is needed to determine the exact shape or level of an actual standard.

The research suggests that a 24-hour active maintenance efficiency metric coupled with a separate no-battery mode power provision would be acceptable to the battery charger industry for two reasons:

- It allows engineers to develop the most cost-effective solution to reduce energy consumption in the charge and battery maintenance modes combined—enabling efficiency trade-offs between modes not possible with separate charge and maintenance mode efficiency levels.
- It is similar to the internationally successful and industry-accepted external power supply metric, where an active mode efficiency and no-load power are separately defined.

Internal Power Supply Standards

Because the test procedure itself is still undergoing final revisions and the voluntary initiatives to encourage greater power supply efficiency in computers (www.80Plus.org) are just getting underway, Ecos does not recommend that the Energy Commission take any action on mandatory internal power supply efficiency for any product categories at this time. The Energy Commission may wish to revisit this situation in 2008 to assess the extent to which market initiatives have matured and additional measured data are available on internal power supply efficiency by product category.

In general, industry favors whole-product efficiency specifications for electronic products over approaches that address the efficiency of individual components within them. These specifications generally employ an efficiency metric that considers the overall function of the device relative to the power or energy consumption needed to perform that function. Figure 15 gives an example of the ENERGY STAR® computer monitor specification. In this program, manufacturers test the power use while the monitor is in active mode and then compare that value to the number of pixels the monitor is capable of displaying on screen. Such specifications permit tradeoffs between various aspects of component efficiency and tend to encourage, though not require, the use of highly efficient internal power supplies as one design strategy.

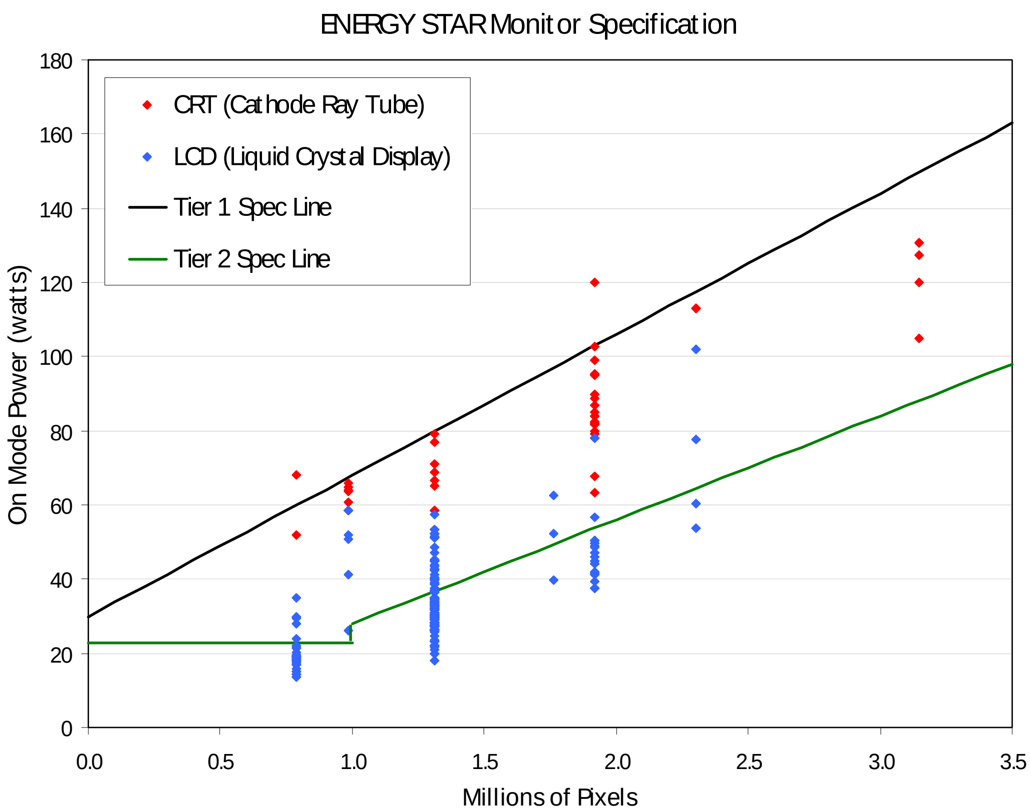

Figure 15: ENERGY STAR® whole-product computer monitor specification

The monitor specification is one example of three ENERGY STAR® specifications that address the active mode efficiency of internal power supply products. The monitor specification has been relatively successful; the other two specifications for computers and imaging equipment are new, and manufacturer participation and energy savings is not yet fully known.

4.2.2 Recommended Next Research Steps

A number of recommended research steps are currently being funded by a new Energy Commission contract (500-06-007 Consumer and Office Electronics):

- The residential plug load field study gathered a significant amount of useful data to support the overall effort to curb miscellaneous residential energy use. A complementary next step could be to conduct a field measurement study to understand plug load energy use in commercial offices. Identifying overall energy use as a percent of the total, office electronics duty cycles, and average power levels by mode would be helpful to characterize the energy use of these products in an office setting.
- The field research data demonstrated that televisions are the largest single electronic energy user in the average home. TV energy use is expected to grow as screen size and hours of use increase over time. Unfortunately, no existing test procedure can produce repeatable energy efficiency measurements for all television technology types. As a result, no body of energy consumption data exists to support a standards ruling process in California. An important next step would be to develop a standard, repeatable test procedure to help characterize TV efficiency.
- The field research identified desktop computers as one of the products with the largest opportunity for energy savings. (More than 200 million desktop computers are currently in use in the U.S, each consuming an average of 300–400 kWh per year). Increasing desktop computer efficiency by simply installing highly efficient power supplies is steadily making progress in the market, but the opportunity to seek overall system efficiency is now ripe. Therefore, it is important to seek the best components industry has to offer, and combine them to develop desktop computer prototypes for demonstration to utility emerging technology groups, industry, and other stakeholders. This effort could include a demonstration sample for both market-ready products and promising technologies that have yet to take hold in the market. After demonstration, the technologies should be promoted to stakeholders as a clear direction for energy efficient computing.
- The Ecos/EPRI battery charger research and other general research on the efficiency of internal power supply devices revealed that secondary power supplies, known to industry as DC-DC converters or voltage regulator modules, are embedded within electronic systems. They operate downstream of a product’s primary AC-DC power supply and are employed to develop the diverse array of voltages required by complex

electronic systems (the current generation of microprocessors operate at voltages as low as 0.9 volts DC, even though AC-DC computer power supplies typically output 12, 5, and 3.3 volts only). Little is known about the total energy dissipated by these devices. They are a diffuse but potentially large opportunity for additional energy savings. More research could be done to test the secondary power supplies to characterize their efficiency and estimate achievable energy savings.

In addition to these currently funded projects, other opportunities suggested by this research could be pursued by the Energy Commission:

- Two drafts of a battery charger energy efficiency test procedure were created under this contract. The current draft resulting from that research, Draft 2, is nearly complete, but needs one more round of revision and input from stakeholders before it can be considered final for use with Energy Commission Energy Efficiency Standards. The significant energy savings opportunities for battery chargers confirm the value of finalizing the test procedure for use in a standards process. This effort would include more testing, with an emphasis on large battery chargers (greater than 100 watt input).
- The battery charger technical research suggested that large three-phase battery chargers used with forklifts and plug-in hybrids are significantly different than consumer-grade chargers. The large savings opportunity for these chargers suggests that an efficiency test procedure be developed and the energy savings opportunity better characterized.
- Although demand response has been explored for residential HVAC systems, it has never been proposed for plug load energy use. The large energy usage of residential electronics suggests that significant energy savings opportunities exist if utilities could influence consumer usage patterns of the most energy intensive plug loads, such as televisions and computers. Research into consumer response to a plug-load demand response system could create an opportunity for utilities to employ these types of systems in California homes.

4.3 Benefits to California

The research results delivered under this project position the Energy Commission and electric utilities to pursue policies, programs, and other market intervention to reduce plug load energy use in the residential sector. Summarized below are the near-term direct benefits to California associated with each element of the project.

Field Research

The residential plug load field measurement allows policy makers and utilities to determine policy and program priorities for plug loads. Future programs and policies developed in California can use these findings to cost-effectively save energy and reduce load growth during on and off peak periods. The most important findings follow:

- 15 percent–19 percent of the electricity used by California homes is attributable to plug loads; hence this category of products is worth consideration for energy efficiency and demand response initiatives.
- Entertainment and IT electronics constitute the vast majority of the plug load energy use.
- Most of the plug load energy is used when the products are operating, not when they are in standby.

The work with Brand Electronics to refine its existing plug load meter design to meet the needs of energy efficiency field research will also yield significant technology benefits to future California plug load studies. These same meters can now be purchased by utilities and energy service companies seeking to understand and propose ways to reduce plug loads in customer buildings. Further refinements in the software and hardware may be needed to simplify operation in the field, but the first key steps have now been taken.

Power Supplies

The internal power supply test procedure development was instrumental in developing a utility-funded desktop computer energy efficiency program, 80 PLUS, that offers financial incentives to computer manufacturers that install power supplies with a minimum efficiency of 80 percent and power factor correction. Data taken with the internal power supply test procedure as part of the 80 PLUS program indicate a growing prevalence of models that can surpass the 80 percent efficiency level. By the end of September 2006, more than 75 separate power supply models for desktop computers complied with a minimum efficiency requirement of 80 percent and a minimum power factor of 0.9. Earlier models available in 2004 and 2005 could only manage efficiency levels in the 60 to 75 percent range, so the change in the marketplace has been rapid and decisive.

ENERGY STAR® elected to incorporate a power supply efficiency requirement into its labeling program for computers on the strength of these data provided by this PIER-funded research. ENERGY STAR®'s new specification for computers (www.energystar.gov/index.cfm?c=revisions.computer_spec) will be completed in October 2006 and is scheduled to take effect in the marketplace in July 2007.

Our analysis of external power supply efficiency demonstrated that additional energy savings are possible in more stringent future external power supply efficiency specifications, as long as voltage and current are taken into account. This information enables ENERGY STAR®/Energy Commission to look at more stringent EPS standards in the future.

The question of whether to include a power factor correction requirement in the ENERGY STAR® specification hinged on whether or not PFC could be shown to deliver additional quantifiable energy savings benefits to the electric grid (and resulting pollution prevention benefits). EPRI Solutions and Jon Koomey answered that question with the computer power factor research that was a part of this project. Their research found that power factor correction adds another 12 percent–21 percent to the resulting energy savings attributable to an efficient computer power supply, primarily by reducing distribution losses in the building itself. As a result of this research, ENERGY STAR® elected to include the 0.9 power factor requirement.

Though the internal power supply test procedure has been initially applied to desktop computers, applications of the procedure to STB and server power supplies is likely in late 2006/2007. ENERGY STAR® specification efforts on both product categories are gaining momentum, and power supplies represent a logical initial means of reducing energy use. STBs as currently designed often consume nearly the same amount of power whether actively tuning a television signal or waiting in standby mode, so these policy efforts will also increase the usefulness of future field monitoring efforts (reducing power use enough in standby mode to be evident on field monitoring results).

Battery Chargers

The battery charger technical research enables policy makers at the California Energy Commission to pursue a mandatory minimum efficiency standard for battery charger systems. A draft test procedure to measure the efficiency is nearly complete, more than 60 products have been measured, and a technical paper has been created that explains how battery chargers can be made more efficient. Research shows that the energy savings potential is substantial and technologies exist in the market today that are much more efficient than average.

The research team's interaction with members of the battery charger industry is already prompting design changes to new battery charging products, prior to the formal proposal of mandatory efficiency standards for the product category. ON Semi and an AA battery charger manufacturer both confirmed this in meetings with team members at industry conferences. These changes will likely manifest themselves first in designs that minimize energy consumption during battery maintenance mode and eventually in products that also incorporate simple switching to eliminate charger power consumption when no battery is present. Some of these changes are occurring at the semiconductor level, with new designs emerging that can automatically and economically "retune" existing battery charger circuits to give batteries only the energy they need to counter self-discharge, rather than the amount they can tolerate before suffering a shortening of useful life. Thus the plan for transferring ideas and technology began during the research and not after. The research expands policymaker options by showing exactly how much energy different devices use, so that policies (and the limited resources of policy makers) can be aimed at the end uses that present the greatest opportunities.

Information Dissemination

Disseminating project findings at a variety of industry meetings and utility forums and via the project websites enabled stakeholders to learn more about the research findings that were uncovered over the course of this project. This outreach benefits the Energy Commission, particularly when they move into policy making activities. Stakeholders are more likely to be planning and preparing for the possible need for efficiency improvements.

The most intriguing long-term benefit of this project emerged at a pair of August 2006 conferences at which Ecos Consulting presented: the EPRI Summer Seminar and the ACEEE

Summer Study. Participants at both conferences independently suggested that it would be useful for policy makers and utilities to begin shifting their perspective on efficient electronics from the narrow realm of quantitative specifications to a more encompassing "efficiency philosophy" that references the high level design approaches manufacturers should be taking to minimize energy use. New electronic products are being introduced so rapidly and in such numbers that detailed product efficiency specifications may not be able to keep pace. However, manufacturers wishing to ensure that such products will be considered energy efficient could benefit significantly by having an "efficiency philosophy" checklist to reference in the design process.

The team created the first draft of such a document and circulated it for comment among a large group of international stakeholders. More work will be needed to refine it further, but it represents a very encouraging long-term approach to electronics efficiency that grew directly out of this PIER-funded research. The international efficiency community intends to discuss it further in future forums.

The other primary long term benefit is to make further use of the Internet to heighten competition among manufacturers of energy efficient electronic products. This is particularly true for TVs, STBs, battery chargers, and other types of electronic devices for which no mandatory federal labeling of efficiency is in place, and where voluntary efficiency specifications focus only on a few product operating modes. The team's websites www.efficientpowersupplies.org and www.efficientproducts.org have begun the effort of publicizing efficiency differences, but more work is needed to collect product data and call buyers' attention to the most efficient tested products. Some early discussions are underway among the team members and other stakeholders to create such a website, and there may be public announcements forthcoming in late 2006/early 2007 about next steps.

GLOSSARY

AC	alternating current
ACEEE	American Council for and Energy Efficient Economy
APEC	Applied Power Electronics Conference
ATM	automated teller machine
CRT	cathode ray tube
DC	direct current
DOE	(United States) Department of Energy
EEDAL	Energy Efficiency of Domestic Appliance and Lighting
EPRI	Electric Power Research Institute
EPS	external power supply
HVAC	heating, ventilating, and air conditioning
I^2R	The product of the electric current squared and the resistance
IT	information technology
kVA	1000 volt-amps
kWh	kilowatt-hour
LBNL	Laurence Berkeley National Laboratory
LCD	Liquid Crystal Display
Li-Ion	lithium-ion
MW	megawatt
NiCd	nickel cadmium
NiMH	nickel metal hydride
NRDC	Natural Resources Defense Council
PC	personal computer
PFC	power factor correction
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
RD&D	Research, development, and demonstration

STB	set top box
THD	total harmonic distortion
TV	television

REFERENCES

Blosser, J., H. Kameth, et al. (2006). Battery Charger Laboratory Test Data File, California Energy Commission Public Interest Energy Research Funding.

Brown, R., W. Rittelmann, et al. (2006). Appliances, Lighting, Electronics, and Miscellaneous Equipment Electricity Use in New Homes. 2006 ACEEE Summer Study on Energy Efficiency in Buildings. Asilomar Conference Center, Pacific Grove, California

Cadmus Group (2005). Battery Charger Data Spreadsheet, EPA ENERGY STAR®.

Ecos Consulting (2004). Power Supply Efficiency: What Have We Learned? Durango, CO, California Energy Commission PIER Program.

Energy Information Administration (2001). 2001 Residential Energy Consumption Survey (RECS).

Energy Information Administration (2006). Annual Energy Outlook 2006: Residential Sector Energy Demand: 67.

ENERGY STAR® (2005). Test Methodology for Determining the Energy Performance of Battery Charging Systems: 6.

Foster, S., et al. (2003). Proposed Test Protocol for Measuring the Energy Efficiency of Battery Charging Appliances, California Energy Commission: 19.

Lawrence Berkeley National Laboratory (2004). PIER Final Report: Developing and Testing Low Power Mode Measurements Methods. Sacramento, CA, California Energy Commission.

Porter, S. F., et al. (2006). Beyond Power Supplies: Addressing Battery Charger Systems as the Second Common Denominator in Electronic Products. ACEEE Summer Study 2006. Pacific Grove, CA, ACEEE.

Porter, S. F., et al. (2006). Draft 2 Energy Efficiency Battery Charger System Test Procedure, California Energy Commission Commission

Public Interest Energy Research (PIER) program (Contract number 500-04-030): 15.

Roth, K. W., R. Ponoum, et al. (2006). U.S. Residential Information Technology Energy Consumption in 2005 and 2010. Cambridge, MA.