Codes and Standards Enhancement (CASE) Initiative For PY2010: Title 20 Standards Development

Title:
Analysis of Standards Options for Battery Charger Systems

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1 Executive Summary

The Pacific Gas and Electric Company (PG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of appliance standards. This CASE report provides comprehensive technical, economic, market, and infrastructure information for battery charger systems.

Today, approximately 170 million products that contain battery chargers are in use in California's homes, offices, retail stores, medical facilities, and warehouses. Cell phones, cordless tools, bar code scanners, electric forklifts, and electric baggage carts are all products that rely on battery charger systems. Many manufacturers have redesigned corded or gas powered products to include rechargeable batteries. Rechargeable consumer products offer substantial economic and environmental advantages over those with disposable batteries and are more convenient than corded consumer products. Battery powered lift-trucks and golf carts are generally less expensive to operate than fossil fuel based alternatives. However, of all the energy consumed by battery chargers in California, only 40% of it is eventually delivered from the battery to power our rechargeable products.

PG&E and its consultant Ecos recommend that California adopt a technology-neutral standard for small and large battery charger systems. A small charger standard would address both consumer and non-consumer chargers and become effective in 2012. A large charger standard would address non-consumer products only and take place in two phases. Tier 1, effective in 2012, would remove the least efficient products from the marketplace. Tier 2, effective in 2013, requires efficiencies comparable to the most efficient designs currently in the marketplace.

Battery chargers that do not currently meet the standards could comply by incorporating well understood ac-dc power supply and battery control circuitry design using components widely available from suppliers. The cost of improving the efficiency of a single small battery charger system can be less than a dollar for some consumer products. The upfront cost of improving the efficiency of large non-consumer chargers is clearly cost effective. Annual cost savings on energy bills can pay back added first cost within the first year of operation of large chargers. In some cases, customers will see electric bill savings equal to ten times the initial incremental cost of efficiency improvement.

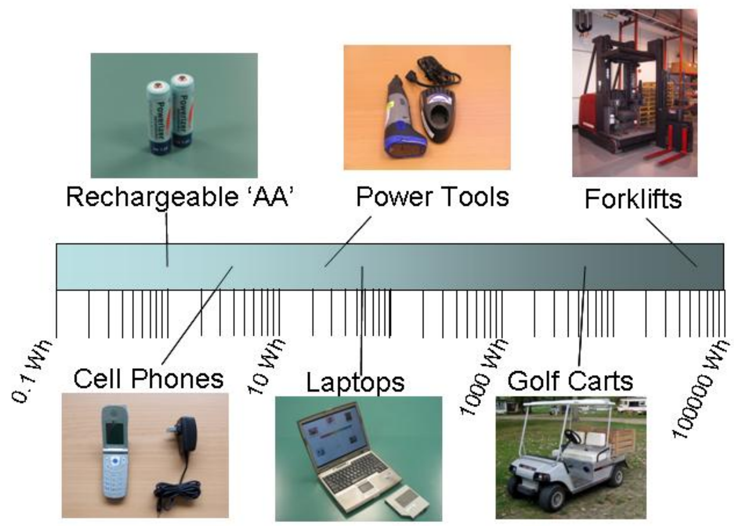
The California Energy Commission's adoption of PG&E's proposed standards would represent savings of 2,700 GWh per year. Savings would be sufficient to power 390,000 households in California each year. The adoption of the PG&E battery charger standard is a cost effective means of helping California meet it long term energy goals, climate initiatives and air quality guidelines.

2 Product Description

2.1 Technical Description

While many modern electrical appliances receive their power directly from the utility grid, a growing number of everyday devices require electrical power from batteries in order to achieve greater mobility and convenience. Battery charger systems are used to recharge these batteries when their energy has been drained. These systems are employed by a variety of end uses, from low power cell phones to high power industrial forklifts (also known as lift-trucks) (Figure 1).

Figure 1: Various battery powered devices and their relative battery capacities



Source: (Geist, Kameth et al. 2006)

The term "*battery charger systems*" refers collectively to battery chargers coupled with their batteries. Battery charger systems include, but are not limited to:

- electronic devices with a battery that are normally charged from ac line voltage through an internal or external power supply and a dedicated battery charger;
- the battery and battery charger components of devices that are designed to run on battery power during part or all of their duty cycle (such as many portable appliances and commercial material handling equipment);
- dedicated battery systems primarily designed for electrical or emergency backup (such as emergency egress lighting and uninterruptible power supply (UPS) systems);
- Devices whose primary function is to charge batteries, along with the batteries they are designed to charge. These units include chargers for power tool batteries and chargers for automotive, AA, AAA, C, D, or 9 volt rechargeable batteries, as well as chargers for batteries used in motive equipment, including golf carts, electric material handling equipment, lift-trucks, airport electric ground support equipment (EGSE), port cargo handling equipment, tow tractors, personnel carriers, sweepers and scrubbers.

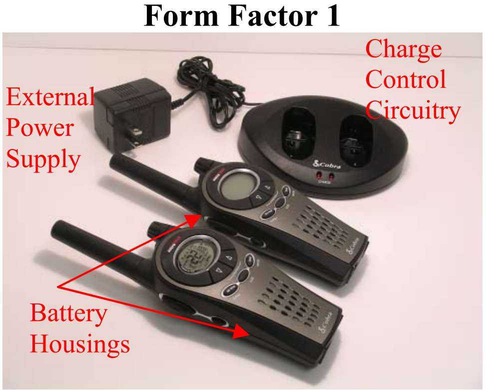
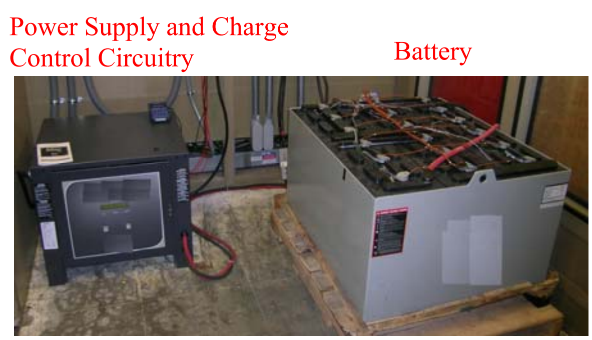
All battery charger systems have three functional components:

- A power supply (either internal or external) that converts high voltage ac (either single phase or three phase) to low voltage dc;
- Charge control to regulate electric current going to the battery during charge and battery maintenance modes;
- A battery that stores energy for the end use product.

These electrical components can be housed in a variety of ways, and one cannot determine the efficiency of the charger by examining these external housings that are also known as form factors. The four different battery charger configurations (Table 1) are:

1. Power supply, charge control circuitry, each in separate housings.
2. Power supply and charge control circuitry in one housing, battery in separate housing.
3. Charge control circuitry and battery in one housing, power supply in separate housing.
4. Power supply, charge control circuitry, and battery all in the same housing.

Table 1: Form factor configurations of battery chargers

<table>
<tr><th>Form Factor 1</th><th>Form Factor 2</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>The power supply, the charge control circuitry and the battery are contained in separate housings.</td><td>The power supply and the battery charge control circuitry is contained in a single housing. The battery is contained in a separate housing.</td></tr>
<tr><th>Form Factor 3</th><th>Form Factor 4</th></tr>
<tr><td>
</td><td></td></tr>
<tr><td>The charge control circuitry and battery are inside of the cell phone. The power supply is contained in a separate housing.</td><td>The power supply, the charge control circuitry and the battery are contained in a single housing.</td></tr>
</table>

Four basic charge control designs and four general chemistries are found in the marketplace today (Table 2 and Table 3). Details about these designs can be found in

Designing Battery Charger Systems for Improved Energy Efficiency: A Technical Primer (Geist, Kameth et al. 2006) available at www.efficientproducts.org.

Table 2: Summary of Battery Charge Control Designs

Charging Technology	Typical Efficiency Range	Example Products	Market Segment	Relative Cost per Watt
Linear	10 % - 35%	Cordless phones, power tools	Residential, Commercial	Low
Switch Mode	40% - 60%	Laptop computers, cell phones	Residential, Commercial	High
Ferroresonant	25% - 50%	Golf carts, lift-trucks	Commercial, Industrial	Low
Silicon Controlled Rectifier (SCR)	30% – 55%	Recreational vehicle battery chargers, lift-trucks	Commercial, Industrial	Medium

Source: (Geist, Kameth et al. 2006)

Table 3: Chemical characteristics of most common battery chargers found in today's marketplace

	Lead-Acid	Nickel Cadmium (NiCd)	Nickel Metal Hydride (NiMH)	Lithium Ion (Li-ion)
Self Discharge Rate	Very Low	Moderate	High	Low
Overcharge tolerance	High	Moderate	Low	Very Low
Example Applications	UPSs, deep cycle emergency backup systems	toys, cordless phones, cordless tools	digital cameras, cordless tools, two-way radios	video cameras, cell phones, laptop computers
Technology Maturity	Mature	Mature	Developing	Developing
Energy Density	Low	Low-Moderate	Moderate	Very High
Price	Low	Moderate	Moderate	High
Toxicity	High	High	Low	Low

Source: (Geist, Kameth et al. 2006)

Differences among charge control designs are evident, even when comparing nearly identical products. Figure 2, below, shows test results of two, 7 volt lithium ion power tools available commercially. The charger on the left is a linear design, which is 24% efficient over a 24-hour charge and maintenance cycle. The charger on the right is switch mode design and is nearly twice as efficient over the same 24-hour period with significantly less energy used in battery maintenance and no battery modes.

Figure 2: Power tool efficiency comparison

Tool Charger	Tool Charger
Li-Ion battery	Li-Ion Battery
24% 24-hr Efficiency	43% 24-hr Efficiency
Maintenance Power: 0.5 W	Maintenance Power: 0.2 W

Battery charger systems operate in three modes: charge mode, maintenance mode, and no battery mode. In charge mode the battery is accumulating charge. Maintenance mode occurs when the battery is fully charged and the charger is simply supplying energy to counteract natural discharge. No-battery mode indicates that the battery has been physically disconnected from the charger.

Figure 3: Switch Mode Battery Charger Power Profile

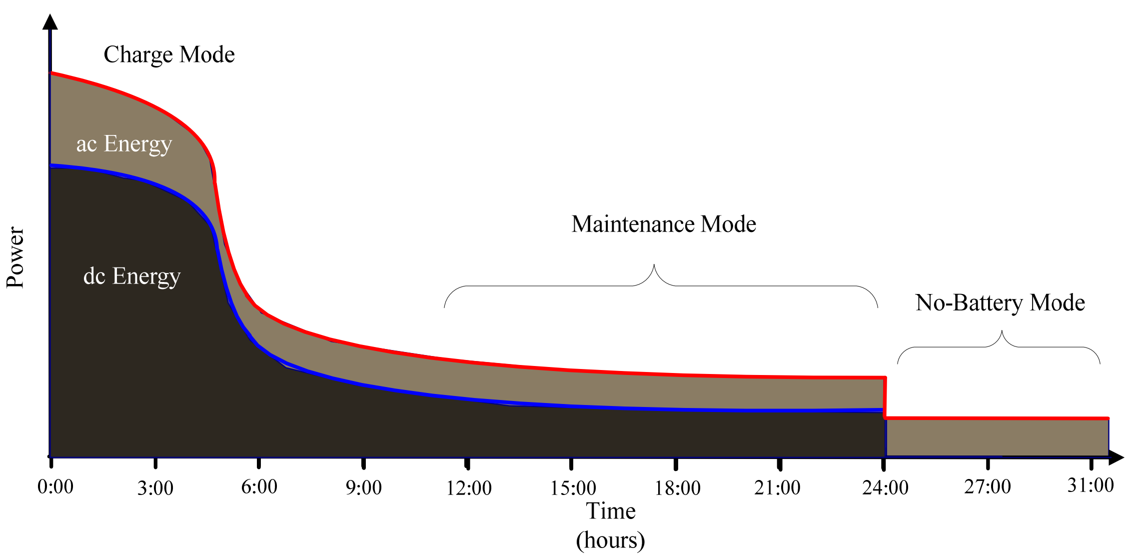


Figure 3 shows the 24-hr charging profile of a small switch mode battery charger, with no battery mode measured following the procedure of the *Energy Efficiency Battery Charger System Test Procedure* (see section 4). During charge mode, the battery charger delivers energy to the battery to bring the battery from a state of discharge to state of charge. When the battery is at or near 100% capacity, many battery chargers will continue to deliver some amount of energy to the battery to counteract the effects of battery self discharge. This mode of operation is referred to as "battery maintenance mode". In no battery mode, the battery is removed from the power supply or charger cradle. The battery charger may still draw power in this mode even though no battery is connected to the system.

2.2 Battery Charger System Categories: Small and Large, Consumer and Non-consumer

Small and large battery chargers differ in design and application, so the metrics of charge mode efficiency are different for each. For small battery charger systems, charge mode efficiency is defined over a 24-hour period. Power conversion efficiency and charge return factor determine the charge mode efficiency in large chargers. The power drawn in battery maintenance and standby modes is also an important factor for all types of chargers. Table 4 below provides a snapshot of these battery charger efficiency metrics and their respective ranges.

Table 4: Snapshot of Battery Charger Performance Ranges

	Small Battery Chargers Consumer and Non-consumer	**Large Battery Chargers** Non-consumer only	
Efficiency Metrics	***24-hr System Efficiency***	***Charge Return Factor***	***Power Conversion Efficiency***
	2% - 71%	1.34 - 1.05	74% - 93%
Maintenance Power Range	0.12 W - 205 W	0.04 W - 290 W	
No Battery Power Range	0.05 W - 70 W	0.04 W - 280 W	

For small battery chargers, the 24-hour system efficiency metric characterizes the amount of energy out of the system during discharge over the energy into the system during a 24-hr period of being connected to the charger. Efficient chargers will have higher 24-hour system efficiency, because they will likely only charge the battery until it is full. However, chargers with poor 24-hour efficiency will likely charge the battery for the entire 24-hour period.

For large battery chargers, charge return factor is the first part of characterizing how well battery chargers charge batteries. Large lead-acid batteries require some amount of over-charge to prevent the buildup of sulfates and extend battery life. Too much over-charging can damage the battery and shorten its life. Charge return factor is defined as the ratio of ampere-hours into the battery over the ampere-hours out of the battery. Charge return factor should ideally be about 1.05 – 1.07. Power conversion efficiency is the second part of characterizing the charge mode performance of large battery chargers. Power conversion efficiency characterizes the performance of the electronics used to charge the battery. Power conversion efficiency is defined as the power out of the charger over the power into the charger. An efficient large battery charger would have a high power conversion efficiency value.

The U.S. Department of Energy is in the process of creating a mandatory efficiency standard for consumer battery charger systems. Once enforced, this federal standard will preempt the scope of the Title 20 standard that addresses consumer chargers. Consumer chargers are found only in the small chargers category. For the purposes of this analysis, savings associated with consumer and non-consumer chargers will be called out separately for the small chargers category. All large chargers are non-consumer and therefore not expected to be preempted by the federal standard.

3 Manufacturing and Distribution Channel Overview

Hundreds of different original equipment manufacturers (OEMs) employ battery charger systems in their end use products. Because this is only one element of the product design, manufacturers of small battery charger systems usually rely on other component manufacturers and subsystem integrators to provide elements of the power supply, charge control circuitry and battery. Larger battery systems, such as lift-truck systems, are more likely to be designed and manufactured by the OEM.

Small battery charger systems are sold in a variety of retail outlets, including: consumer electronic stores, computer stores, grocery stores, drug stores, hardware stores, sporting goods stores, and general purpose retail outlets such as Sears, Target and Walmart. They are also available at numerous online retailers. Large battery chargers are usually sold through distributor networks that may also sell matching batteries and end use products.

4 Energy Usage

PG&E and its consultant Ecos estimate the energy used by battery charger systems in California is 7,700 GWh annually, enough to power 1.1 million California homes. Of all this energy consumed, on average only 40% of it is eventually delivered from the battery to power our cell phones, laptop computers, electric golf carts, and other rechargeable products. Technology exists today to double this system efficiency. Additional energy savings can be garnered from improvements in power factor.

4.1 Test Methods

4.1.1 Current Test Methods

Four basic approaches to test battery charger system energy efficiency are currently published. Other test procedures that are relevant to battery testing, safety, etc. can be found in the References section of *Energy Efficiency Battery Charger System Test Procedure* (Porter, Bendt et al. 2008).

Small Appliance Battery Charger Test Procedure

Three different entities, the U.S. Environmental Protection Agency (EPA) ENERGY STAR® Program, Canadian Standards Association (CSA), and U.S. Department of Energy (DOE) have published some version of this small appliance battery charger test procedure. Originally developed in 2005, during a period less than a year, the small appliance test procedure's purpose was to enable the U.S. Environmental Protection Agency's voluntary specification for a subset of battery charging products (ENERGY STAR 2005).

The test procedure only measures power in battery maintenance and no battery modes and provides a "non-active energy ratio" for the purposes of comparing battery charger efficiency. Efficiency and energy use in charge mode are not considered. The test procedure was originally created to measure:

- battery charger products whose principal output is mechanical motion, light, the movement of air, or the production of heat
- stand alone battery chargers sold with products that use a detachable battery, and
- battery charger products intended to replace standard sized primary alkaline batteries

DOE and EPA ENERGY STAR have both recently indicated the intent to build on this test approach by adopting many of the provisions found in the CEC-adopted *Energy Efficiency Battery Charger System Test Procedure* (discussed below). In its recent Notice of Proposed Rulemaking (U.S. DOE 2010), DOE stated its intent to adopt a modified version of part 1 of the CEC procedure for its consumer battery charger efficiency standard.[1] EPA's announcement to expand the scope of the battery charger ENERGY STAR label suggested reliance on part 1 and part 2 of the CEC procedure (U.S. EPA 2010).[2] CSA is also considering modifying the Canadian version of the test procedure to include charge mode. These recent developments suggest that this test procedure is likely to be phased out of use.

Energy Efficiency Battery Charger System Test Procedure (Adopted CEC Method)

Pacific Gas and Electric, California Energy Commission Public Interest Energy Research (PIER) Program, and Southern California Edison jointly created a comprehensive test procedure which was recently adopted in final form by the California Energy Commission in December 2008. Development of the Energy Efficiency Battery Charger

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[1] Available http://www1.eere.energy.gov/buildings/appliance_standards/residential/battery_external_preliminaryanalysis_public_mtg.html

[2] Available http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/battery_charging_sys/BCS_Revision_Announcement_Letter.pdf

System Test Procedure Version 2.2, which began in 2003, has benefited from the input of hundreds of comments from stakeholders and multiple drafts.[3]

The CEC battery charger system test procedure enables testing of all types of battery charger systems regardless of end use and has two parts. Part 1 applies primarily to battery charger systems for smaller, consumer-oriented products and Part 2 applies to battery charger systems for larger, non-road vehicle chargers. The two part test procedure allows a test methodology that is appropriate for the unique characteristics of smaller and larger battery charger systems. Both parts of the test procedure measure energy consumption in charge, maintenance, and no battery modes and they also measure energy consumed as the charger interacts with an actual battery.

Part 1 specifies that the battery charger undergoes a 24-hour charge cycle, and 5-hour discharge cycle. The energy delivered from the battery during discharge can be compared to the energy consumed by the charger during charge, the result of which can be defined as the battery charger system efficiency. This efficiency measurement captures both energy used in the charging process and energy lost as heat in the battery discharge process. The 24-hour period is used to provide a common basis for comparison, whether or not a charger gives a “charging complete” indication. Maintenance mode energy consumption is measured by integrating the energy usage over the last 4 hours of the testing period. Similarly, no battery and off mode power are measured for 10 minutes.

Part 2 of the procedure begins with subjecting the charger to three discharge/charge cycles using three different depths of discharge. The measurements taken distinguish between energy lost in the charger and energy lost in the battery. Charge return ratio is one metric used to quantify battery charger performance. Defined as the ratio of ampere-hours into the battery over ampere-hours out, it represents a quantity related to how well the battery charger charges the battery. Power conversion efficiency and power factor are recorded for three key points during recharge, maximum, median and minimum power levels. Energy consumption is measured for 72 hours of maintenance mode and one hour of no battery mode.

Electric Vehicle Charge Test Procedure

The DOE electric vehicle battery charger performance test procedure, used for electric vehicle technology development, was written in 2004 (Electric Transportation Applications 2008). The method prescribes the measure of power conversion efficiency, charge mode energy, and total system efficiency. Because the system efficiency is defined in units of miles per kWh, the test procedure is only applicable for a subset of battery charger systems employed in motive products. In other motive products, distance traveled (miles) is only part of the function of the product. Lift-trucks, for example, not only travel a distance, but they also lift and move cargo.

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[3] For a complete summary of development and comments received, see http://efficientproducts.org/product.php?productID=4.

California Air Resources Board (CARB) Hybrid Electric Vehicle Test Procedure

The CARB hybrid electric vehicle test procedure, which is still in development, is used to quantify the emissions associated with hybrid electric vehicles. The procedure covers both off board charge capable (e.g. plug-in hybrids) and non-off board charge vehicles. The procedure requires the vehicle battery to be discharged by driving and the mileage accumulated be recorded. A record of the dc energy delivered to the battery during the test from regenerative breaking is not required and as such energy into the battery over the discharge test is not captured. During the battery discharge the net dc energy out of the battery is recorded. The ac energy and dc energy required to charge the battery after the discharge test is also recorded.

The table below illustrates the different metrics that are covered by each of the current test procedures (Table 5). Notice that the CEC test procedure is able to capture the efficiency for both small and large battery chargers.

Table 5: Scope of Test Methods

Measured Quantities		Small Appliance Test Procedure* (ENERGY STAR, CSA, DOE)	DOE Electric Vehicle Charger	California Air Resource Board Hybrid Electric Vehicles	Adopted CEC Method, Forthcoming DOE Methodu (Small)	Adopted CEC Method (Large)
Power Conversion Efficiency			X	◊	◊	X
Modes (power)	Charge		X	◊	◊	X
	Maintenance	X			X	X
	No Battery	X			X	X
Battery Losses (energy into battery – energy out)			◊		◊	◊
End use efficiency (motor, lighting, miles/kWh, etc.)			X	X		

X reporting requirement
◊ embedded in measured results
* expect this to be phased out and replaced by modified version of CEC method
u details of DOE method forthcoming. Table is based on DOE's last publically indicated direction

4.1.2 Proposed Energy Efficiency Test Method

The small appliance and electric vehicle test procedures were developed for a narrow range of products, and they do not comprehensively cover all battery charger systems' modes of operation. PG&E and its consultant Ecos therefore recommend the *Energy Efficiency Battery Charger System Test Procedure* because it has been adopted by the California Energy Commission and it enables a standard proposal that will obtain energy savings from all modes of operation and the widest range of battery charger systems.

4.2 Baseline Energy Use Per Product

Annual battery charger system energy use depends on both the annual duty cycle and the power draw in each different mode. PG&E and its consultant Ecos estimate that the duty cycles of battery charger systems vary significantly, from as little as one charge per month for video cameras to as many as three times a day for industrial lift-trucks. Duty cycle data was derived from a variety of sources including Ecos' 2006 Battery Charger

Census (Herb and Porter 2006) and 2006 Final Field Research Report (Porter, Moorefield et al. 2006).

Table 6: Battery Charger System Duty Cycle Table

Market Segment	Product Categories	Charge (% of time)	Maintenance (% of time)	No Battery (% of time)	Unplugged (% of time)
Small Consumer	Auto/Marine/RV	1%	42%	46%	10%
	Cell Phones	3%	30%	19%	48%
	Cordless Phones	35%	56%	9%	0%
	Personal Audio Electronics	2%	25%	35%	38%
	Emergency Systems	0%	100%	0%	0%
	Laptops	4%	56%	30%	10%
	Personal Care	3%	86%	3%	9%
	Personal Electric Vehicles	36%	28%	35%	1%
	Portable Electronics	1%	11%	1%	87%
	Portable Lighting	0%	99%	0%	1%
	Power Tools	2%	48%	13%	37%
	Universal Battery Charger	0%	66%	17%	17%
	Golf Carts/Electric Carts	20%	47%	13%	19%
Small Non-consumer	Emergency Backup Lighting	0%	100%	0%	0%
	Handheld Barcode Scanners	13%	52%	35%	0%
	Two-Way Radios	19%	31%	50%	0%
Large Non-	Single Phase Lift-trucks	45%	31%	24%	0%

Market Segment	Product Categories	Charge (% of time)	Maintenance (% of time)	No Battery (% of time)	Unplugged (% of time)
consumer	Three Phase Lift-trucks	94%	0%	6%	0%

Table 7 shows the typical power use of each battery charger product group. The percentage of time in each mode by product (Table 6) was combined with each respective power value to calculate the annual energy usage per year. The categories of products listed here are the combination of a number of similar products; the table summarizing the product grouping can be seen in Appendix A. Power for each battery charger unit was derived from a variety of sources including Ecos lab testing (Ecos 2004-08), PG&E lab testing (PG&E 2009), Southern California Edison lab testing (SCE 2008), Battery Charger Census (Herb and Porter 2006), industry research papers (Porter, Moorefield et al. 2006), and other industry research materials (Appliance Magazine 2007).

Table 7: Baseline Energy Use per Product

Market Segment	Product Categories	Charge (W)	Maintenance (W)	No Battery (W)	Percent of Units Operating During Peak Period [a]	Unit Electricity Consumption (kWh/yr)
Small Consumer	Auto/Marine/RV	200.0	41.9	49.3	21%	462
	Cell Phones	5.8	0.5	0.3	28%	3.7
	Cordless Phones	2.7	2.2	1.7	95%	20
	Personal Audio Electronics	6.1	0.5	0.1	16%	2.0
	Emergency Systems	1.8	2.9	2.5	100%	25.7
	Laptops	49.4	3.0	1.9	32%	33
	Personal Care	4.3	1.0	0.9	80%	8.5
	Personal Electric Vehicles	261.4	34.1	33.9	31%	947
	Portable Electronics	20.0	2.5	0.9	6%	3.0

Market Segment	Product Categories	Charge (W)	Maintenance (W)	No Battery (W)	Percent of Units Operating During Peak Period [a]	Unit Electricity Consumption (kWh/yr)
	Portable Lighting	5.0	1.6	0.4	70%	14
	Power Tools	20.0	3.5	1.8	30%	23.2
	Universal Battery Charger	10.0	1.1	0.9	26%	8.0
	Golf Carts/Electric Carts	581.0	103.0	1.6	14%	2,533
Small Non-consumer	Emergency Backup Lighting	1.6	1.6	1.6	100%	14.4
	Handheld Barcode Scanners	11.2	3.0	0.2	46%	26.6
	Two-Way Radios	4.2	2.0	0.9	6%	21.3
Large Non-consumer	Three Phase Lift-trucks [b]	5,785	88.5	33.5	100%	46,216
	Single Phase Lift-trucks [b]	2,000	50.0	50.0	19%	8,460

[a] Percentage of units operating during peak period was calculated using PG&E's number for peak electricity demand hours per year, 762 hours, and evenly distributing the products' usage over one year. This results in the total coincident peak demand for any product being 9% of their total demand for one year. [b] Three phase lift-trucks are assumed to endure heavy use, with as many as three charges per day, which is equivalent to constant operation and thus always operating during peak period. Single phase lift-trucks are assumed to endure moderate use.

Although duty cycles vary from product to product, the most significant contribution to overall energy use by small battery charger systems occurs in maintenance mode (75%). Even though the power drawn in this mode is lower than charge mode, many chargers spend a significant amount of their duty cycle operating in this mode. Energy use during charge mode represents 15% percent of the total small battery charger energy use and is the second largest contributor to overall energy use. Time spent in charge mode is relatively short, but the power drawn during this mode is relatively high. No battery mode energy use makes up only 10% of the total energy use of small battery charger systems.

Large battery charger's energy usage breakdown by mode varies dramatically from small battery chargers in that the majority of the energy usage occurs in charge mode. This fact emphasizes the importance of the metrics of power conversion efficiency and charge return factor to energy savings potential in large battery charger systems. The large amount of power delivered during charge mode, in excess of 6 kW at times, translates into a significant amount of energy lost during conversion even with 90% power conversion efficiency, which is equivalent to 600 watts lost continuously during charging.

Though large battery chargers make up only a small portion of the total number of battery chargers in California, their energy use exceeds the total energy use of small battery chargers per year by 1,200 GWh. Approximately 2/3 of total small battery charger energy use is saved with proposed mandatory efficiency standard. Approximately 8% of total large battery charger energy use is saved with implementation of Tier 2 proposed mandatory efficiency standard.[4]

4.3 Efficiency Measures

The efficiency metrics for battery charger systems vary depending on the scale of the charger. In both Part 1 and Part 2 of the test procedure, the combination of metrics accounts for all the energy use of the product, including the modes where the most energy is consumed: battery maintenance and charge mode.

4.3.1 Part 1 of the Test Procedure for Small Battery Chargers

The efficiency of small battery chargers that are tested using Part 1 of the energy efficiency test procedure can be defined by three parameters:

- **24-hour charge efficiency**: the ratio of dc energy that can be discharged from the battery to ac energy into the battery charger during a 24-hour charge/maintenance mode cycle; see Figure 5. This is equivalent to the ratio of energy measured at point 3 to the energy measured at point 1; see Figure 4.
- **Average power in battery maintenance mode** (watts)
- **Average power in no battery mode** (watts)

The 24-hour charge and maintenance efficiency approach quantifies the useful service that the battery charger provides for the consumer when the battery is installed on the charger. This approach also avoids the technical difficulty associated with determining the difference between charge and maintenance mode energy use. While maintenance and no battery mode power levels are directly measured, and will be regulated under the proposed standard language, charge mode energy is not separated from or quantified under the 24-hour test, but will be intrinsically regulated under the 24-hour efficiency standards language.

4.3.2 Part 2 of the Test Procedure for Large Battery Chargers

Power conversion efficiency is one parameter used to characterize large battery charger systems, which are tested under Part 2 of the energy efficiency test procedure. This metric is defined as the ratio of the energy into the battery, measurement point 2, to the energy into the power supply, measurement point 1 in Figure 4. Large scale chargers can operate with a variety of standard batteries (typically lead-acid), and therefore it is

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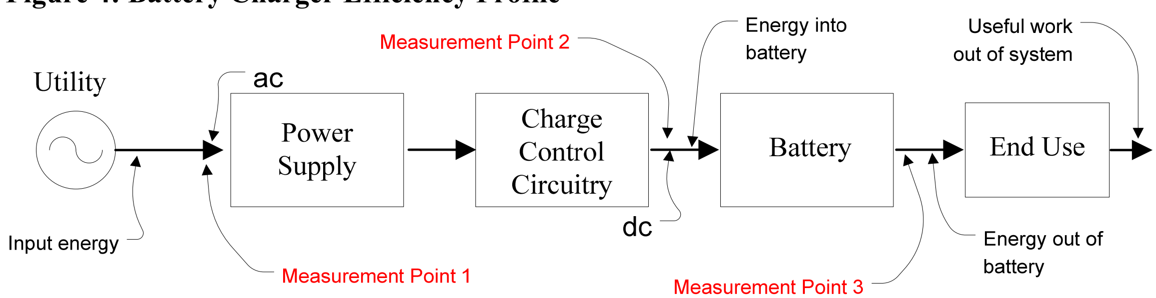
[4] See Table 16 for more details

difficult to identify a specific battery to use for any efficiency measurement. Consequently, the efficiency metrics differ slightly:

- **Charge efficiency**: the ratio of dc output power of the charger (watts) and the ac input of the charger (watts), expressed as a percent. This is equivalent to the ratio of the energy measured at point 2 to the energy measured at point 1 during a charge cycle.
- **Charge return factor**: the number of ampere-hours returned to the battery during the charge cycle divided by the number of ampere-hours delivered by the battery during discharge; this metric is similar to the total battery charger system efficiency metric of Part 1, except that it is measured in ampere-hours rather than watt-hours.
- **Average power in battery maintenance mode** (watts)
- **Average power in no battery mode** (watts)
- **Power Factor**

Figure 4: Battery Charger Efficiency Profile



4.3.3 Power Factor

Power factor is the ratio of real power to apparent power, and is expressed as a percentage ranging from 0 to 1. Poor power factor results from non-linear loads that distort the current drawn from ac outlet. This distortion leads to energy losses in the electrical distribution wiring in the walls of California's buildings. These losses, approximately 1270 GWh per year for residential buildings, are the equivalent to about one third of the energy produced by an average power plant. These energy losses cannot be easily attributed to particular appliances, but improving battery charger efficiency and power factor results in savings of about 380 GWh per year. Therefore, improving the power factor of battery chargers can reduce the statewide energy use associated with these devices. In addition to the consumer and industrial efficiency metrics outlined above, power factor is an element considered when evaluating overall battery charger energy use. Proposed standards in this document require a power factor correction requirement. See Appendix B, for more details about power factor and energy use.

4.3.4 Strategies for Improving Efficiency

While designers of battery operated products often maximize the energy efficiency of their end-use devices to ensure long operation times between charging, they often ignore how much energy is consumed in the process of converting ac electricity from the utility grid into dc electricity stored in the battery. For each different charge control technology (linear, switch mode, etc.), there are strategies that can significantly improve the efficiency of power conversion and charge control.

General strategies to improve efficiency that are applicable to all charge control technology types including linear, switch mode, ferroresonant, silicon controlled rectifier (SCR), high frequency, and hybrids, include:

- **Lowering charging currents**: reduces charge mode and maintenance mode power levels and heating losses.
- **Battery sensing circuitry**: reduces no battery mode power, reduces unnecessary overcharge energy usage, improves charge return factor, reduces heat in the battery and can also lengthen battery life.
- **Higher internal system voltage**: may reduce resistive and conversion losses, and may also reduce system current (Geist, Kameth et al. 2006).
- **Reduced fixed energy consumption**: may reduce no-battery mode power and energy usage overall.

To understand the feasibility of these improvements, PG&E's consultant Ecos modified a residential power tool charger to employ two of these strategies. PG&E's consultant Ecos was able to improve the 24-hour charge efficiency by more than 5 times, from 12% to 63%. The transformer was replaced with a capacitor, which reduces the fixed energy consumption, and lowered charge current to 10 mA. The charge time was increased significantly, from 24 to 96 hours; however the lengthened charge time could be suitable for a residential power tool, which is used infrequently and spends most of its time in maintenance mode.

Well understood strategies exist to further improve the efficiency of linear designs:

- Using full wave rectifiers instead of half wave rectifiers can drastically improve efficiency. Half wave rectifiers waste half of the input power through heat in the step down transformer. Full wave rectifiers deliver twice the output power as half wave with the same transformer power losses.
- Including more sophisticated charge control, such as voltage and current controllers, helps to reduce power used in battery maintenance and no battery mode.
- Replacing linear power supplies with switch mode power supplies can easily and cost-effectively improve the 24-hour efficiency of small chargers by nearly 15% (Geist, Kameth et al. 2006). Any efficiency improvement in power conversion will cascade energy savings in all three modes of battery charger operation: charge, maintenance, and no battery.
- Substituting the entire linear battery charger with a switch mode design, including the power supply and the charge regulating elements, can improve 24-hour

efficiency by around 40%, while simultaneously reducing battery maintenance and no battery mode power (Geist, Kameth et al. 2006).

Switch mode chargers can be made more efficient through sophisticated design methods, including:

- **Hysteresis charging**: can reduce energy usage in maintenance mode by using short spurts of high current to maintain the battery's voltage.
- **Resonant switching configuration**: can reduce switching losses in larger switch mode battery chargers when operating in charge mode. In this circuit design, power transistors switch on and off at the precise time that the voltage or current passes through zero, reducing heating loss in the transistors. (Geist, Kameth et al. 2006).
- **Synchronous rectification**: can reduce voltage drop and thus power losses in the power supply by using a transistor to conduct during certain cycles of operation as opposed to a diode.
- **Charge control**: can utilize current and voltage regulating circuits.
- **Periodic maintenance**: with a combination of battery voltage sensing circuitry and the switching controlled energy delivery, switch mode systems can provide periodic maintenance to batteries, as opposed to constant unchecked battery maintenance.

Ferroresonant chargers can be made more efficient by incorporating:

- **Hybrid technology**: can optimize the magnetic flux coupling in the transformer to improve power conversion efficiency.

SCR chargers can be made more efficient by incorporating:

- **More advanced SCRs**: can reduce switching losses by supporting higher switching frequencies.

SCR chargers are likely to be supplanted by more technologically advanced and efficient high frequency, insulated gate bipolar transistors (IGBT) based chargers. High frequency chargers have much lower switching losses and thus much better power conversion efficiency.

For more information about other efficiency improvement strategies for chargers in particular see Appendix C and EPRI's "Designing Battery Charger Systems for Improved Energy Efficiency, A Technical Primer" (Geist, Kameth et al. 2006).

Improving power factor is straight-forward for most battery charger systems. The idea is to reduce current and voltage distortion, as well as reduce the peak current. Switch mode battery charger designers can drastically improve power factor by substituting the controller IC with one that includes power factor correction, available in today's market for little or no additional cost. Ferroresonant chargers have no switching components and thus intrinsically have good power factor. SCR chargers typically have poor power factor because of their slow switching frequencies and high current.

Hybrid chargers, also known as controlled ferroresonant chargers, combine the current control of SCRs with the robustness and good power factor of ferroresonant chargers; the power conversion efficiency is significantly better than the basic ferroresonant charger in exchange for a slight reduction in power factor. Modern high frequency chargers have extremely good power factors because of their high switching frequencies and are the benchmark for what is possible.

Hybrid and high frequency chargers represent the newest technologies available in the large battery charger market and some manufacturers have expressed concerns that the technologies are perceived to be "unproven" in terms of reliability and that the perception could impede rapid market share proliferation.

By regulating power factor in battery charger systems through the proposed standards, the state of California stands to save a significant amount of energy. Energy savings potential from improved power factor in battery charger systems in California is estimated to be 150 GWh per year to 575 GWh per year. For a more detailed discussion on power factor improvement, please refer to appendix B.

4.4 Standards Options Energy Use Per Product

The small battery charger standards proposal, which addresses both consumer and non-consumer chargers, consists of a single tier that takes effect in 2012. The small standard requires efficiencies comparable to the most efficient products that are currently mass produced in the marketplace and includes a power factor requirement.

The large battery charger standards proposal addresses non-consumer chargers only, and consists of two Tiers, 1 and 2, which would take effect in 2012 and in 2013, respectively. The first tier (Tier 1) allows manufacturers to become accustomed to testing and reporting results, removes the least efficient products from the marketplace, and allows many products in each product category to qualify. The second tier requires efficiencies comparable to the best efficiencies currently available in each mode of the best performing products. The Tier 2 proposal provides cost effective energy savings over the design life of the product, in some cases as much as ten times as much energy savings than the cost to achieve the savings (see section 7).

4.4.1 Small battery chargers proposal

The proposed efficiency standards set a limit on the total amount of energy allowed in a 24-hour charge cycle and set a maximum level for maintenance power and no battery power.There is also a power factor requirement subject to peak current magnitude and voltage inputs. The 24-hour charge and maintenance energy allowance was developed to allow for:

1. energy used during a charge and maintenance cycle to increase as battery capacity increases (the Δ Energy portion of Figure 5)
2. proper maintenance of the battery (maintenance energy offset portion of Figure 5)

The 24-hour charge cycle was chosen because it is long enough to capture the portion of a variety of battery chargers and avoids the complication of pinpointing the transition between charge and maintenance modes.

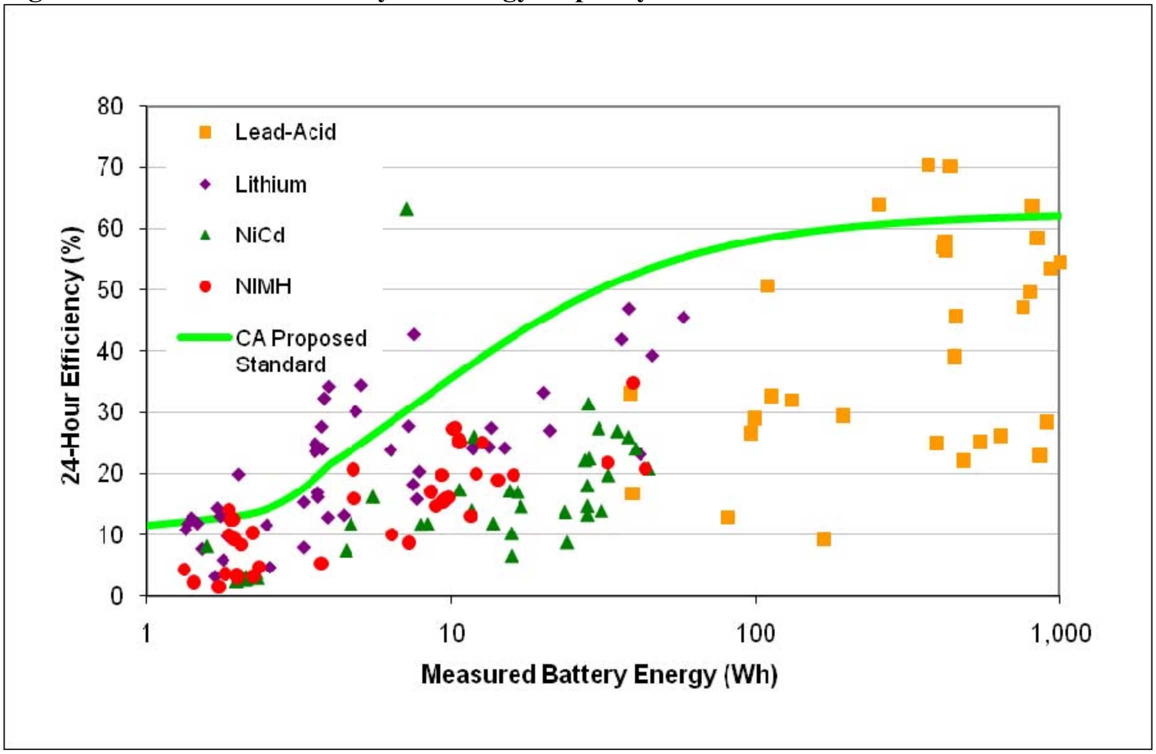
Because the majority of a small battery charger's energy is used in maintenance mode, a separate power limit (watts) for maintenance mode is included in this proposal. Although no battery mode is the mode with the lowest overall energy use, it is simple to measure and easy to reduce. Setting a requirement for no battery mode ensures that efficiency improvements in charge and battery maintenance do not increase energy consumption in no battery mode.

Table 8 summarizes the standards proposal for small consumer and small non-consumer battery chargers.

Table 8: Proposed Small Battery Charger Standards (Consumer and Non-consumer)

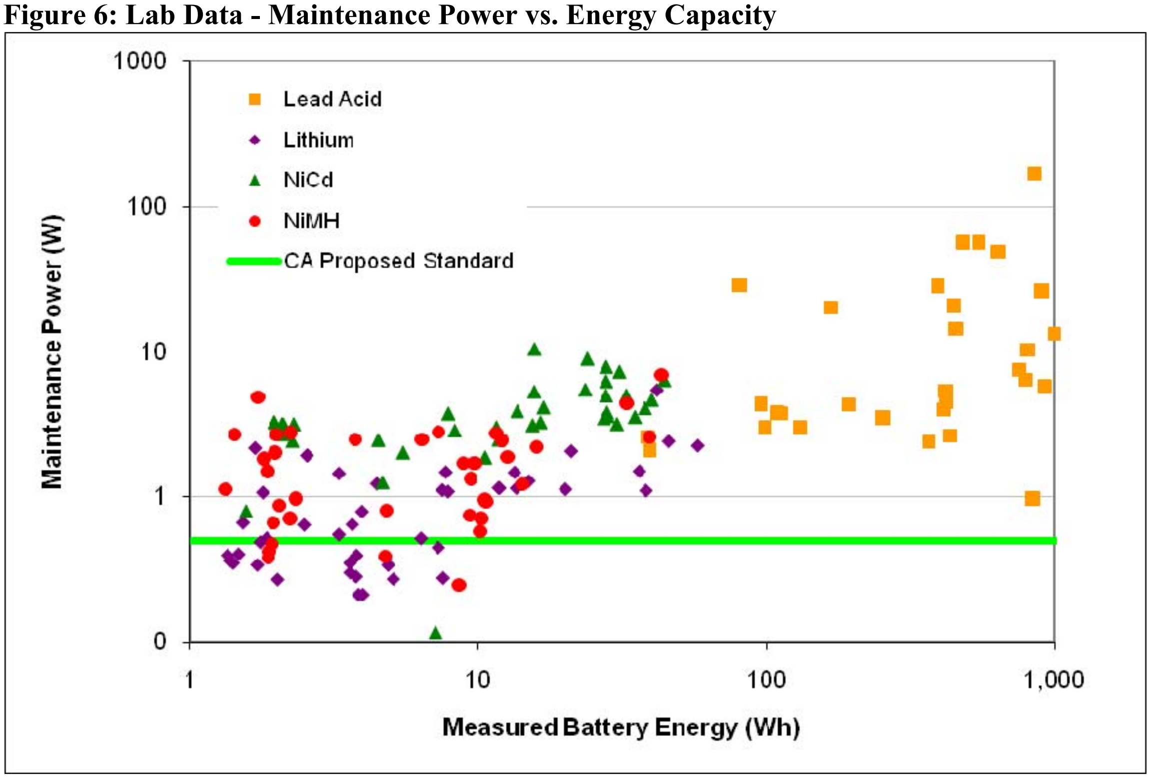
Metric	Requirement
24 hour charge and maintenance energy (Wh)	Less than or equal to: **$12 + 1.6E_b$** (E_b = battery capacity)
Maintenance Power	Less than or equal to: **0.5 W**
No Battery Power	Less than or equal to : **0.3 W**
Power Factor	Depends on input current

Figure 5: Lab Data - Efficiency vs. Energy Capacity



* Qualified products above line

Figure 6: Lab Data - Maintenance Power vs. Energy Capacity

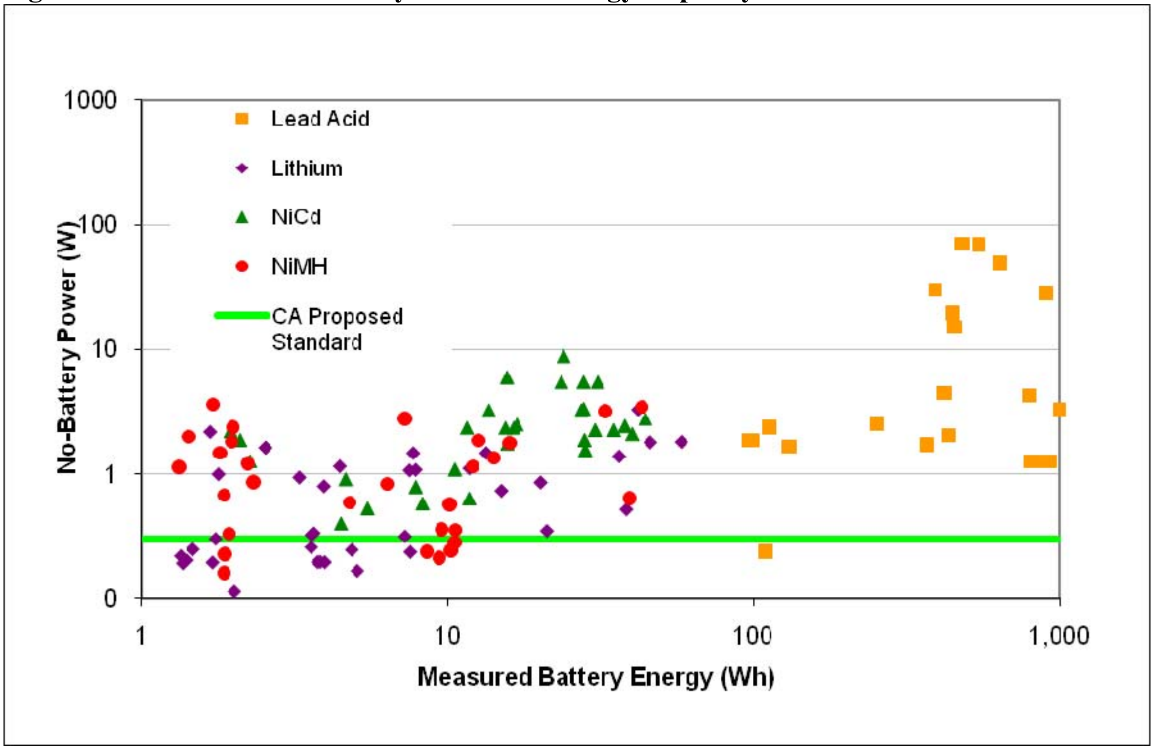


* Qualified products below line

Figures 5, 6, and 7 display the results of lab testing and characterize the relationships between efficiency, maintenance power, no battery power, battery chemistry, and energy capacity. These data were used in the derivation and development of the standards. The data point markers represent battery charger systems that were tested for the development of the proposed standards. For Figure 5, points that fall above the proposed standard lines are compliant with the standard. In Figures 6 and 7, points at or below the line are compliant with the standard. Please note the energy capacity is on a logarithmic scale in all three figures.[1]

[1] The special case standards for emergency exit lighting and inductive chargers are not shown on the charts below although PG&E's consultant Ecos has tested an emergency exit sign and inductive toothbrush charger that meets the emergency exit special standards.

Figure 7: Lab Data – No Battery Power vs. Energy Capacity



* Qualified products below line

4.4.2 Large battery chargers proposal

The proposed efficiency standards specify an efficiency range for charge return factor, set minimum levels for power conversion efficiency and power factor, and set maximum levels for average maintenance power and average no battery power. The Tier 1 proposal eliminates the poorest performing products (see Figure 9). Tier 2 pushes the market to adapt the best performance levels of each metric in the proposal across each technology (see Figure 10).

Table 9 summarizes the proposed standards for large battery chargers.

Table 9: Proposed Large Battery Charger Standards

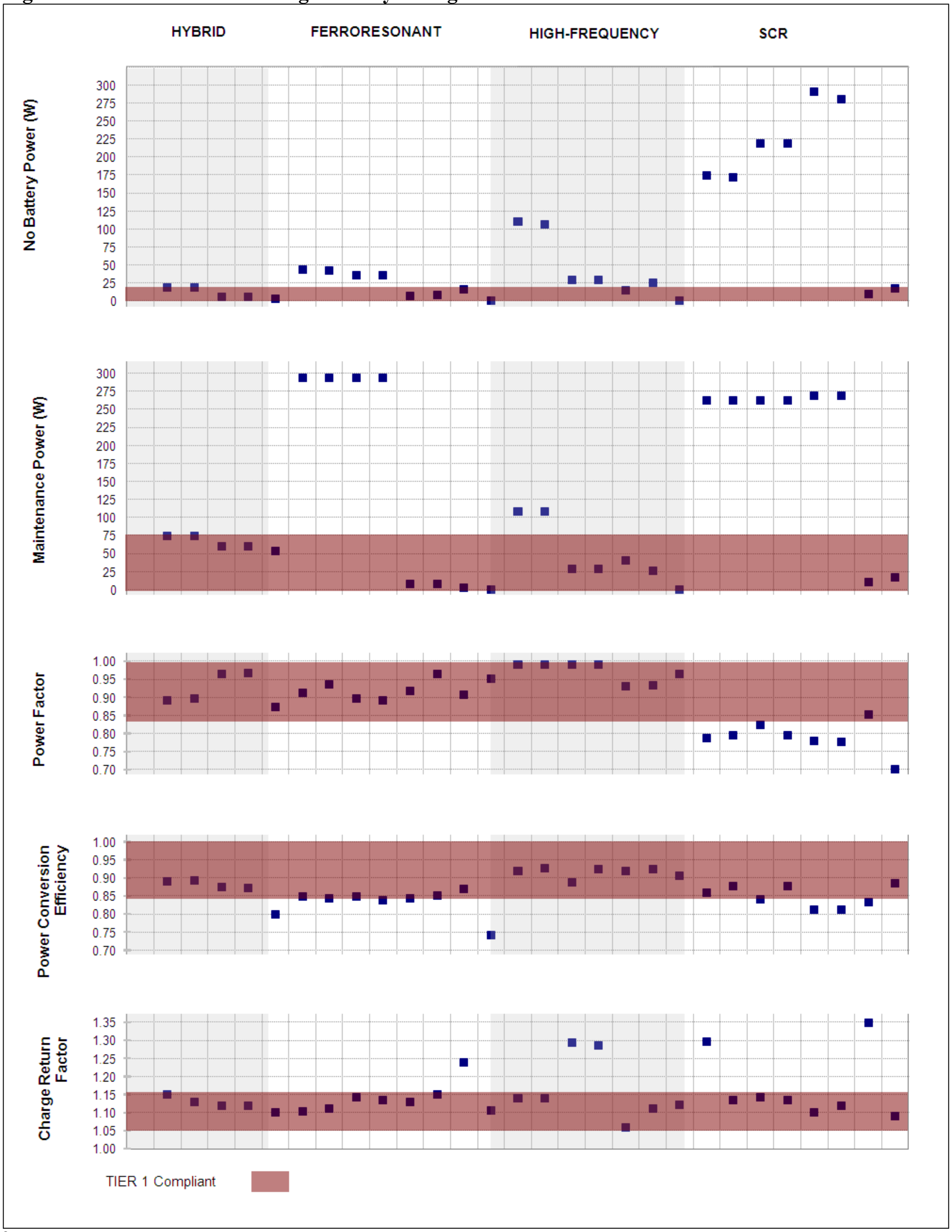
		Tier 1	Tier 2
Charge Return Factor	**100%, 80% DOD**	$1.05 \leq C_{rf} \leq 1.15$	$1.05 \leq C_{rf} \leq 1.10$
	40% DOD	$1.05 \leq C_{rf} \leq 1.20$	$1.05 \leq C_{rf} \leq 1.15$
Power Conversion Efficiency		Greater than or equal to: **84%**	Greater than or equal to: **89%**
Power Factor		Greater than or equal to: **0.85**	Greater than or equal to: **0.95**
Maintenance Power		Less than or equal to: **75 W**	Less than or equal to: **10 W**
No Battery Power		Less than or equal to: **20 W**	Less than or equal to: **10 W**

Many of the large battery chargers covered under the industrial and commercial proposal are used as many as 20 times per week. With charge times ranging from 8 to 10 hours, large battery chargers spend a majority of their time in charge mode, actively charging the battery. Thus, the performance metrics associated with the largest amount of energy use are power conversion efficiency and charge return factor.

All of the large battery chargers tested for this report utilized lead-acid batteries, which are currently used almost exclusively for industrial and commercial applications. Lead-acid batteries require a certain amount of over charge, represented by charge return factor, to maintain a long life and retain charge. International standards recommend a charge return factor between 1.05 and 1.20 for all large battery chargers. A few of the battery chargers in Figure 9 and 10 fall well out of that range. Too much over charge and the battery will have a shorter life and energy is wasted through heat. The optimum charge return factor falls between 1.05 and 1.10.

Figure 8 shows a breakdown of efficiency performance metrics by charger technology, organized per charger, compared to the Tier 1 proposal. The figure shows each metric associated with a particular charger. About 50% of the chargers tested meet all of the levels in the Tier 1 proposal. Many chargers meet portions of the proposal and could become compliant by reducing maintenance and no battery power. Maintenance and no battery power are the easiest elements of the proposal to meet.

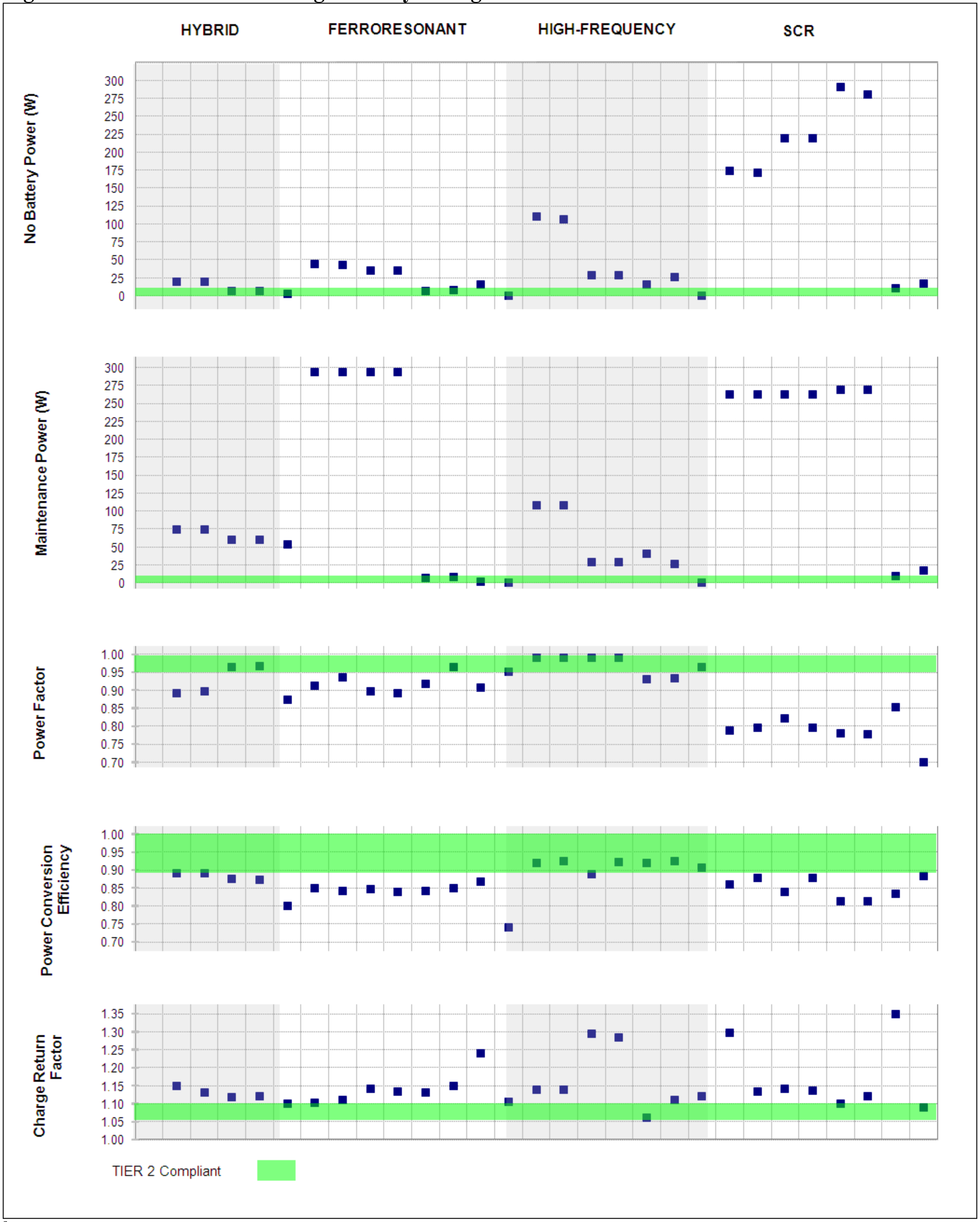
Figure 8: Lab Data – Tier 1 Large Battery Charger Performance [a]



[a] Test results shown correspond to 80% depth of discharge. * Squares at least 50% in band are compliant. Data shown from 15 unique chargers under varied test conditions.

Figure 9 shows a breakdown of efficiency performance metrics by charger technology compared to the Tier 2 proposal. Exisiting products have challenges meeting all of the metrics in the proposal; however with some relatively simple changes many of the hybrid and high frequency chargers could meet the Tier 2 proposal. The nature of large battery charger market intrinsically includes some drivers for efficiency because of the large amount of energy they consume and their expense. This means that much of the savings that could be achieved by the adoption of these proposals is captured with marginal movement in performance metrics like power conversion efficiency and charge return factor. An improvement of a few percentages in either metric can yield significant energy savings (see section 6).

Figure 9: Lab Data – Tier 2 Large Battery Charger Performance[a]



[a] Test results shown correspond to 80% depth of discharge. * Squares at least 50% in band are compliant. Data shown from 15 unique chargers under varied test conditions.

The typical per unit energy usage associated with this standards proposal is summarized in Table 10. The number of hours spent in each mode of operation was combined with the respective power use of each mode and then mapped to an annual duty cycle. Because energy savings associated with the power factor requirement are calculated based on a building model, a per product estimate of energy usage is not included here. Please see Section 5 for an estimate of overall power factor energy savings.

Table 10: Proposed Energy Use per Product

Market Segment	Product Categories	Charge Mode (W)	Maintenance (W)	No battery (W)	Unit Electricity Consumption (kWh/yr)	Percent of Units Operating During Peak Period [a]
Small Consumer	Auto/Marine/RV	142.9	0.5	0.3	66.4	21%
	Cell Phones	3.9	0.5	0.3	3.1	28%
	Cordless Phones	0.9	0.5	0.3	5.6	95%
	Personal Audio Electronics	2.7	0.5	0.1	2.0	16%
	Emergency Systems	1.8	0.5	0.3	4.4	100%
	Laptops	47.0	0.5	0.3	15.8	32%
	Personal Care	1.6	0.5	0.3	4.3	80%
	Personal Electric Vehicles	186.8	0.5	0.3	421.9	31%
	Portable Electronics	14.3	0.5	0.3	1.4	6%
	Portable Lighting	3.6	0.5	0.3	4.4	70%
	Power Tools	14.3	0.5	0.3	7.5	30%
	Universal Battery Charger	47.7	0.5	0.3	3.6	26%
	Golf Carts/Electric Carts	523	0.5	0.3	2,118	14%
Small Non-	Emergency Backup Lighting	1.5	0.5	0.3	10.0	100%

Market Segment	Product Categories	Charge Mode (W)	Maintenance (W)	No battery (W)	Unit Electricity Consumption (kWh/yr)	Percent of Units Operating During Peak Period [a]
consumer	Handheld Barcode Scanners	10.9	0.5	0.3	7.2	46%
	Two-Way Radios	4.1	0.5	0.3	16.0	6%
Large Non-consumer	Three Phase Lift-trucks [b]	Tier 1: 5,523 Tier 2: 5,111	Tier 1: 44.1 Tier 2: 10.0	Tier 1: 12.6 Tier 2: 10.0	Tier 1: 46,117 Tier 2: 42,677	100%
	Single Phase Lift-trucks [b]	Tier 1: 1,909 Tier 2: 1,767	Tier 1: 50.0 Tier 2: 10.0	Tier 1: 20.0 Tier 2: 10.0	Tier 1: 8,205 Tier 2: 7,593	19%

[a] Percentage of units operating during peak period was calculated using PG&E's number for peak electricity demand hours per year, 762 hours, and evenly distributing the products' usage over one year. This results in the total coincident peak demand for any product being 9% of their total demand for one year. [b] Three phase lift-trucks are assumed to endure heavy use, with as many as three charges per day, which is equivalent to constant operation and thus always operating during peak period. Single Phase lift-trucks are assumed to endure moderate use.

5 Market Saturation and Sales

5.1 Current Market Situation

In the last two decades, battery charger systems have become integral to many products that were formerly only available as corded models. The number of U.S. wireless telephone subscriptions passed landline subscriptions in 2005 and currently outnumber landline subscriptions by 75 million (TIA 2008). Construction contractors rely on powerful cordless drills and saws, which offer improved convenience over older models. This trend toward portable devices, which has increased consumer convenience, has also introduced a proliferation of products into the marketplace that contain rechargeable batteries. PG&E and its consultant Ecos estimate that over 1 billion rechargeable battery systems are currently in use in homes, businesses, retail stores, and medical institutions around the country. Other trends suggest that this number will continue to grow:

- Shipments of laptops in the U.S. increased by 30% in 2007, due in part to the wide availability of wireless services and decreases in product price (IDC 2008).
- Sales of emerging products have double and triple digit growth: MP3 players have grown by 155% per year between 2004 and 2007 (Consumer Electronics Association (CEA) 2007); Bluetooth headsets by 69% per year between 2005 and 2007 (Kong 2007).

- Sales of digital cameras, camcorders, portable audio, portable communications and electronic gaming products grew 14% to nearly $54 billion in 2007 (Gerson 2008).
- Sales of lift-trucks chargers are expected to continue to rise as older chargers are replaced, overseas shipping increases, warehouses shift to more automated and advanced systems, and fossil fuel powered lift-trucks are replaced by battery powered ones, though growth is expected to slow by 2013 when older units have been replaced by newer ones.

5.1.1 Baseline Case

The following battery charger systems stock and sales estimates were derived from a variety of sources. When available, stock numbers were used but more often, stock was generated from annual sales data and product lifetime assumptions. The majority of data available is principally U.S. national sales or stock and is therefore scaled using the ratio of Californian households to U.S. households, 10.5% (U.S. Census Bureau 2003; 2009). In some cases, the categories listed below represent aggregation of product-specific battery charger system stock and sales data (e.g. information appliances). A complete list of products included in each group can be found in Appendix A.

In total, PG&E and its consultant Ecos estimate ownership of approximately 12 battery small consumer charger systems in each of California's 12.7 million households. These plus the commercial (non-consumer chargers) total to nearly 170 million small battery charger systems in use statewide.

Consumer demand for device portability has increased the number of battery charger systems employed in end use products (Section 3), but within that general trend, sales of some battery charger products are shrinking (e.g. cordless land line phones) because they are being replaced with other portable products (e.g. cell phones). The sales rates of certain products are expected to change over time as the demand for those products change. Older technologies like CD players will continue to be replaced by MP3 players, so that CD players' sales decrease and MP3 player sales increase.

Table 11: California Stock and Sales for 2009

Market Segment	Product Categories	California Stock		California Annual Sales
		Units (millions)	Saturation (%)	Units (millions)
Small Consumer	Auto/Marine/RV	1.8	15%	0.18
	Cell Phones	47.9	378%	28.27
	Cordless Phones	20.5	162%	3.21
	Personal Audio Electronics	29.8	236%	10.52
	Emergency Systems	5.3	42%	2.6
	Laptops	16.0	126%	4.57
	Personal Care	8.7	69%	1.84

		California Stock		California Annual Sales
	Personal Electric Vehicles	0.1	1%	0.04
	Portable Electronics	10.3	81%	2.00
	Portable Lighting	1.2	9%	0.01
	Power Tools	15.3	121%	2.87
	Universal Battery Charger	0.9	7%	0.11
	Golf Carts/Electric Carts	0.175	1%	0.017
Small Non-consumer*	Emergency Backup Lighting	7.9	62%	0.075
	Handheld Barcode Scanners	2.4	18%	0.78
	Two-Way Radios	0.6	5%	0.30
Large Non-consumer*	Three Phase Lift-trucks	0.074	1%	0.005
	Single Phase Lift-trucks	0.029	0%	0.002
	CA Total	**169**		**57**

* These products are not typically found in residential buildings. Saturation numbers are given for comparison purposes only.
note: Cell Phones category consists of both cell phones and cell phone accessories

The projected sales rates for the respective product categories were developed by analyzing the market penetration rates and proliferation of the products. Some products, like cell phones and MP3 players, are currently experiencing double digit sales growth, but as the market becomes more saturated, the growth rate is expected to slow. In some products, like computers, market saturation may not be reached until multiple products are present in each household.

Table 12: California Battery Charger System Compound Annual Growth Rates

Market Segment	Product Categories	CAGR 2010	CAGR 2013
Small Consumer	Auto/Marine/RV	3%	3%
	Cell Phones	19%	2%
	Cordless Phones	-10%	-9%
	Personal Audio Electronics	12%	2%
	Emergency Systems	0%	0%
	Laptops	29%	12%
	Personal Care	4%	3%
	Personal Electric Vehicles	18%	24%
	Portable Electronics	9%	18%

Market Segment	Product Categories	CAGR 2010	CAGR 2013
	Portable Lighting	1%	1%
	Power Tools	5%	5%
	Universal Battery Charger	3%	3%
	Golf Carts/Electric Carts	16%	11%
Small Non-consumer	Emergency Backup Lighting	0%	0%
	Handheld Barcode Scanners	6%	7%
	Two-Way Radios	0%	0%
Large Non-consumer	Three Phase Lift-trucks	7%	1%
	Single Phase Lift-trucks	7%	1%
	CA Average CAGR:	**10%**	**3%**

5.1.2 High Efficiency Options

In certain end use applications (e.g. laptops and cell phones), the market drivers for small size and increased portability have led to more efficient battery charger systems. More efficient chargers produce less heat while operating, allowing product engineers to enclose more circuitry into a smaller space without fear of overheating the product beyond consumer tolerances. Similarly, in high power applications, such as lift-truck chargers, lifetime energy use may also be considered by purchasers who ultimately pay for the electricity to operate the charger. Industrial lift-trucks for example can use 46 MWh per year of electricity. Reducing annual energy use by as little as 10% can save approximately $400 dollars a year in electricity costs, or $6000 over a 15 year design life.

For the remaining small battery charger products, price is often the principal consideration when designing a battery charger system. Tests of more than 100 small battery charger products in the PG&E data set confirm that price sensitive products, such as residential power tools, are generally less efficient than products with portability market drivers. In contrast, large battery chargers are more expensive than small battery chargers and are typically priced around $2,000. The purchase of a large battery charger is already viewed by most purchasers as an investment, where efficiency and reliability are market incentives. Therefore, the price exchange for more efficient and reliable technologies is often factored into a purchase decision.

5.1.3 Compliance Rates

Because efficiency data were not available from any external source, proposed standard compliance rates were estimated based on lab data and qualitative trends uncovered in market research. Each product category was placed in one of four different compliance categories and a quantitative percentage of compliance was applied:

- Mostly compliant: 90%;
- Somewhat compliant: 50 %;

- Rarely compliant: 10%;
- Not compliant: 0%.

Table 13: California Battery Charger Recommended Standard Compliance Rates 2009

Market Segment	Product Categories	Compliance Rate
Small Consumer	Auto/Marine/RV	0%
	Cell Phones	50%
	Cordless Phones	0%
	Personal Audio Electronics	90%
	Emergency Systems	10%
	Laptops	10%
	Personal Care	0%
	Personal Electric Vehicles	10%
	Portable Electronics	10%
	Portable Lighting	0%
	Power Tools	10%
	Universal Battery Charger	50%
	Golf Carts/Electric Carts	50%
Small Non-consumer	Emergency Backup Lighting	50%
	Handheld Barcode Scanners	50%
	Two-Way Radios	50%
Large Non-consumer	Three Phase Lift-trucks	Tier 1: 50% Tier 2: 0% [a]
	Single Phase Lift-trucks	Tier 1: 50% Tier 2: 0% [a]
	***CA Total:**	**42%**

* This is the compliance rate after passage of Large non-consumer chargers

5.2 Future Market Adoption of High Efficiency Options

In the product data set, neither chemistry nor battery size is not a predictor of battery charger system efficiency. Even though many small Li-Ion systems are relatively efficient (21 % on average over 24 hour charge and maintenance), there are other examples of Li-Ion systems with low efficiency. One Li-ion cordless phone tested had a 24-hour system efficiency of 4.6%. This suggests that current trends to increasingly employ Li-Ion batteries in an effort drive up battery capacity and battery energy density in consumer products are unlikely to ensure that more efficient chargers are produced in the absence of an efficiency standard.

The industrial and commercial lift-truck applications are dominated by lead-acid battery powered and propane powered technology. The highly volatile carbon based fuel prices coupled with heavy use of many lift-trucks often drive lift-truck purchasers to select battery powered lift-trucks. The current state of technology makes lead-acid battery technology the most cost effective and reliable option for battery powered lift-trucks. Fuel cell technology is an emerging alternative to battery powered lift-trucks, but at the current price the market is not likely to adopt fuel cell powered lift-trucks for quite some time.

Without the presence of the proposed battery charger system efficiency standard, the average efficiency of individual battery chargers is expected to remain constant within each product end use. Consumer end use products with market pressure for portability (e.g. MP3 players, cell phones, etc.) are likely to continue to employ relatively efficient battery charger systems (15% to 50%). Commodity end use consumer products that compete on a cost basis are expected to remain relatively inefficient (2% to 10%). In the absence of a standard, the charge return factor and power conversion efficiency of large chargers are also likely to remain constant at 1.15 and 85% respectively.

Small charger efficiency standards set efficiency requirements above products that typically have relatively efficient battery charger systems. PG&E and its consultant Ecos estimate that only 50% of current cell phones and 10% of current laptops could meet the proposed small charger standard. The proposed Tier 2 standard for large battery chargers will push the market to performance levels currently attainable with the best technology. Marginal improvements in power conversion efficiency and charge return factor will potentially yield a significant amount of savings.

As the overall number and variety of battery charger systems increase over time (Section 3, Section 5.1.1), it is likely that the principal method to curb battery charger system energy use is to mandate efficiency targets.

6 Savings Potential

6.1 Statewide California Energy Savings

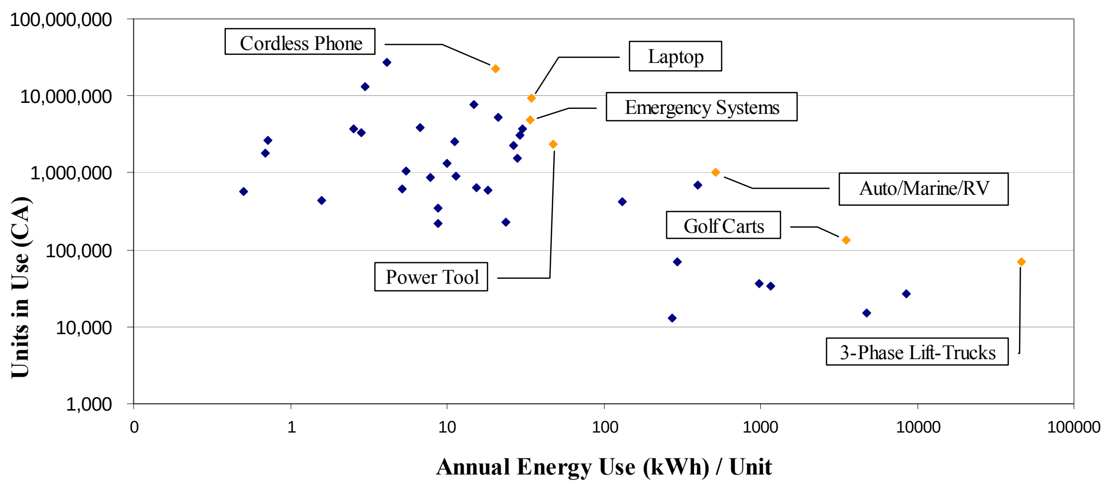
Today, battery charger systems approximately 7,700 GWh per year in California, the equivalent of powering approximately 1.1 million homes in California (Table 14). Figure 10 shows the number of units in use and the energy use per unit for each product category. Those categories that are higher (more products in use) or further to the right (more energy use per product) contribute most significantly to California's total battery charger system energy use:

Composition of California battery charger energy use:

- Three Phase Lift-trucks (48%)
- Auto/Marine/RV (12%)
- Laptops (7%)
- Golf Carts/Electric Carts (6%)
- Cordless Phones (6%)
- Power tools (5%)
- Emergency systems (3%)

- Cell phones (3%)
- Single Phase Lift Trucks (3%)

Figure 10: Breakdown of battery charger system energy usage by product category



* Logarithmic scales; *orange diamonds represent the categories of products with the highest state-wide energy use, either because there are many units in use (cordless phones) or because each unit uses a large amount of energy (lift trucks); * blue diamonds represent other categories of battery chargers

Some categories, like power tools, consume a relatively low amount of energy per unit (23 kWh annually), but there are a significant numbers of units in use (15.3 million). Other battery charger categories, such as auto/marine/RV chargers, have fewer units in use (1.8 million), but each unit uses over 462 kWh annually. Three Phase lift-trucks have the most dramatic numeric range in California to the total amount of energy use: with about 74,000 units composing the stock, annual energy use per unit is 46,000 kWh per year. There are a variety of other product categories that comprise the remaining energy usage (Table 14).

Energy use per unit (from Table 10 in Section 4) for each product category was multiplied by the product stock in each year (from Table 11 in Section 5) to generate the baseline usage shown in Table 14. Forecasted energy use per unit was derived based on the specifications of the tiered standards, their date of adoption, and the amount of product stock and sales each standard would affect. This analysis was based on sales and stock projections out to 2013.

Table 14: California Statewide Baseline Energy Use

Market Segment	Product Categories	For Annual Sales (2009)		Entire Stock (2009)	
		Coincident Peak Demand [a] (MW)	Annual Energy Consumption [b] (GWh/yr)	Coincident Peak Demand [a] (MW)	Annual Energy Consumption [b] (GWh/yr)

		For Annual Sales (2009)		Entire Stock (2009)	
Small Consumer	Auto/Marine/RV	11.5	86	114.8	855
	Cell Phones	14.2	105	24.0	179
	Cordless Phones	8.8	65	56.0	417
	Personal Audio Electronics	3.6	27	10.1	75
	Emergency Systems	8.7	76.7	46.6	227
	Laptops	20.4	152	71.4	532
	Personal Care	2.1	16	9.9	74
	Personal Electric Vehicles	5.7	42	12.5	93
	Portable Electronics	0.7	3.6	2.6	19.2
	Portable Lighting	0.0	0.2	2.1	16
	Power Tools	9.5	71	50.6	377
	Universal Battery Charger	0.1	0.9	0.9	6.9
	Golf Carts/Electric Carts	6.0	44	59.5	442
Small Non-consumer	Emergency Backup Lighting	1.3	11.3	12.9	113
	Handheld Barcode Scanners	1.0	8	8.2	64
	Two-Way Radios	0.2	3.2	1.7	12.8
Large Non-consumer	Three Phase Lift-trucks	28.4	212	456.9	3403
	Single Phase Lift-trucks	2.1	15	33.0	246
	Device Subtotal	***124***	***939***	***974***	***7,152***
	Power Factor Subtotal[c]				***587***
	Total	**124**	**939**	**974**	**7,739**

[a] Coincident peak demand was calculated by using the average ratio of peak demand to average demand from California Independent System Operator and applying the ratio as a multiplication factor towards the amount of power used by product for the amount of time specific to the period of time the product operations on peak. [b] Energy use was calculated by taking the estimated power use by mode for each product and multiplying time spent in each mode; [c] Power factor losses are estimated I^2R losses associated with average building wiring scenarios.

Table 15: Estimated California Statewide Energy Savings for Standards

Market Segment	Design Options	For Annual Sales		After Entire Stock Turnover [a]	
		Coincident Peak Demand Reduction (MW)	Annual Energy Savings (GWh/yr)	Coincident Peak Demand Reduction (MW)	Annual Energy Savings (GWh/yr)
Small Consumer	Auto/Marine/RV	11.1	82.6	110.9	826.0
	Cell Phones	2.6	19.5	5.2	39.1
	Cordless Phones	4.3	32.0	26.4	196.8
	Personal Audio Electronics	0.7	5.2	2.0	15.1
	Emergency Systems	7.2	63.3	21.4	188
	Laptops	18.0	298.0	60.2	448.2
	Personal Care	1.1	8.3	5.3	39.5
	Personal Electric Vehicles	8.7	64.4	15.2	113.4
	Portable Electronics	0.1	3.3	2.4	17.7
	Portable Lighting	0.0	0.1	1.5	11.3
	Power Tools	7.7	57.4	41.1	306.3
	Universal Battery Charger	0.1	0.5	0.6	4.3
	Golf Carts/Electric Carts	1.9	13.9	18.8	139
Small Non-consumer	Emergency Backup Lighting	0.5	5.1	4.6	51.4
	Handheld Barcode Scanners	0.8	5.8	6.3	46.6
	Two-Way Radios	0.03	0.5	0.24	3.8
Large Non-consumer	Three Phase Lift-trucks	Tier 1: 0.1 Tier 2: 3.2	Tier 1: 0.6 Tier 2: 16.2	Tier 1:1.0 Tier 2: 35.8	Tier 1: 7.4 Tier 2:266.9
	Single Phase Lift-trucks	Tier 1: 0.1 Tier 2: 0.3	Tier 1: 0.6 Tier 2: 1.8	Tier 1: 1.0 Tier 2: 3.5	Tier 1: 7.5 Tier 2: 25.8
	Total*	**68.3**	**678**	**361**	**2,739**

[a] Total stock turnover savings estimates calculated with respect to stock turn over projections for 2013.
*Note: totals are for Tier 2. Power factor savings are included with the product by product estimates.

Table 15 shows the estimated energy savings from the adoption of the standard and Tier 2 of the large non-consumer standards. The resulting savings estimates are based on projected sales of products with battery charging systems in 2013. The stock turnover savings estimates are based on projected stock in 2013. The saving calculations for Tier 2 (large chargers only) are relative to baseline energy consumption. The largest energy savings potential exists in the following product categories: auto/marine/RV, laptops, power tools, three phase lift-trucks, emergency systems, cordless phones, power tools, and golf carts/electric carts.

Emergency systems, residential cordless tools, and cordless phones spend almost all of their time in maintenance mode. Because many currently use simple battery chargers with no charge control circuitry, energy is lost in the battery as heat as the charger continues to trickle charge even though the battery is full, heating up the battery and reducing battery life. In contrast, lift-trucks and golf carts spend most of their time in charge mode. The majority of savings potential in these products comes from improving power conversion efficiency and charge return factor. If the entire 2009 stock of California battery chargers became compliant with the small charger standard and the Tier 2 of the large charger standard, 35% of the current energy use could be saved.

In addition to the baseline numbers shown in Table 14, further energy is lost in building wiring because of low power factor typical of many of these products. These losses occur because battery charger systems with low power factor inefficiently draw electricity from the wall outlet, heating up the wiring in building circuits (I^2R losses). Power factor losses caused by poor power factor in switch mode power supplies in California residences are estimated to be between 500 GWh and 2000 GWh per year. For a more complete discussion of power factor and its impact on energy usage, see Appendix B.

6.2 Other Benefits and Penalties

This proposed standard, if enacted, is extremely unlikely to cause any non-energy environmental penalties, and would result in many environmental benefits. Because more efficient products operate at lower internal temperatures, the lifetime of consumer products could increase. The standard would result in improved California air quality and a reduction in CO_2 emissions. These savings can be quantified in terms of power plants saved, carbon emissions avoided, and fewer cars on the road.

Table 16: Environmental Benefits of Energy Savings: Equivalencies

Small BCS Energy Savings	70% of current energy use
Large BCS Energy Savings	8% of current energy use
All BCS Energy Savings [a]	35% of current energy usage
rosenfeld [b]	0.9
Equivalent California household electricity usage savings [c]	390,000 homes

[a] This is equivalent energy savings after small charger standard and large charger tier 2 standard, 2,739 GWh/year. Energy savings calculated based on energy savings per unit with tiered standards and standard energy use, multiplied by the stock in 2009. These figures include the estimates of power factor losses and savings.
[b] a rosenfeld is the equivalent of displacing a 500 MW existing coal plant operating at a 70% capacity factor with 7% T&D losses. Displacing such a plant for one year would save 3 billion kWh/year at the meter and reduce emissions by 3 million metric tons of CO_2 per year (Koomey 2010) available at http://iopscience.iop.org/1748-9326/5/1/014017/.
[c] based on average 2008 California holdhold residential electricity consumption of 7,044 kWh/year, 587 kWh/month; see 'Average monthly residential electricity consumption, prices, and bills by state' in Table 5 available: http://www.eia.doe.gov/cneaf/electricity/esr/table5_a.xls - U.S. Energy Information Administration.

Note: Benefits calculated from projections of energy savings as a function of the entire 2009 stock of battery chargers being subject to small charger standard and Tier 2 of the large charger standard, including power factor savings.

In addition, because the Federal government and a number of other international entities are considering efficiency standards for battery chargers, adopting the proposed standards would enable other jurisdictions to reference California's approach. This could have benefits to manufacturers, who prefer one harmonized standard over a "patchwork" of standards around the world. In particular, the U.S. DOE is required to make a standards determination by 2011 (see Section 8.2 for further details) and could reference California's adopted standard.

7 Economic Analysis

The PG&E and its consultant Ecos' economic analysis shows that the proposed standards for battery charger systems provide an overwhelmingly large energy savings benefit to the state of California. The net present value of total stock turnover in 2013 subject to the small charger standard and large charger Tier 2 standard is $2.4 billion.

7.1 Incremental Cost

The incremental cost of bringing the categories of small consumer and non-consumer battery chargers into compliance with the proposed standards depends on battery technology, power rating, and product end use. The design improvements discussed below will enable a battery charger to reach the most stringent proposed standard levels (including large charger Tier 2 levels). The incremental costs for this analysis were developed considering the following design improvements:

- As a general pattern, the cost of improving the efficiency increases as the size of the power system increases. For example, cost to improve the efficiency of auto/marine/RV battery chargers and uninterruptible power supplies (UPS) is higher than that of smaller power systems such as power tools.
- Improving the efficiency of a low power product like a cordless phone or power tool can cost less than $1.00, because changes can be as simple as swapping out linear power supplies with switch mode supplies. For a total incremental cost less than $2.00, switch controlled current regulating components, usually dc to dc converters, can be incorporated to significantly reduce maintenance and no battery losses.
- A battery charger can be totally redesigned and brought to market at an incremental manufacturing cost near zero. By replacing some components with more efficient ones, incremental costs near $0.40 are common.
- High compliance rates in categories such as cell phones, laptops, and portable audio electronics means the added cost to bring these appliances into compliance is functionally zero.

Large battery chargers are operated primarily in the industrial sector under heavy use and facilities managers are regularly faced with high electricity bills. They are generally more familiar with efficient technology benefits that save the company electricity costs over time. For this reason, some initial efficiency improvements in large chargers have been made as a result of market demand, but charge return factor and power conversion can further improved. The following incremental cost information is relevant to large chargers:

- Smarter charging electronics that more carefully charge the battery and lower maintenance and no battery power are in some cases available as modularized add-ons.
- Tier 1 levels can generally be met with improved charge control technologies, which are more widely available as modular improvements to existing battery chargers.
- The incremental cost of achieving Tier 2 levels for large battery charger is on average double the incremental cost of achieving Tier 1 levels; this is primarily driven by the fact that the power conversion efficiency technologies needed to achieve Tier 2 levels require newer technology that is currently more expensive.
- In some cases, large charger operators can recover the Tier 2 incremental cost ($100 to $400) of the more efficient chargers in the first year of operation, and certainly within the lifetime of the charger.

The majority of products in some categories, such as personal audio electronics, already comply with the standards. Since compliant products are already competitive in the market, any additional cost of compliance must be negligible. These high-compliance categories are estimated in this analysis to have zero incremental cost for the relevant standard. These categories also have a rather small energy savings opportunity, so they have little effect on the total cost/benefit results. Standards continue to make sense for these products to ensure that the future products continue to be energy efficient.

7.2 Design Life

Design life of a battery charger system depends on the end use product market, the product design, usage profile, and the end use product cost. Design life for battery charger systems vary:

- Products with a high turnover rate, such as cell phones, have a short lifetime, because consumers are constantly presented with models that employ new features and functions.
- Some battery charger products such as MP3 players, personal care electronics, and cordless phones do not have batteries that are easily replaceable by the consumer. Often these products are disposed of when the battery fails.
- Power tools, portable lighting, auto/marine/RV chargers, and universal battery chargers are typically used infrequently and have a longer design life.
- Products that are more expensive typically have a longer design life because the cost of replacement can be prohibitive. Batteries are also easily replaced by the consumer. These include lift-trucks, laptops, and personal electric vehicles.

Table 17 gives the specific lifetimes assumptions used for this analysis. These are considered conservative because PG&E and its consultant Ecos have only accounted for the first owner of the product. Products may be transferred to a second owner, lengthening the lifetime and therefore increasing the energy savings.

Table 17: Design Life by Product Category

Market Segment	Product Category	Design Life (years)
Small Consumer	Auto/Marine/RV	10.0
	Cell Phones	2.0
	Cordless Phones	5.0
	Personal Audio Electronics	3.0
	Emergency Systems	7.0
	Laptops	4.0
	Personal Care	5.0
	Personal Electric Vehicles	9.7
	Portable Electronics	5.2
	Portable Lighting	10.0
	Power Tools	6.5
	Universal Battery Charger	8.0
	Golf Carts/Electric Carts	10.0
Small Non-consumer	Emergency Backup Lighting	10.0
	Handheld Barcode Scanners	8.0
	Two-Way Radios	8.0
Large Non-consumer	Three Phase Lift-trucks	15.0
	Single Phase Lift-trucks	15.0

7.3 Lifecycle Cost / Net Benefit

The cost and benefits of the battery charger products were evaluated over their respective lifecycles using the California Energy Commission (CEC) methodology for calculating net present value (NPV). The present value of the energy savings of the proposed standards was calculated by taking the difference between the baseline annual energy use of each product and the projected annual energy use of each product after the standards are enacted. This difference is then multiplied by the present value of the cost of electricity (CEC 2008) over the products' design life. The total benefit of the standard per unit was calculated by subtracting the added first cost from the present value of energy savings (Table 18 and Table 19).

PG&E and its consultant Ecos excluded from the analysis expected reductions in product maintenance cost after the proposed standard takes effect. The standard will generally improve charge control, reduce battery overcharging, and extend battery lifetime, therefore reducing maintenance costs. For products such as MP3 players with integrated non-removable batteries, an increase in the battery lifetime could mean consumers would not need to replace their devices as frequently. For products where the batteries are often replaced or switched out as they wear out, the consumer may not need to replace batteries as frequently.

Most energy savings in large battery chargers are garnered by improving power conversion efficiency and charge return factor. Improvements in charge return factor will assure that the battery is adequately overcharged to improve its lifetime. The long lifetimes and large energy savings potential of lift-trucks coupled together provides a mechanism for recovery of the incremental cost of the efficiency improvements.

The net present value of small charger standard and large charger Tier 2 standard, based on the projected sales in 2013, is $452 million. The net present value of the small chargers and large charger Tier 2 standard after an entire stock turnover with respect to the stock of 2013 is over $2.4 billion. The large net present values are driven by the large number of battery chargers in use in California and the large lifecycle benefit to cost ratios resulting from significant electricity savings.

In addition to these specific calculations, PG&E and its consultant Ecos conducted a sensitivity analysis to identify the maximum additional first cost that would still enable a positive cost benefit to the state of California. Our results confirm that the standard would still provide net savings benefit to the electric customer.

Table 18: Lifecycle Costs and Benefits per Unit for Standards Options

Market Segment	Design Options	Design Life (years)	Lifecycle Benefits per Unit (Present Value $)[b]	
			Total PV Costs [a] (Added First Cost)	**Total PV Benefits** (Energy Savings)
Small consumer	Auto/Marine/RV	10.0	10.0	452
	Cell Phones	2.0	0.0	0.09
	Cordless Phones	5.0	0.4	7.9
	Personal Audio Electronics	3.0	0.0	0.13
	Emergency Systems	7.3	3.0	17.8

	Laptops	4.0	0.0	7.9
	Personal Care	5.0	0.4	2.15
	Personal Electric Vehicles	9.7	2.0	569
	Portable Electronics	4.9	0.0	0.80
	Portable Lighting	10.0	0.4	10.8
	Power Tools	6.5	0.55	11.8
	Universal Battery Charger	8.0	0.0	0.1
	Golf Carts/Electric Carts	10.0	200	1,098
Small Non-consumer	Emergency Backup Lighting	10.0	3.0	86.0
	Handheld Barcode Scanners	8.0	0.5	21.8
	Two-Way Radios	8.0	0.5	34.2
Large Non-consumer	Three Phase Lift-trucks	15.0	Tier 1: 150 Tier 2: 400	Tier 1: 174 Tier 2: 6,214
	Single Phase Lift-trucks	15.0	Tier 1: 100 Tier 2: 200	Tier 1: 459 Tier 2: 1,648

[a] PV = Present Value [b] Calculated using the CEC's average statewide present value statewide energy rates that assume a 3% discount rate (CEC 2008).

Table 19: Lifecycle Costs and Benefits for Standard Options

Market Segment	**Design Options**	**Lifecycle Benefit / Cost Ratio** [a]	**Net Present Value ($)**[b] Per Unit	For First Year Sales	After Entire Stock Turnover
Small Consumer	Auto/Marine/RV	45	442	92,180,000	921,840,000
	Cell Phones	N/A[c]	0.09	2,720,000	5,450,000
	Cordless Phones	19.8	7.5	16,260,000	100,100,000
	Personal Audio Electronics	N/A[c]	0.13	1,410,000	4,130,000
	Emergency Systems	5.9	14.8	33,689,000	130,650,000
	Laptops	N/A[c]	7.9	57,730,000	192,730,000
	Personal Care	5.39	1.75	3,570,000	16,980,000
	Personal Electric Vehicles	284	567	70,890,000	124,800,000
	Portable Electronics	N/A[c]	0.80	2,352,000	9,198,000
	Portable Lighting	27	10.4	120,000	12,460,000
	Power Tools	22	11.3	39,240,000	209,570,000
	Universal Battery Charger	N/A[c]	0.1	60,000	110,000
	Golf Carts/Electric Carts	4.5	792	13,778,000	137,785,000
Small Non-consumer	Emergency Backup Lighting	57.3	84	66,347,000	663, 470,000
	Handheld Barcode Scanners	43.6	21.3	6,405,000	51,240,000
	Two-Way Radios	136.9	68.0	2,547,000	20,380,000
Large Non-consumer	Three Phase Lift-trucks	Tier 1: 1.2; iter 2: 15.5	Tier 1: 24: Tier 2: 5,814	Tier 1: 140,000; Tier 2: 39,120,000	Tier 1: 1,770,000 Tier 2: 438,520,000
	Single Phase Lift-trucks	Tier 1: 4.6 Tier 2: 8.2	Tier 1: 359 Tier 2: 1,448	Tier 1: 820,000 Tier 2: 3,850,000	Tier 1: 10,570,000 Tier 2: 43,130,000
	Total*			**452,268,000**	**2,419,073,000**

[a] Total present value benefits divided by total present value costs. [b] Positive value indicates a reduced total cost of ownership over the life of the appliance. [c] Products with lifecycle benefit to cost ratios listed as N/A (not applicable) have a zero incremental cost of improving their designs to meet the proposed standards.
*Total is for small charger standard and large charger Tier 2 standard

8 Acceptance Issues

8.1 Infrastructure issues

Out of more than 100 small battery charger tests performed, 22% of the products would meet the standard requirements. Out of the 15 unique large battery chargers tested, 30% of the products would meet the Tier 1 requirements and none would meet the Tier 2 requirements. Section 4.3 discusses possible design changes that manufacturers can utilize to meet standards levels requirements. While many battery charger systems will likely undergo a redesign to meet the proposed Tier 2, the tentative targets are feasible for the following reasons:

- Highly efficient power supplies are one of the key design strategies for enabling systematic efficiency improvements in battery charger systems. The existing California Title 20 standards for external power supplies and the recent enactment of Federal external power supply standard required by the Energy Independence and Security Act of 2007 (EISA) have ensured that efficient power electronics components and innovative power supply designs are already employed in the marketplace. Efficient power electronics components at low incremental cost are now readily available for battery charger system manufacturers and designers.
- Some high volume products, such as cell phones and MP3 Players, already easily meet proposed small charger standards, requiring no near term redesign efforts. Such products are already relatively efficient compared to battery chargers with lower mobility requirements (such as cordless vacuums and toothbrushes) or safety design constraints.
- The recommended compliance year for small standards is 2012, allowing manufacturers approximately two years to source components and adjust designs. Electronic product design cycles typically run anywhere from one to two years (Johnson 2006), allowing ample time for small standard criteria to be built into product specifications.
- Discussions with manufacturers and industry experts have helped shape the structure and levels of the large battery charger standards. There is wide support from stakeholders who have participated thus far and feedback has been optimistic on the industry's ability to meet the intrinsic demands of the standard, in terms of technology and cost.

8.2 Existing Standards

While ENERGY STAR was the first government entity to specify efficiency levels for battery chargers, its 2005 specification and test procedure only addresses a small range of small battery charging products in low power modes. The scope of the ENERGY STAR specification includes:

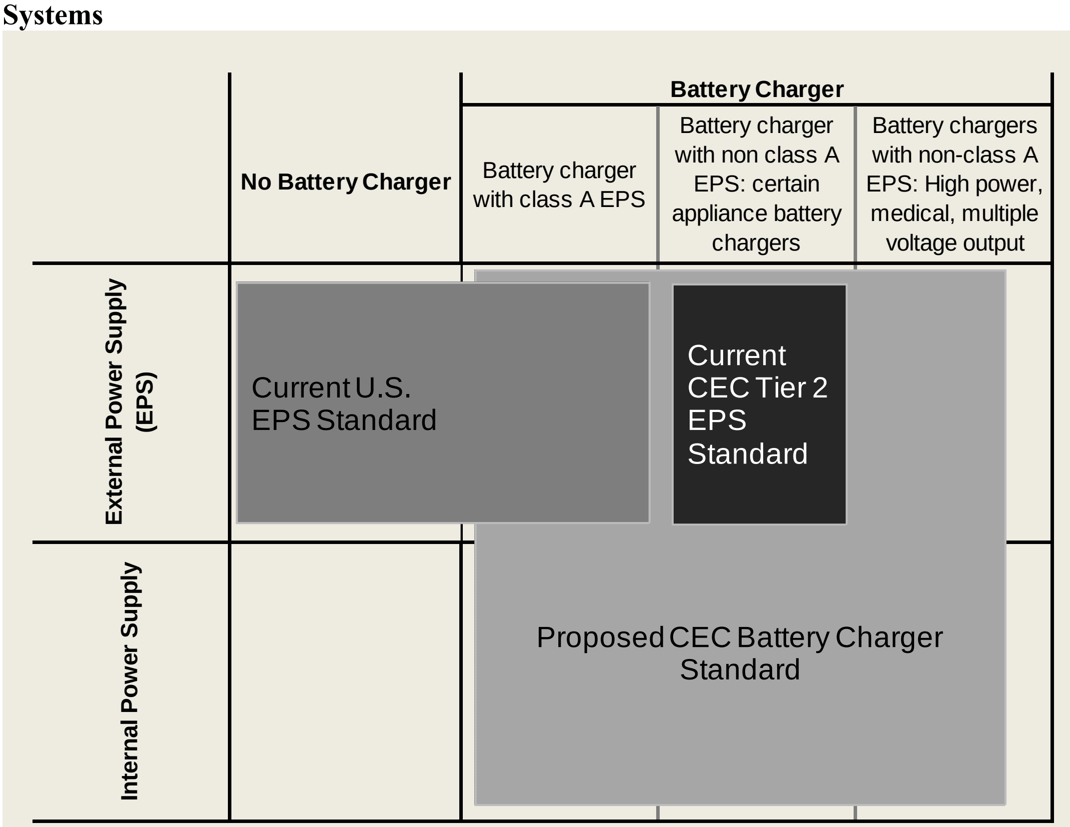
- Battery charging products whose principal output is mechanical motion, light, the movement of air, or the production of heat.
- Stand alone battery chargers sold with products that use a detachable battery.

- Battery charging systems intended to replace standard sized primary alkaline cells.

The ENERGY STAR specification yields less energy savings than what is possible by a California standard due to the limited scope and exclusion of charge mode. ENERGY STAR has announced its intent to incorporate charge mode into a future battery charger system specification and is interested in reviewing the energy efficiency test procedure that has been adopted by the CEC for use in conjunction with the California standard (U.S. EPA 2010).

Department of Energy (DOE) released a rulemaking framework document in June 2009 and its preliminary analysis in September of 2010 laying out its approach to evaluate a federal standard for consumer battery chargers. EISA states that July 2011 is the final action date for federal battery charger standards. The enforcement date for standards could fall within two to three years after this final action date. California battery charger standards could also influence the scope and methodology of the federal battery charger standard.

Figure 11: Current Scope of Coverage for External Power Supplies and Battery Charger Systems



Because many battery charger systems also utilize external power supplies, policymakers and stakeholders are concerned about product compliance under two separate California efficiency standards (Figure 11). The federal external power supply standard required by EISA supersedes the former California Title 20 external power supply standard for many but not all external power supplies. This group of external power supplies that must meet efficiency standards are referred to in the legislation as “class A” power supplies.

California has changed its policy language to recognize the federal government jurisdiction over the regulation of this "class A" group external power supplies. EISA specifically allows for a product to be subject to both an external power supply standard and a standard for the product being powered, in this case, the battery charger system. Thus, the external power supply standard does not interfere with any California regulation of battery chargers systems.

A DOE Preliminary Standards technical support document, released in September 2010, indicates that DOE is considering higher standards levels for class A external power supplies. In addition, DOE made a determination in 2010 that efficiency standards were warranted for remaining external power supplies, or "non class A" (U.S. DOE 2010). Eventually, California's external power supply standard is likely to be pre-empted by DOE's approach, but it remains clear that the external power supply regulations do not interfere with California's ability to regulate battery charger efficiency ahead of a DOE standard battery charger standard.

Natural Resources Canada, the Australian Greenhouse Office and the European Commission have all expressed interest in creating a battery charger system efficiency standard in their own jurisdictions. Natural Resources Canada indicated in a 2008 stakeholder meeting the intent to regulate battery chargers in the near future, and to call upon the Canadian Standards Associated (CSA) to include charge mode in their proposed test procedure, in harmony with the California proposals. The European Commission released a scoping study in 2007 that investigated the battery charger topic (European Commission DG TREN 2007). The outcome in California is likely to influence battery charger policy that these international jurisdictions are expected to enact.

8.3 Stakeholder Positions

Responses to the battery charger test procedure and standards range from supportive to resistant:

- The Power Sources Manufacturers' Association (PSMA), which represents manufacturers of power electronics components and power supplies, supports efficiency standards for power supplies specifically and power systems more generally. In a letter submitted to manufacturers and regulatory agencies in 2004, co-chairs of the energy committee at PSMA state, "We believe that, wherever possible, the entire power system needs system examination for potential efficiency improvement in addition to examining individual components within the power structure, architecture, conversion, and/or conveyance path" (PSMA Energy Committee 2004).
- Manufacturers of three phase battery charger systems for industrial non-road vehicles, such as lift-trucks, have expressed support for an efficiency standard, indicating that it will allow them to distinguish their products in the marketplace.
- In 2007, several stakeholders submitted constructive line-by-line style comments to improve the PIER/PG&E funded battery charger test procedure (Bendt 2007). These manufacturers, who worked with the authors in a spirit of collaboration, are

unlikely to have significant opposition to the standard but rather will seek to review and improve the standard technically, if needed.

- A select few stakeholders are likely to challenge the rationale of a universal battery charger system standard that applies to all end use products. These manufacturers may seek exemptions for their battery charger systems or modification to the standard. Rationale varies, but initial comments on the test procedure suggest the following concerns (Bendt 2007):
    - The duty cycles of some battery charger systems do not include a significant time in charge mode and therefore should not be required to meet a battery charger standard that includes a charge mode efficiency requirement.
    - Certain battery charger products likely to be used near water in the home (shavers, toothbrushes, etc.) have unique safety design requirements that make meeting an efficiency standard more challenging.
    - Appliance battery chargers are unique and therefore should be exempted from the proposed standard.
    - Battery charger systems with input power ratings less than 2 watts cannot be significantly improved and do not represent an opportunity for significant energy savings should be removed from the scope.

In each case, the authors of the test procedure believed that the test procedure is a suitable procedure for measuring the efficiency of the products, and so all products listed above remained in the scope of the test procedure (Bendt 2007). PG&E's consultant Ecos have considered these concerns and determined that the proposed standards are suitable for these product classes as well.

We expect consumer battery charger manufacturers to have concerns regarding the adoption of a California standard ahead of a U.S. DOE-developed federal standard. Manufacturers are likely to have questions about how to consider two standards in the product redesign process.

Lastly, manufacturers and policymakers may need more information regarding how the California external power supply standard and the proposed battery charger standard will apply to those products that would be required to meet provisions in both standards (see Section 8.2 above).

8.4 Technology Developments

Technological improvements will continue to change the landscape of battery charger systems. Battery technology, nano-electronics, and semiconductor technology will drive the future of battery charger systems.

Improvements in battery technology will change the way battery chargers are used and likely proliferate new areas of portable electronic applications. Massachusetts Institute of Technology's Department of Materials Science and Engineering published a study March of 2009 in the scientific journal Nature (Kang, Ceder 2009) which discussed recent achievements in nano-battery technology manufacturing. Some important insights into the phenomenon of charge transportation in lithium batteries were discovered. The study found that the limiting factor of charge transportation was the diffusion of charge across the interface of the cathode and the electrolyte, and not bulk diffusion in the cathode material.

Kang and Cedar were able to successfully manufacture an ion-conducting surface which enabled ion diffusion across the interface to provide incredibly high rates of charge transportation. This means that in the future high energy density batteries will be able to deliver and receive charge as fast as capacitors. This will revolutionize battery chargers and their use. However, the manufacturing process for this technology is still in early stages of development and it will be many years before this technology becomes widely available.

Another important consideration drawn from the results of this study is the extremely high power demands of ultra fast charging batteries. A 1 Wh cell phone battery could potentially require a 360 W power supply, which may be 5 or 6 times larger than the phone itself. In addition to size concerns for ultra fast charging power supplies, there are implications for the power grid, which could potentially be subjected to power spikes and peak demand surges.

Inductive chargers are a battery charger technology that will likely see rapid proliferation in the market in the next few years. Inductive chargers use near field magnetic coupling to move electrons without physical contact and the power of the magnetic field decreases with the square of the distance, which means the potential for very poor efficiencies is likely. This efficiency of this technology is not widely known because it has not been widely tested.

9 Recommendations

9.1 Recommended Standards Options

Based on our analysis, PG&E and its consultant Ecos recommend that California adopt a two tiered standard for battery charger products, with special cases for emergency exit lighting and inductive chargers.

9.1.1 Small Battery Chargers (Consumer and Non-consumer)

The small battery charger standard, which would go into effect in 2012, limits battery charger products' 24-hour charge and maintenance energy to $12 + 1.6E_b$. Maintenance power and no battery power can be no higher than 0.5 watts and 0.3 watts, respectively. The power factor requirements range from 0.5 to 0.9, depending on the input current of the charger (as detailed in Section 9.2).

9.1.2 Large Battery Chargers (Non-consumer only)

Tier 1 requires an appropriate charge return factor. The charge return factor, C_{RF}, shall be required to be between 1.05 and 1.15 for 80% and 100% depth of discharge and for 40% depth of discharge the charge return factor shall be between 1.05 and 1.20. This should stimulate smarter charging behavior. The average maintenance power shall be capped at 75 watts and average no battery power shall be capped at 20 watts. The power conversion efficiency shall be greater than or equal to 84%, which should eliminate the poorest performers from the market. The power factor shall be greater than or equal to 0.85.

Tier 2 pushes the market to adapt the best performance levels across each technology. The charge return factor, C_{RF}, shall be between 1.05 and 1.10 for 80% and 100% depth of discharge and for 40% depth of discharge the charge return factor shall be between 1.05 and 1.15. The average maintenance power and average no battery power shall not exceed 10 watts. The power conversion efficiency shall be greater than or equal to 89%. The power factor shall be greater than or equal to 0.95.

Analyses indicate that the incremental cost of improving battery charger products to meet the proposed standards is low and the benefit-to-cost ratios are high.

9.2 Proposed Changes to the Title 20 Code Language

Definitions

A *battery charger system* is defined as a battery charger coupled with its battery.

This term covers all rechargeable batteries or devices incorporating a rechargeable battery and the chargers used with them. Battery charger systems include, but are not limited to:

1. electronic devices with a battery that are normally charged from ac line voltage or dc input voltage through an internal or external power supply and a dedicated battery charger;
2. the battery and battery charger components of devices that are designed to run on battery power during part or all of their duty cycle (such as many portable appliances and commercial material handling equipment); dedicated battery systems primarily designed for electrical or emergency backup (such as emergency egress lighting and uninterruptible power supply (UPS) systems);
3. Devices whose primary function is to charge batteries, along with the batteries they are designed to charge. These units include chargers for power tool batteries and chargers for automotive, AA, AAA, C, D, or 9 V rechargeable batteries, as well as chargers for batteries used in motive equipment, such as golf carts, electric material handling equipment and vehicles, including lift-trucks, airport electric ground support equipment (EGSE), port cargo handling

equipment; tow tractors, personnel carriers, sweepers and scrubbers are examples of these types of motive equipment.

4. Battery charger systems that are rated for ac input of 600 volts or less, which connect to the utility grid with a plug or are permanently connected.

An *emergency exit sign* is a product subset of small battery charger systems and is defined as a permanently hardwired, continuously illuminated signs identifying the location of exits.

An *inductive charger* is a product subset of small battery charger systems and is defined as a battery charger system whose charge control circuitry transfers energy to the battery wirelessly. No direct electrical contact is made between the charger and the battery.

The test procedure that shall be used to test battery charger systems for the purposes of this standard shall be the *Energy Efficiency Battery Charger System Test Procedure* (Porter, Bendt et al. 2008) available online at http://www.efficientproducts.org.

A *small battery charger* is a battery charger system that is within the scope of Part 1 of the aforementioned test procedure, and also includes consumer non-road motive equipment, such as golf carts.

A *large battery charger* is a battery charger system that is within the scope of Part 2 of the aforementioned test procedure.

E_{CM} is the total charger input energy (charge and maintenance energy) accumulated over the entire duration of the charge test and is measured in watt hours.

Small Battery Charger Standard

The small battery charger standard shall take effect in 2012.

For all *small battery charger systems*, E_{CM} shall not exceed $12 + 1.6E_b$ (units in Wh), where E_b is measured energy capacity of the battery. This is equivalent to

$$Efficiency \geq \frac{E_b}{(12 + 1.6E_b)}$$

The maintenance power for all *small battery charger systems* shall not exceed 0.5 watts. The no battery power for all *small battery charger systems* shall not exceed 0.3 watts.

For all *small battery charger systems,* if the peak ac input current exceeds 1 amp in charging, maintenance or no battery mode, then the power factor in that mode shall either (a) be at least 0.55, or (b) be at least 0.50 at both 115 V, 60 Hz and 230 V, 50Hz.

Note: If not reported, the peak current shall be calculated as

$$I_{peak} = \frac{(InputPower * CurrentCrestFactor)}{(InputVoltage * PowerFactor)}$$

In addition, if ac rms input current exceeds 1 amp in charging, maintenance, or no battery mode, then the power factor shall be at least 0.90 in that mode.

Note: The rms input current shall be calculated as:

$$I_{rms} = \frac{InputPower}{(InputVoltage * PowerFactor)}$$

For *emergency exit signs*, E_{CM} shall not exceed $20 + 1.6E_b$ (units in Wh), where E_b is measured energy capacity of the battery. This is equivalent to

$$Efficiency \geq \frac{E_b}{(20 + 1.6E_b)}$$

The maintenance power for all *emergency exit signs* shall not exceed 0.8 watts.
The no battery power for all emergency exit signs is not applicable as these products do not have a no battery mode.

Inductive chargers may either meet the *small battery charger systems* requirements, or the following alternative requirement:

E_{CM} shall not exceed the product of 1.0 watts and T_{CM}, where T_{CM} is defined as the total time duration of the charging test (at least 24 hours).

The maintenance power for all *inductive chargers* shall not exceed 1.0 watt.
The no battery power for all *inductive chargers* shall not exceed 1.0 watt.

Large Battery Charger Standard

Tier 1:

Tier 1 shall take effect in 2012.

For *large battery charger systems* the charge return factor, C_{RF}, shall be $1.05 \leq C_{RF} \leq 1.15$ for 80% and 100% depth of discharge.

For 40% depth of discharge the charge return factor shall be $1.05 \leq C_{RF} \leq 1.20$.

The average maintenance power for *large battery charger systems* shall not exceed 75 watts.

The average no battery power for *large battery charger systems* shall not exceed 20 watts.

The power conversion efficiency for *large battery charger systems* shall be greater than or equal to 84%.

The power factor for *large battery charger systems* shall be greater than or equal to 0.85.

Tier 2:

Tier 2 shall supersede Tier 1 in 2013.

For *large battery charger systems* the charge return factor, C_{RF}, shall be $1.05 \leq C_{RF} \leq 1.10$ for 80% and 100% depth of discharge.

For 40% depth of discharge the charge return factor shall be $1.05 \leq C_{RF} \leq 1.15$.

The average maintenance power for *large battery charger systems* shall not exceed 10 watts.

The average no battery power for *large battery charger systems* shall not exceed 10 watts.

The power conversion efficiency for *large battery charger systems* shall be greater than or equal to 89%.

The power factor for *large battery charger systems* shall be greater than or equal to 0.95.

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Appendix A: Grouping of Battery Chargers

Consumer	Non-Consumer
Auto/Marine/RV	***Emergency Backup Lighting***
Marine Chargers	***Handheld Barcode Scanners***
Auto/RV Chargers	***Lift-Trucks***
Cell Phones	***Commercial Two-Way Radios***
Cell phones	
Cell phone accessories (Bluetooth headset)	
Cordless Phones	
Emergency Systems	
Power (uninterruptible power supply)	
Security (security system)	
Golf Carts/Electric Carts	
Golf carts	
Neighborhood electric vehicles (NEV)	
Laptops	
Lighting	
Lanterns	
Flashlights	
Personal Care	
Oral Care (rechargeable toothbrush)	
Hair Trimmers/Clippers (beard trimmer)	
Shavers (men's and women's shavers)	
Personal Electric Vehicles	
Electric wheelchairs	
Electric scooters	
Portable Audio Electronics	
iPods, MP3 players	
Portable CD players	
Portable Electronics	
Toys (remote controlled car)	
Video (digital camera, video camera)	
Consumer two-way radios	
Power Tools	
Electric House Wares (cordless vacuum, fan)	
Outdoor Appliances (lawn and garden tools, lawn mower)	
Power Tools (cordless drills, saws, screwdrivers)	
Universal Battery Chargers	

Appendix B: Power Factor Discussion and Calculation Methodology

The proposed battery charger standards include requirements for a minimum power factor for some chargers. This section explains the rational for those requirements.

Many battery chargers draw their input power in brief, high current spikes. These high current spikes lead to significant I^2R losses in the wiring upstream of the plug. The purpose of the power factor requirements is to minimize unnecessary upstream energy losses. The requirements will also improve power quality by reducing voltage drops and keeping the grid supply closer to a true sinusoidal waveform. These power quality benefits are considered incidental; the primary purpose is to reduce energy waste.

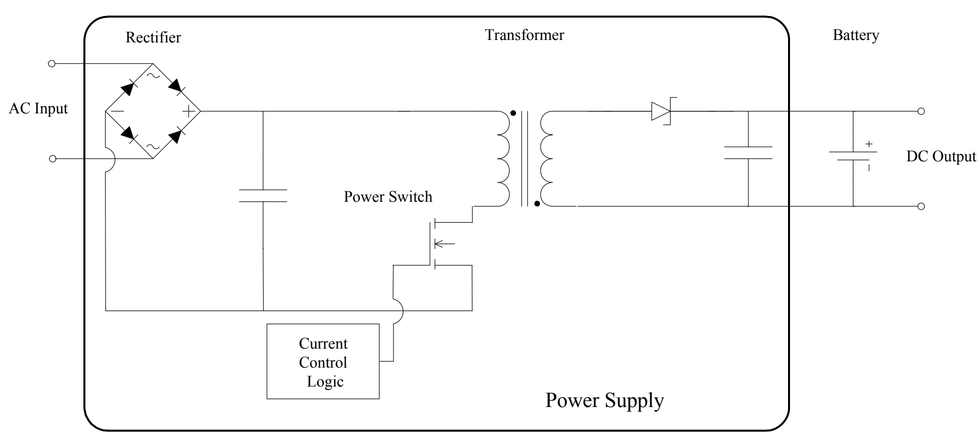
The following issues are considered here:

1. The nature of battery charger design which creates current spikes.
2. A simple estimation of the upstream energy losses this causes.
3. Design options which improve power factor and reduce upstream losses.
4. The rationale for the standards and expected improvements.

Power Factor Problems in Battery Chargers

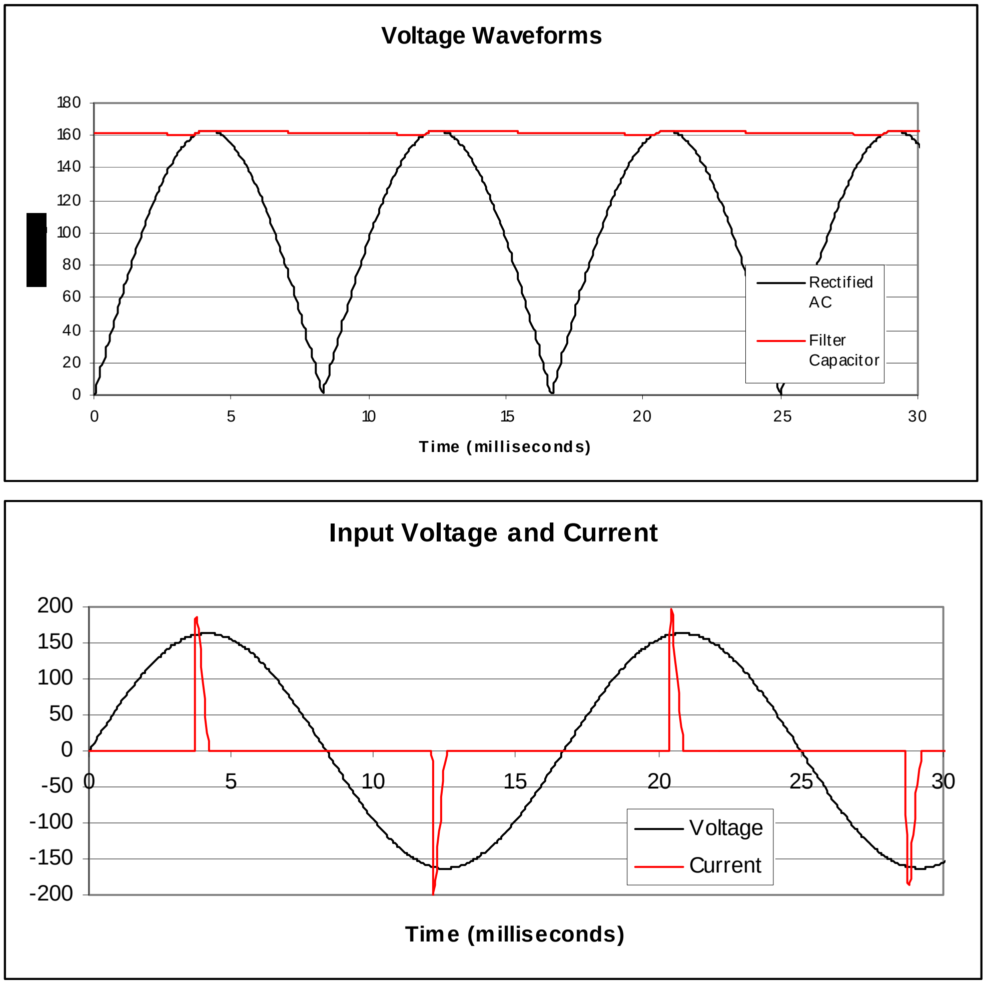
This simplified circuit diagram shows the key components in a typical switch mode battery charger. Figure B1 shows the fly-back configuration, but exactly the same issues arise for the buck or boast configurations as well.

Figure B1: Simplified Switch Mode Power Supply Schematic



The bridge rectifier diodes conduct current during a brief interval in each half cycle when the input voltage exceeds the voltage of the input filter capacitor. This interval is often short, a few hundred microseconds. Typical waveforms are shown in Figure B2.

Figure B2: Waveforms for Switch Mode Power Supplies



Since all the power for the charger is drawn during this brief interval, the current is quite high. For example, one power tool battery charger draws 229 watts at 115 volts. One would expect this to require about 2 amps (229W/115V=1.99A). The actual peak current is nearly 23 amps.

Estimates of Energy Loss

Most of the energy loss is in the distribution wiring between the breaker box and the outlet (1). For example, 100-foot run of 14/2 copper Romex wire has a resistance of about 0.5ohms. This length is typical for commercial buildings and not unreasonable for larger residences.

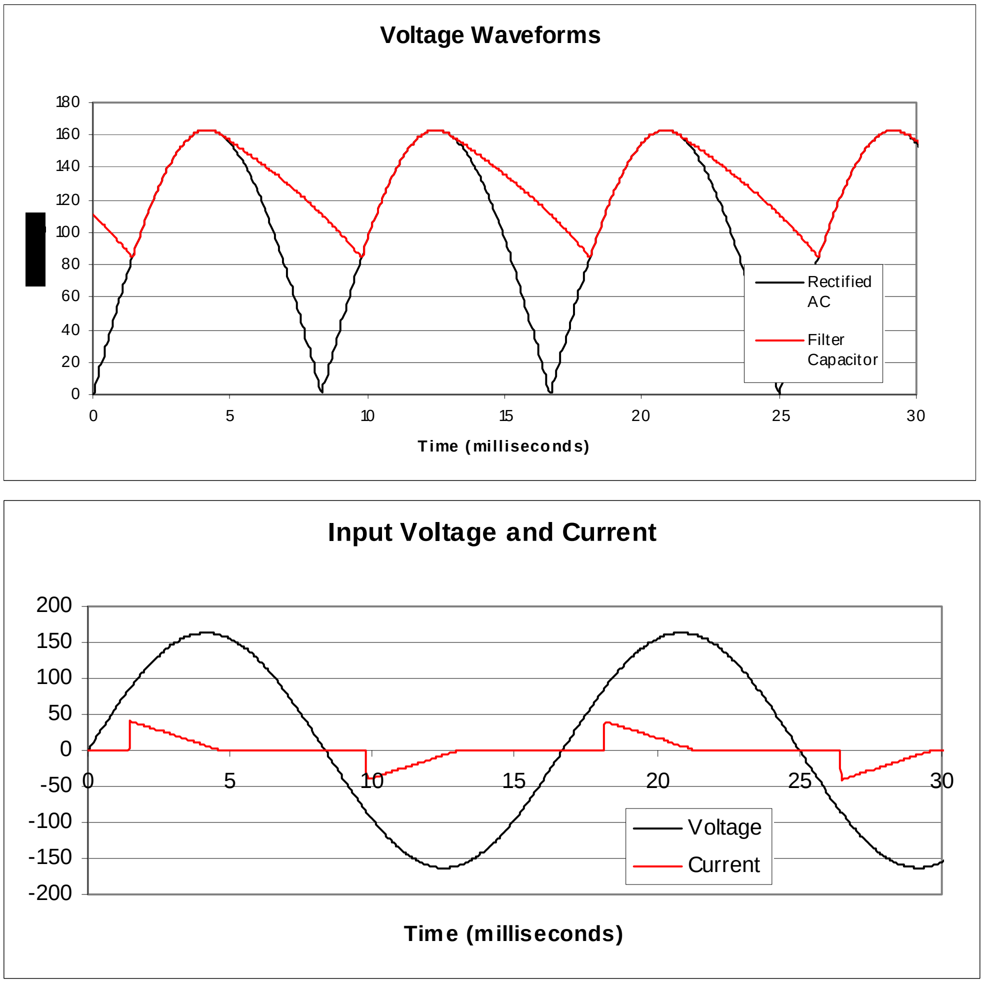
Most homes will have a number of battery chargers and also other electronics with switch mode power supplies on the same circuit. Unfortunately, all the switch mode supplies have their current peaks at the same moment, synchronized with the peak of the ac waveform. Thus, all the peak currents should be totaled to get the losses on each circuit.

With multiple devices on a circuit, the peak currents can easily be 20 to 30 amps during time of heavy usage. The I^2R resistive losses would be 200 to 450 watts. These peaks have a rather small duty cycle, so the average power loss on a circuit may be 10 to 30 watts. Fortenbery and Koomey (Fortenbery and Koomey 2006) measured losses of 11 to 57 watts per circuit for computers in commercial settings. Considering a few circuits per household and several hours per day of heavy use, the total energy loss in California is probably between 500 and 2,000 GWh/yr. This could be reduced by 50% to 80% if all the devices were power factor corrected. Improved battery charger efficiency (even without improving power factor) will result in savings due to the lower total current being drawn. These savings are expected to be 50 to 200 GWh/yr.

Techniques to Improve Power Factor

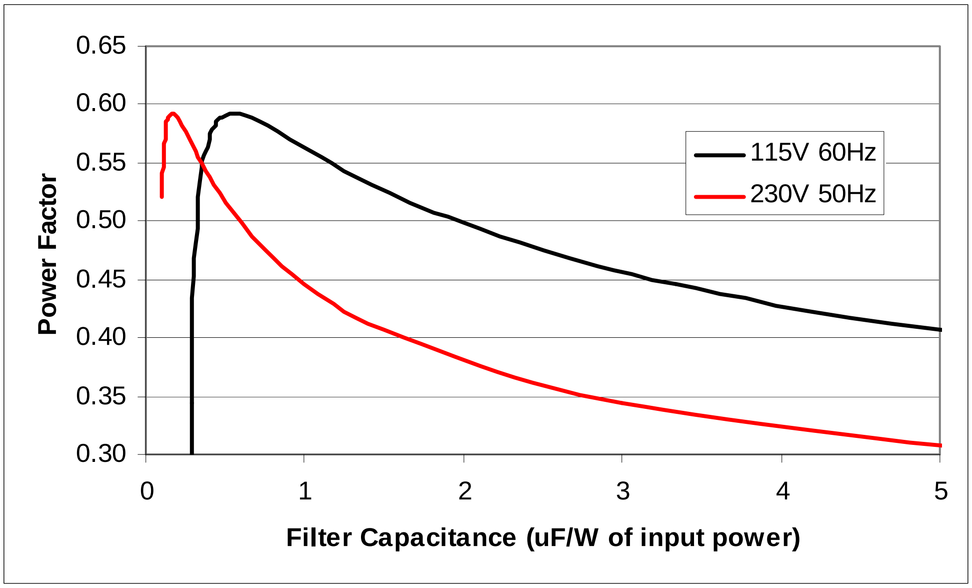
Two simple techniques to improve power factor are considered here. The first is simply careful selection of the filter capacitor. If we use a smaller capacitor and allow more ripple voltage on the capacitor, the rectifier will conduct for a longer time, resulting in lower peak currents. Ripple voltage is a problem for linear power supplies, but not for switch mode supplies. The resulting waveforms are shown in Figure B3.

Figure B3: Switch mode waveforms with improved power factor



One can calculate the power factor as a function of the filter capacitor, with the result shown in Figure B4.

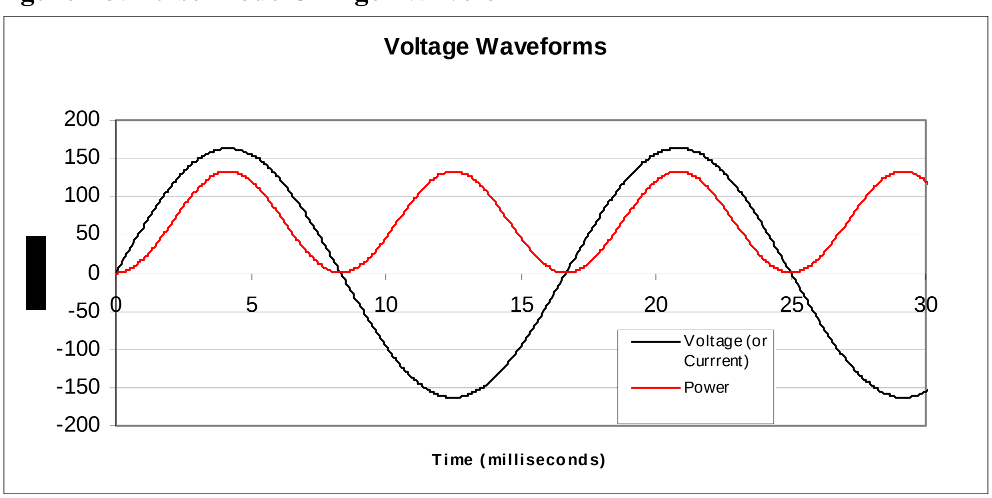
Figure B4: Optimum Filter Capacitor Selection



As can be seen, a power factor of 0.59 is easily possible. Since many of the battery chargers tested have power factors as low as 0.35, it is likely that this design option is not being used consistently. It should actually cost a few cents *less* to use a smaller filter capacitor, so we believe this technique should be widely encouraged for even the smallest battery chargers. The optimum value for the capacitance is 0.55 uF/W for 115V operation (pf=0.592) or 0.36 uF/W for 115V/230V chargers (pf=0.547 for either input voltage).

The second technique considered is to use 120 Hz pulse mode charging. The goal here is to achieve a power factor near unity. A unity power factor means that the load appears resistive and the input current is proportional to the input voltage. The input power should be 120 Hz sine-squared pulses. These waveforms are illustrated in Figure B5.

Figure B5: Pulse Mode Charger Waveform



If one were constructing a regulated dc supply, one would need an energy storage device (usually a capacitor) to store energy from the peaks for delivery during the valleys. This would require a two stage power supply, one stage to charge the capacitor according to the input power waveforms and a second stage to regulate the delivered power. However, for a battery charger, the battery itself can be the energy storage device. One simply delivers energy to the battery in 120 Hz pulses. Many linear mode battery chargers already use 60-Hz or 120-Hz pulses from rectified but unfiltered ac.

To achieve 120-Hz pulses with a switch mode supply, one uses the same circuit as shown in Figure B1. The input filter capacitor should be quite small, so it provides a return path for the high frequency switching current but gives negligible filtering at 120Hz. The control component is designed to deliver 120-Hz pulses instead of constant dc charging current. Controller ICs for power factor corrected battery chargers using this strategy are currently available and cost about the same as non-corrected controllers. (One example is the NCP1651 from ON Semiconductor.)

The proposed standard is a two step standard using the following levels. These standards would apply separately to each mode. In practice though, usually only the charging mode draws enough current to be of concern.

Battery chargers with a peak input current of less than 1 amp (at 115V 60Hz) would not be subject to power factor requirements. However, given the simplicity of the first method for power factor improvement, manufacturers are encouraged to voluntarily raise the power factor to .55 or better in charging mode. About 90% of existing products are in this category. The savings that could be obtained by mandating power factor improvement are probably less than 1 kWh/yr per device.

Battery chargers with a peak input current of 1 amp or more (at 115V 60Hz) in any mode would be required to meet one of the following two requirements:

1. Have a power factor of at least 0.55 at 115V 60Hz, or
2. Have a power factor of at least 0.50 for both 115V 60Hz and 230V 50Hz.

The second option allows manufacturers to make a single device for international markets that provides reasonable power quality on any grid. This requirement is expected to cost nothing to implement and is estimated to save from 25 to 100 GWh/yr of losses in the distribution wiring (Fortenbery and Koomey 2006).

Battery chargers with an rms input current of 1 amp of more (at 115V 60Hz) in any mode must have a power factor of 0.90 or better and a current crest factor not exceeding 2.20 in that mode. This requirement will apply to perhaps 2% of battery chargers, only those that draw more than 50W. Again, this requirement can be met with no additional cost and no loss in efficiency. The savings are estimated to be between 20 and 70 GWh/yr.

The savings estimates given here are quite approximate. Further research into typical distribution wiring layouts, appliance placement, and waveforms is recommended. This would allow for more precise estimates and indicate other opportunities for energy savings. But even this level of analysis is sufficient to show that the power quality requirements will provide cost effective energy savings and should be included in the battery charger standards.

More details of the energy savings estimates

The energy estimates are a simple "back of the envelope" calculation which gives only a very rough estimate of the energy losses. A more detailed study would look more carefully at the distribution of products on various circuits, the amount of time with coincident modes, and the details of the current waveforms. But even with very simple assumptions for these quantities, we can get an estimate.

The annual energy consumption of household battery chargers in California is about 3000 GWh/yr. This does not include golf carts, lift-trucks, or other large battery chargers. Battery chargers represent about 20% of household electronic plug load consumption, so total electronic load is about 15,000 GWh/yr. Each household has several circuits in the breaker box, but usually only 2 to 5 of them power plugs. Assuming that 3 circuits get most of the electronic loads in each of 12.7 million households, we assume 38 million circuits. From this we get the energy consumption per circuit of 395 kWh/yr/circuit (=15000GWh/38M). Next we assume that most of the energy is drawn during a time of coincident use of 3 hours per day (1100hours/yr). Dividing 395 kWh / 1100 hours gives 359 W drawn during use.

The next step is that a very large number of switch mode power supplies for battery chargers and other products have a power factor of 0.3 to 0.5. Using 0.4 as typical we can compute the rms current as

Irms = Power / (Voltage * pf) = 359 W /(115V * 0.4) = 7.8 Amps

Assuming a 100-foot run of 14/2 Romex with 0.5 ohms resistance, the power lost in the wiring is per circuit:

P lost = (Irms)^2 * R = (7.8)^2 *0.5 = 30.4 W

Multiplying this back by 1100 hours and 38 M circuits gives an annual energy loss of 1270 GWh/yr. The energy estimate would be larger if we considered if our model included the fact that some circuits carry more current and some less. The estimate would be lower if we considered that use may not be coincident, that different waveforms are not truly additive, and that many circuits may be shorter than 100 feet. All told, an educated guess of the uncertainty leads us to state a range of 500 –2000 GWh/yr.

The next question is how much of this power can be saved by improving just battery chargers, while leaving all the other loads unchanged. First, let us consider improving the battery charger efficiency with no change in the power factor. Assume we reduce the battery charger energy consumption by 67% to 1000 GWh/yr, while other loads remain at

12000 GWh/yr. Following the same calculations as above, we get that an "average" circuit has an rms current of 6.76 amps (=13000GWh/(38M*1100hr*115V*0.4pf)) during use and the total energy lost is 955 GWh/yr (=6.76A^2*0.5ohm*1100hr *38M), a savings of 316 GWh/yr. Again, we have estimated an uncertainty and give a range of 100 - 400 GWh/yr.

Now, assume that the 1% of chargers that draw more than 1 amp rms actually use 25% of the 1000 GWh/yr (250 GWh/yr). These will have a power factor of .9 while the remaining 12750 GWh/yr of electronic loads plus smaller chargers remains at 0.4 power factor. The "average" circuit will have a current of 6.63 amps rms (=12750GWh/(38M *1100hr*115V*0.4pf)) from the pf=0.4 loads and 0.06 amps rms (=250GWh/(38M *1100hr*115V*0.9pf)) from the pf=0.9 battery chargers.

But because these currents have different waveforms, the rms currents cannot be added. We will assume that the composite waveform the pf=0.4 loads is a rectangular pulse. For a rectangular pulse with a duty ratio of "d", the power factor is sqrt(2*d) and the current crest factor (peak /rms) is 1/sqrt(d). For pf=0.4, we calculate that d=0.08 and cf = 3.54. Almost all the energy lost is lost during the brief, high current pulses, so we want to know the peak current.

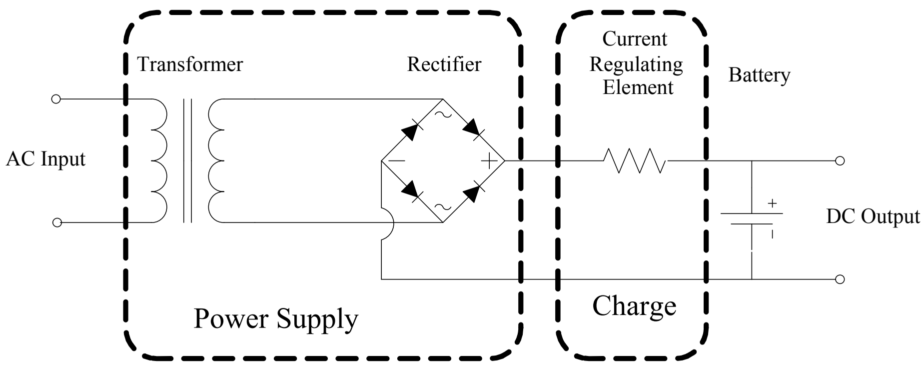
For the pf=0.4 loads, we get the peak current is 23.47 amps (=6.63 Arms*3.54cf). The pf=0.9 loads (which have nearly as sine wave current) add 0.08 amps peak (=0.06 Arms*sqrt(2)). The total peak current is 23.56 amps (=23.47+0.08), giving a peak power loss of 277 watts (=23.55A^2*0.5ohm). With a duty ratio of 0.08, this is 22.16 W average (=277W*0.08dr). Again, multiplying be the number of hours of use and the number of circuits give a total energy loss of 926 GWh/yr (=22.16W*1100hr*38M). This is a savings of 29 GWh/yr from the 955 GWh/yr with no power factor improvement. Again, we include the uncertainty and state a range of 20 – 70 GWh/yr.

Now we add the further case of chargers between 1 amp peak and 1 amp rms. Assume these chargers (about 10% of the total number) consume 500 GWh/yr and will have a power factor of 0.55. They contribute 0.19 amps rms (=500GWh/(38M*1100hr*115V *0.55pf)) our "average" circuit. A power factor or .55 implies a duty cycle ratio of 0.15 and a crest factor of 2.58. Thus, these chargers contribute 0.49 amps (=0.19Arms*2.58cf) to the peak current. With 12250 GWh/year remaining at pf=0.4, the current of these is 6.37 amps rms (=12250 GWh/(38M*1100hr*115V*0.4pf)) or 22.55 amps peak (=6.37 Arms *3.54cf). Our total peak current has been reduced to 23.12 amps (0.082 + 0.49 + 22.55) and gives an energy loss of 894 GWh/yr (=23.12A^2*0.5ohm*0.08dr*1100hr *38M). This saves an additional 32 GWh/yr (from the 926 GWh/yr above), and again a range of 25 – 100 GWh/yr is used.

Appendix C: Battery Charger Topology Discussion

Linear chargers typically consist of a step down transformer and a rectifier. The transformer lowers the ac input voltage to a voltage manageable by the rectifier, and provides electrical isolation between the grid and the charging system. In Figure C1 below a full wave bridge rectifier is depicted with a resistor to regulate the current flowing into the battery. This type of battery charger uses a passive charge control element. Excess energy not delivered to the battery is lost through the resistor as heat.

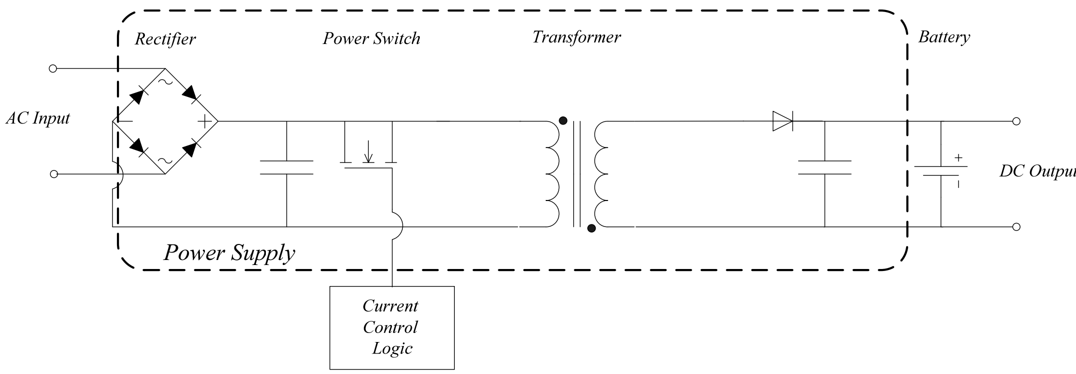
Figure C1: Linear battery charger using resistor to regulate output current



Characteristics of this type of charger are high maintenance mode power, voltage variance that can cause battery heating and premature battery degradation, and battery overcharging. These designs are common to power tools, cordless phones, and other relatively inexpensive battery powered products with batteries not sensitive to overcharge. Linear battery chargers are an older, less expensive technology that is also relatively inefficient. 24-hour efficiencies of linear chargers in consumer products measured by PG&E's consultant Ecos range from 2%-35% (Geist, Kameth et al. 2006).

Switch mode battery chargers function by converting high voltage ac to high voltage dc through the use of a rectifier and input capacitor. After this conversion, the dc voltage is lowered through the use of a switching control device, typically a transistor. The transistor-based switching circuit (shown in Figure C2) is used to precisely control the current and voltage to the battery (Geist, Kameth et al. 2006).

Figure C2: Single stage switch mode charger using a transistor to control charging current



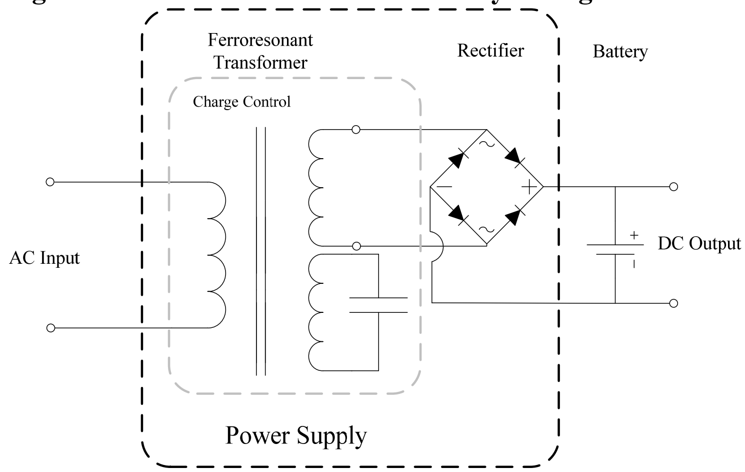
Some switch mode chargers can provide precise charge control (no overcharging), high charge efficiencies, and low battery maintenance power. Switch mode battery chargers range in sophistication from single stage chargers used for cell phones to multistage fast chargers used for lift-truck batteries. They are most common in laptop computers, cell phones, and other small portable electronics. Switch mode technology is used in battery charger systems with batteries that are intolerant of overcharging and is well suited for control systems to enable “smart charging” that is often employed in higher cost products. System efficiency of switch mode battery chargers typically ranges from 40% to 70% (Geist, Kameth et al. 2006).

Ferroresonant battery chargers are the most durable and widely used battery charger for industrial applications. They are composed of a transformer and a tank circuit that resonates at the designed ac input frequency to provide a flux regulated circuit. The capacitor in parallel with the inductive winding of the transformer creates a resonance at the specific ac input frequency. Then the current through the winding and the voltage on across the capacitor dictates the amount of flux through the transformer. Thus, the voltage and current delivered to the battery are limited as a function of flux. See Figure C3 for the circuit diagram.

Even the most modern ferroresonant charger are limited in power conversion efficiency to approximately 86% because of eddy current and magnetic saturation heating losses in the transformer core.

Hybrid, also know as controlled ferroresonant, battery chargers use a switching circuit in place of the capacitor in the tank circuit to optimize the resonances and reduces losses in the transformer core. Power conversion efficiency can be increased to approximately 89% with this change and charge return factor can also be improved.

Figure C3: Basic Ferroresonant Battery Charger



SCR battery chargers are also very popular in industrial applications because of their low cost and durability. SCR battery chargers are high powered cousins to typical switch mode battery chargers. A silicon controlled rectifier (SCR) is used to regulate voltage and current to the battery. SCRs are a mature technology that is able to withstand high power applications. They are limited in power conversion efficiency by switching losses. This is primarily due to the fact that they have a significantly limited frequency at which they can switch.

SCR's (Figure C4) are being steadily supplanted by high frequency, insulated gate bipolar transistor (IGBTs), because IGBTs have significantly lower switching losses and can obtain power conversion efficiencies as high as 92%.

Figure C4: Basic SCR Battery Charger