Beyond Power Supplies: Addressing Battery Charger Systems as the Second Common Denominator in Electronic Products

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ABSTRACT

Today, over 1 billion electronic products that contain battery chargers are currently in use in America's homes, offices, retail stores, medical facilities, and warehouses. Bar code scanners, electric fork lifts and carts, cordless and cellular phones, and cordless appliances and tools are all examples of products that rely on battery charger systems. These products offer substantial economic and environmental advantages over those with throwaway batteries and are more convenient than corded products. However, each rechargeable product contains an ac-dc power supply, battery charging circuitry, and low voltage electronics that together consume widely varying amounts of electricity in no-battery, battery maintenance, and charge modes.

Efforts to improve the efficiency of ac-dc power conversion in these devices have already begun to yield significant energy savings; however, more savings could be gained by addressing the efficiency of the battery charging process as well. Like ac-dc power supplies, this approach eliminates the need to separately consider the varying functionality of each product type. By addressing the battery charger subsystem as another common denominator, it is feasible to develop shared technical and policy approaches for a wide array of battery-powered products.

This paper will highlight opportunities to improve the efficiency and reduce the overall energy use of battery charging systems. Specifically, we will review research conducted for the California Energy Commission, which includes:

- Technical and market trends
- A summary of the standardized test method and efficiency data collected
- Estimates of battery charger energy savings potential
- Policy recommendations for market transformation to high efficiency battery chargers

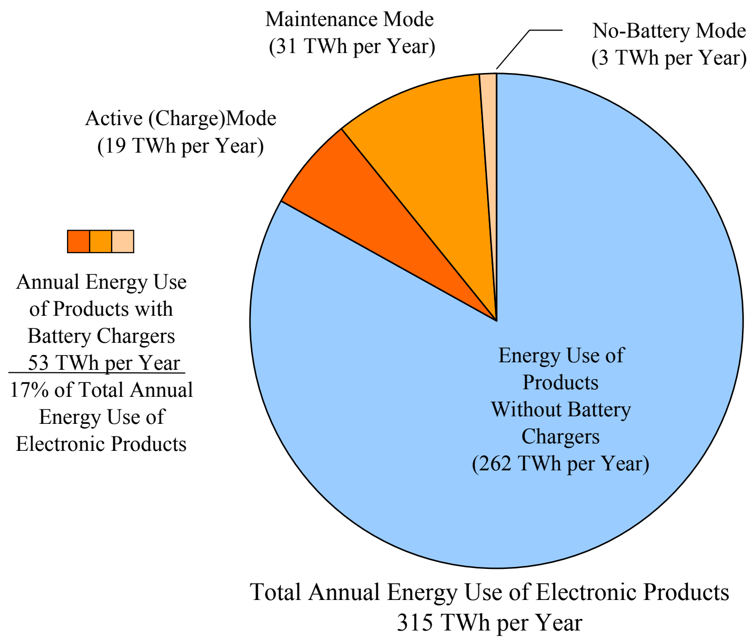
Introduction

In the last two decades, battery charger systems have become integral to many products that were formerly only available as corded models. There are now more cell phones in use than land-line (corded) telephones (Robb 2006). Construction contractors rely on powerful cordless drills and saws, which offer improved convenience over older models that required cumbersome extension cords. This trend toward portable devices, which has increased consumer convenience, has also introduced a proliferation of products into the marketplace that contain rechargeable batteries. We estimate that over 1 billion rechargeable battery systems are currently in use in homes, businesses, retail stores, medical institutions around the country (Herb Forthcoming).

A number of trends indicate that as wireless information technology improves, more cordless battery powered products will be introduced:

- Shipping companies are incorporating the use of GPS enabled cell phones to track their fleet (Robb 2006).
- Commercial/industrial warehouses and medical facilities are increasingly employing portable scanners to track inventory, and in the latter case, patients (Herb 2006).
- Increased distribution of WiMax technology worldwide is enabling digital information devices (e.g., BlackBerry) to operate in more locations (Maloney 2006).
- The number of laptops in use in the U.S. continues to grow at a remarkable pace. Units installed in homes and offices increased by 25 million (43%) from 2004 to 2005 (Consumer Electronics Association 2005).

Figure 1. Annual Energy Use of Electronic Products with Battery Chargers by Mode



Source: Ecos Consulting 2006

These trends suggest a growth in products that employ rechargeable batteries, but already battery charger system energy use represents nearly one-fifth of national electronics energy use,[1] with the majority of energy use occurring when the battery is charging (charge mode) and being maintained (maintenance mode) (Figure 1). Although less expensive to operate and better for the environment than primary, or throwaway batteries, these systems vary widely in their efficiency not only in charge and maintenance mode, but also when there is no battery installed (no-battery mode). Measurements of 13 low battery capacity (2.2 to 5.0 watt-hour) systems (e.g., AA battery chargers, hand-held vacuums, cellular phones, small cordless tools, etc.) revealed that the energy to charge and maintain the battery for 24 hours varied from 5.7 to 50.1 watt-hours, and when no battery was installed, the power drawn by devices ranged from 0.0 to 1.2 watts. We found a similar range in energy use for larger and smaller capacity battery chargers we tested (Blosser et

[1] The energy numbers presented here are meant to be a total of all sectors: residential, commercial, and industrial. Because we are less familiar with the industrial sector, it is possible that we have overlooked some of the energy consumption and savings potential in that market.

al. 2006). If these battery systems were improved, we estimate that the total savings could be worth 28 billion kWh per year nationally, or about 0.8% of national electricity use (Herb Forthcoming).

Battery chargers, like ac-dc power supplies, represent not only a large savings opportunity, but also a common denominator in the electronics market. Our research suggests that these products could be addressed with a single policy activity, much like the successful ENERGY STAR® external power supply voluntary specification and the external power supply mandatory energy efficiency standard in California. In order to enable this kind of policy action, we have developed a battery charger system test procedure, assembled a database on the efficiency of 195 battery charger systems, created preliminary estimates of the energy savings opportunity, initiated research into battery charger duty cycles, and lastly, developed an efficiency metric that could be used in future policy activity. Before we summarize our progress on all these aspects of research, we will explain the basics of battery charger system efficiency.

The Second Common Denominator—Battery Charger Systems

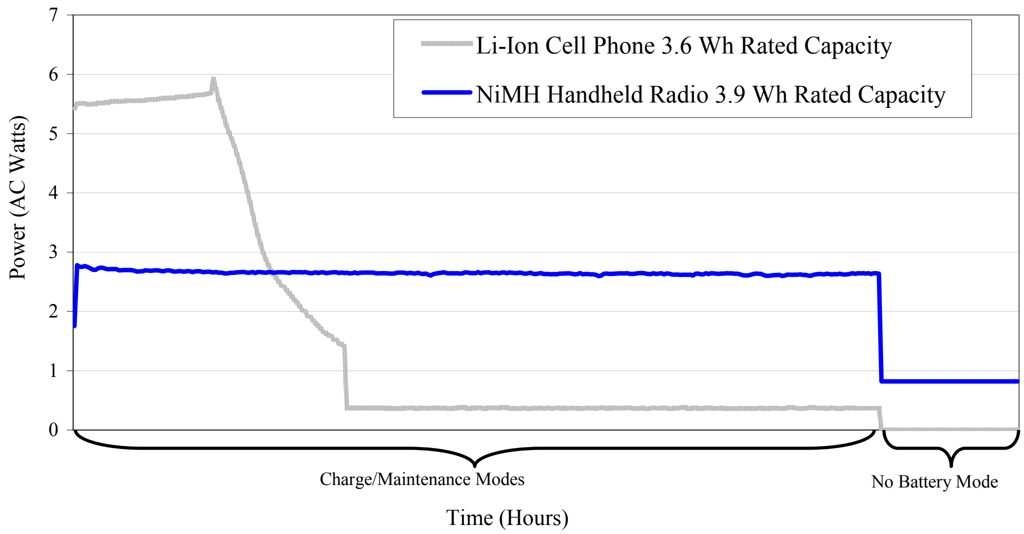
Battery charger systems take high voltage alternating current from the wall outlet and convert it into a form that common battery chemistries can accept as charge and maintenance current. This basic function is common to all battery charging systems, regardless if the battery powered product is a cordless shaver, an uninterruptible power supply (UPS), or an electric vehicle. Because approximately 50% of all electronic products surveyed in our research contain battery charger systems, improving the efficiency of these systems is second only to ac-dc power supplies as a key strategy in improving the efficiency of all electronic products (Foster et al. 2004). These battery charger systems have three basic components:

- A power supply that converts 120 volts ac to low voltage dc (either internal or external)
- Battery charging circuitry that controls the electric current going to the battery during charge and battery maintenance modes
- A battery; the most common chemistries are lead acid, nickel cadmium (NiCd), nickel metal hydride (NiMH), and lithium ion (Li-Ion)

Figure 2 below illustrates the charge, maintenance and no-battery mode levels for two common products of similar battery energy capacity. The battery charger system associated with the handheld radio (blue line) has an inefficient power supply (average efficiency 43%), and a NiMH battery that has a high rate of self-discharge. (Allowing these batteries to sit for a long time without maintenance current from the charger will result in a loss of energy stored in the batteries.) In this particular battery charger, the charge and maintenance modes are indistinguishable because the battery charging circuitry feeds the battery the same amount of current, regardless of the state of charge of the battery. This simple "charging solution," commonly found coupled with those batteries with high self-discharge rates (NiMH and NiCd), tends to overheat the battery and shorten the overall lifetime, but is less expensive to manufacturer than more sophisticated charging circuitry. Also notice that when this particular charger has no battery installed, it continues to draw a significant amount of power (0.8 watts).

In contrast, the other battery charger system in the chart, in this case associated with the cell phone (gray line), has an average power supply efficiency of 73% and employs a Li-Ion battery, whose self-discharge rate is so low that little battery maintenance is required (0.3W). Although not true for all Li-Ion battery charger circuitry, this charger intelligently turns off its power drawn from the wall once the battery is fully charged and when no battery is installed. This results in little power being drawn in the battery maintenance mode after the battery is fully charged and when the phone is disconnected from the charger.

Figure 2. Charge, Maintenance, and No-Battery Mode Power for Two Common Battery Charger Systems



Source: Ecos Consulting 2006

Because the cell phone charger employs a relatively efficient power supply, intelligent charge control circuitry, and a battery chemistry with low self-discharge, it is clearly a more efficient charger than the handheld radio charger. If we take the total energy that is extractable from the battery associated with the handheld radio system and compare that to the ac energy consumed over a 24-hour period, the efficiency is quite low, about 2%. In addition, the product consumes 0.8 watts in no battery mode. On the contrary, the charger associated with a cell phone refuels a battery with nearly identical energy capacity, but achieves 48% efficiency over the 24-hour test period. In addition, the second product's battery charging circuitry shuts off when the battery is not installed, resulting in less than 0.1 watts in no-battery mode. The significant efficiency differences between these two systems suggests that a large energy savings opportunity exists for the battery charger market more generally, but without a test procedure to measure a range of battery charger systems in a consistent and repeatable manner, it is difficult to determine with any precision the true energy savings opportunity.

Test Procedure and Efficiency Metric Development

Creating a Standard Test Procedure

In order to address battery charger systems as a single policy initiative and to enable fair comparison among products, we began development of a standard test procedure and efficiency metric. We used the following principles to guide the test procedure development process (Foster et al. 2004):

- Account for all relevant operational modes of a product (those with significant duration) in order to capture the full picture of energy consumption
- Specify conditions necessary to ensure repeatable energy measurement across test laboratories
- Engage industry throughout the development and revision process

Although another battery charger test procedure was developed by the U.S. EPA ENERGY STAR program (ENERGY STAR 2005), our research suggests this test procedure is not well suited for the wide scope of battery charger systems under consideration here. ENERGY STAR's test procedure covers a limited subset of battery charging systems, including only power tools, kitchen tools, garden tools, and personal care products (such as cordless shavers and toothbrushes). In addition, it only addresses the efficiency during battery maintenance and no-battery mode, ignoring the important energy savings opportunity in charge mode, which we estimate to represent 36% of all energy used by battery charger systems.[2] Lastly, the test procedure was developed without involvement from cell phone, laptop, portable radio, electric vehicle and cordless phone manufacturers, among others, and so its technical content does not necessarily represent the battery charger system industry as a whole.

When we originally began development of the battery charger system test procedure in 2003, we attempted to test charge, maintenance, and no-battery mode separately (Foster et al. 2003). One challenge with this approach is that it is difficult for a technician to definitively determine (via observation) the exact moment when a battery charger transitions from charge mode to maintenance mode. More importantly, some chargers maintain a steady-state power level throughout the charge and maintenance cycle, such that no transition ever takes place (see for example the handheld radio battery charger system in Figure 1).[3] So, with stakeholder input, we changed the approach to combine charge and maintenance mode in a 24-hour test. A 24-hour period was chosen because it ensured that the battery charger completed its charge sequence and entered into maintenance mode, but the test was not so long that it placed an undue cost burden on manufacturers. We retained the battery discharge test and the no battery test from the Preliminary Draft and have since been refining the document with stakeholder input to ensure repeatability through standardization of environmental conditions and specific battery chemistry test provisions (such as rest periods between tests), among other details. In summary, the major provisions of the current Draft 2 include (Foster Porter et al. 2006):

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

[2] Cadmus Group's analysis during the development of the ENERGY STAR specification suggests that for this subset of products, making efficiency improvements in maintenance mode could result in efficiency improvements in charge mode; however, additional data collection and analysis is needed to substantiate this indirect benefit.
[3] Battery charge algorithms vary widely depending on technology and market demands. For more information on charger design, see Geist, et al. 2006.

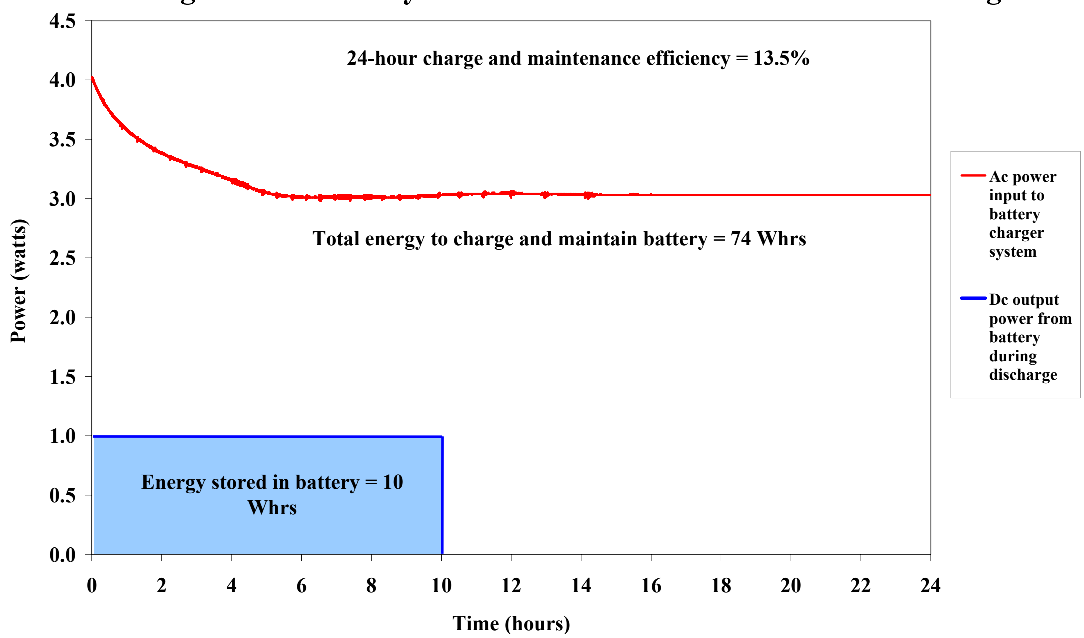
- **No-battery mode test**, where the power use of the charger is measured without the battery installed (measured in watts)

Battery Charger Efficiency Metric

With the standardized data outputs from the test procedure, it is possible to define a battery charger efficiency metric. Efficiency in general is defined as the functional performance of the product divided by the energy or power required to deliver that performance (Foster et al. 2004). Industry defines battery performance differently in different markets. For example, power tool manufactures tend to use battery voltage to market their products. In general, consumers receive higher battery voltage with higher cost products, yet higher battery voltage does not always yield better performance (Consumer Reports 2004). Alternatively, AA battery charger packaging usually reports charge capacity (in ampere-hours) to market AA chargers and to provide some indication of run-time for the consumer. Neither voltage nor charge capacity alone seemed to indicate performance of all battery charger systems, so we chose to consider the product of these two parameters through the discharge test to characterize battery performance.

Taking the product of the voltage, current and time during the course of a standard discharge (described in the test procedure) will yield the energy extractable from the battery. This extractable energy varies based on the battery configuration, chemistry, and manufacturer. For the 9.6 V power tool charger system in Figure 3 below, the amount of energy extracted is represented by the light blue shaded box (10 watt-hours).

Figure 3. Efficiency Measurements of 9.6 V Power Tool Charger



Source: Ecos Consulting 2006

The ac wall plug energy required to deliver that stored battery energy is equal to the ac energy from the wall outlet to charge and maintain that battery before it is used with its associated product, such as a cell phone, flashlight, or electric vehicle. The 24-hour ac energy consumed by the power tool charger in Figure 3 is approximately 74 watt-hours. This ratio of battery energy out of the system to ac energy into the system can be used to compare the efficiency of battery charger systems. In the case of the product measured in Figure 3, this efficiency is 10 watt-hours divided by 74 watt-hours, or approximately 14% efficiency over a 24-hour charge and maintenance cycle.

The 24-hour charge and maintenance efficiency metric approach addresses the useful service that the battery charger provides for the consumer when the battery is installed on the charger, while avoiding the technical difficulty associated with determining the difference between charge and maintenance mode. Yet, almost all battery chargers use energy when they remain plugged into a wall outlet with no battery installed. Although this is usually a small amount relative to the active and maintenance mode energy, it is easy to consider and could produce some savings. Power use (in watts) in this mode could easily be used to compare one charger to another.

We believe this 24-hour active maintenance efficiency metric coupled with a separate no battery mode power provision would be acceptable to the battery charger industry for two reasons. The 24-hour metric approach allows engineers to come up with the most cost-effective solution to reduce energy consumption in the charge and battery maintenance modes combined. This allows for efficiency trade-offs between modes that would not otherwise be possible with separate charge and maintenance mode efficiency levels. In addition, this metric approach is similar to the internationally successful and industry-accepted external power supply metric, where an active mode efficiency and no-load power were separately defined.

Battery Charger Data

In Table 1, we summarize the 24-hour charge and maintenance efficiency and no battery mode power of 195 battery chargers that were measured according to the standard test procedure. We, with our team partner EPRI Solutions, collected efficiency data on 62 products (Blosser et al. 2006). These data are coupled with other efficiency data collected as part of an ENERGY STAR specification development process. On average, battery chargers are 22% efficient over a 24-hour period in the charge and maintenance modes; the least efficient unit tested was 2% and the best efficiency recorded was 69%. Designs already exist to bring battery chargers between 50% and 70% efficient in the charge and maintenance modes, and consume little to no energy (0.1 watt) in the no-battery mode (Geist et al. 2006).

The Energy Savings Opportunity

With these measured data, it is possible to estimate the energy savings opportunity associated with improving battery charger systems. There are three key technical strategies for achieving efficiency gains:

- Improve the efficiency of the power supply
- Reduce battery maintenance mode power through better battery charging circuitry
- Migrate to a battery chemistry that requires little maintenance current

Because many of these battery charger systems are coupled with commodity products, like cordless phones and residential-grade power tools, not all efficiency-improvement strategies can be cost-effectively applied to all battery charger system types. Taking these market restraints into consideration, we have estimated the energy savings potential associated with all battery charger systems. The highlights of this investigation, summarized in Table 2 below, illustrate the large energy savings opportunity of nearly 28 TWh per year, the equivalent of 0.8% of annual U.S. electricity use.

Although we used a data set of 195 products to determine the power levels and efficiencies of most of the products surveyed, there is a lack of information on the way each battery charger system is used. To improve these duty cycle assumptions, we, with our team partner RLW Analytics, have undertaken a project to measure the way in which battery charger systems and other electronic products are used in California homes. Although these data are not currently available, the results of this study are expected to be out in late summer of 2006. We plan to incorporate these field measurements into our savings estimate for further refinement.

Table 1. Battery Charger Laboratory Data

Product Category	Count	Devices Tested in Charge Mode	Typical Chemistry	Efficiency Range on a 24-hour Charge/ Maintenance Cycle	Average Efficiency on a 24-hour charge cycle	No-Battery Mode Range	Average No-Battery Mode
AA Battery Charger	45	7	NiMH	2% - 16%	11%	0.18 - 3.09	1.10
Auto Battery	1	1	LA	NA	25%	NA	1.86
Camcorder	1	1	Li-Ion	NA	54%	NA	0.00
Camera	2	2	Li-Ion	13% - 56%	35%	0.00 - 1.16	0.58
Cordless Phone	5	5	NiCd/NiMH	3% - 7%	4%	0.98 - 3.06	0.04
DVD Player	1	1	Li-Ion	NA	42%	NA	1.39
Egress Lighting	1	1	LA	NA	30%	NA	1.46
Forklift	2	2	LA	28% - 40%	34%	13.41 - 50.32	31.87
Golf Cart	2	1	LA	NA	47%	NA	205.60
Laptop	3	3	Li-Ion	59% - 69%	64%	0.52 - 3.29	1.87
Lighting	1	1	LA	NA	34%	NA	1.00
Mixer, Cordless	1	1	NiCd	NA	7%	NA	0.50
Oral Care	3	3	NiCd	4% - 11%	7%	0.59 - 1.66	1.21
Power Tool	86	33	NiCd	4% - 54%	18%	0.00 - 10.95	2.50
Handheld Radio	1	1	NiMH	NA	2%	NA	0.82
RV Battery Charger	4	4	LA	22% - 28%	25%	26.28 - 69.66	49.31
Shaver	9	4	NiCd	4% - 13%	8%	0.00 - 0.67	0.31
Sweeper, Automatic	12	5	NiCd	11% - 26%	19%	0.00 - 3.45	0.92
Toys	4	2	NiCd	4% - 19%	12%	0.73 - 1.34	1.00
Wheelchair/Scooter	2	2	LA	26% - 33%	29%	16.27 - 49.05	40.52
Wireless Telephone	9	9	Li-Ion	24% - 64%	39%	0.00 - 0.94	0.08
Total	**195**	**89**					

Source: Ecos Consulting 2006 and Cadmus Group 2005

Table 2. Estimated Battery Charger System Energy Savings Potential

Device	Units in Use (Millions)	Total Annual Energy Use (TWh per year)	Annual Energy Savings from Improved External Power Supplies (TWh per year)	Annual Savings from Improved Battery Charging Systems (TWh per year)	Total Annual Savings Nationwide (TWh per year)
Cordless Phones	278	7.2	1.1	4	5.1
Stand Alone Battery Chargers (Marine)[4]	15	5.2	NA[5]	2.5	2.5
Uninterruptible Power Supply (Standby)	14	2.0	NA	1.8	1.8
Power Tools (Commercial)	45	3.6	NA	1.0	1.0
Other	1064	35.1	1.6	15.9	17.5
Total	**1,416**	**53.1**	**2.8**	**25.2**	**27.9**

Source: Herb Forthcoming

Policy Implications

This substantial energy savings opportunity suggests that policymakers, utilities, and other stakeholders would be interested in realizing some of the savings potential though mandatory and voluntary standards and market-based initiatives. To enable this type of action, we began development of a standard way to measure and compare the efficiency of battery charger systems.

The California Energy Commission and ENERGY STAR Program already encourage improvements in the efficiency of external power supplies through their mandatory standard and voluntary specifications, respectively. Smaller capacity battery charger systems, like cell phones and portable radios (e.g., Figure 2), have external power supplies and would be covered under these initiatives. Yet, battery chargers that employ internal power supplies use 70% of the total energy consumed by all battery chargers (Herb Forthcoming). Because they have internal power supplies, these larger scale chargers would not be covered by the external power supply initiatives. Even for products with external power supplies, like the portable radio battery charger system, more energy saving opportunities exist by simply improving the efficiency of the battery charger circuitry and the battery itself (Geist et al. 2006).

In addition, other products with battery charger systems are currently addressed with voluntary or mandatory initiatives to increase their efficiency (Table 3). We recognize that product-specific policy has been a good first step to improving the efficiency of a subset of products that employ battery charging systems, but a more comprehensive approach to battery chargers could have the following benefits:

- Collectively, the current approaches address products that use only 40% of energy consumed by all battery charger systems, and more energy savings could be achieved with a larger scope.
- Half of the initiatives listed below focus only on the low power modes of standby (no-battery) and battery maintenance. The ENERGY STAR specification for one of the largest energy users, the cordless phone, effectively sets a limit on the power use in

[4] These wall plug chargers charge on-board battery banks that power lights, instrumentation, etc.
[5] Not applicable because nearly all of these product types employ internal power supplies.

maintenance and no-battery modes. Additional opportunities exist to further reduce no-battery and maintenance modes and address charge mode.

- Five of the six initiatives listed below do not focus on the battery charging system itself, so no savings opportunities associated with the battery charging circuitry and the battery are captured.
- One policy approach for hundreds of products that contain battery charger systems is easier for policymakers to maintain. Rather than 10 metrics, specifications, test procedures, and programs for 10 distinct products, policymakers can operate and maintain one specification for tens or hundreds of products with one metric, one test procedure, and one program.

Table 3. Battery Charger Systems Energy Efficiency Initiatives

Scope	Effective Date	Agency	Metric and Levels[6]	Percent of Total Annual Energy Consumption by Battery Charger Systems in U.S.
Cordless telephones	January 2004	U.S. EPA ENERGY STAR	Limit on standby mode[7] power (based on technology type and configuration)	14%
Cordless power tools, kitchen appliances, garden tools, and personal care products	January 2006	U.S. EPA ENERGY STAR	Limit on non-active energy ratio (based on nominal battery voltage)	9%
External power supplies	January 2005	U.S. EPA ENERGY STAR	Limit on active mode efficiency and no-load power (based on nameplate output power)	33%
External power supplies	January 2007	State of California		33%
Laptop Computers	Expected effectiveness date: July 2007	U.S. EPA ENERGY STAR	Limit on standby, sleep mode, idle state, and power supply efficiency (same levels for all laptop products)	6%
Audio/DVD (not exclusively powered with batteries)	January 2003	U.S. EPA ENERGY STAR	Limit on standby mode (one level for all products)	<1%
Total: *note: external power supply scope overlaps significantly with the other policy measures				40%

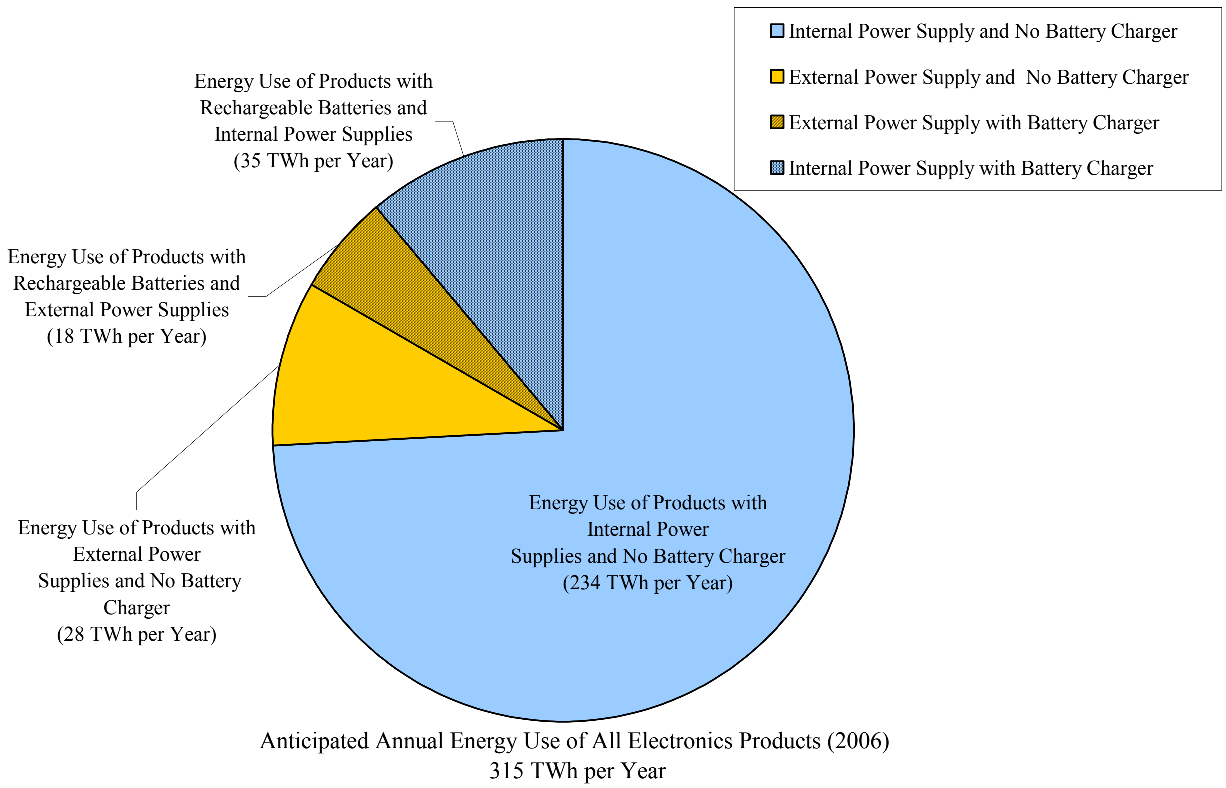
Source: Ecos Consulting 2006

The pie chart in Figure 4 gives our estimate of the annual energy currently consumed by all electronic products in the U.S. (Foster et al. 2005; Herb Forthcoming). This total, which is at least 9% of national annual electricity consumption, can be divided into the energy consumption of products with external power supplies (yellow: 15%) and the energy consumption of products with internal power supplies (blue: 85%). Battery chargers, which have both internal and

[6] For a definition of standby, see IEC 62301; for more details on the specifications, see www.energystar.gov and/or www.efficientpowersupplies.org.

external power supplies, represent nearly one-fifth of total electronic product energy consumption (gray: 17%). By adding a comprehensive battery charger initiative to the current policy initiatives for external power supplies, we have the potential to reduce battery charger energy consumption by over 40% (Herb Forthcoming). This could be achieved by setting efficiency levels for the 24-hour charge and maintenance efficiency and a power limit on no-battery mode.

Figure 4. Estimated Energy Use of Products with Battery Chargers

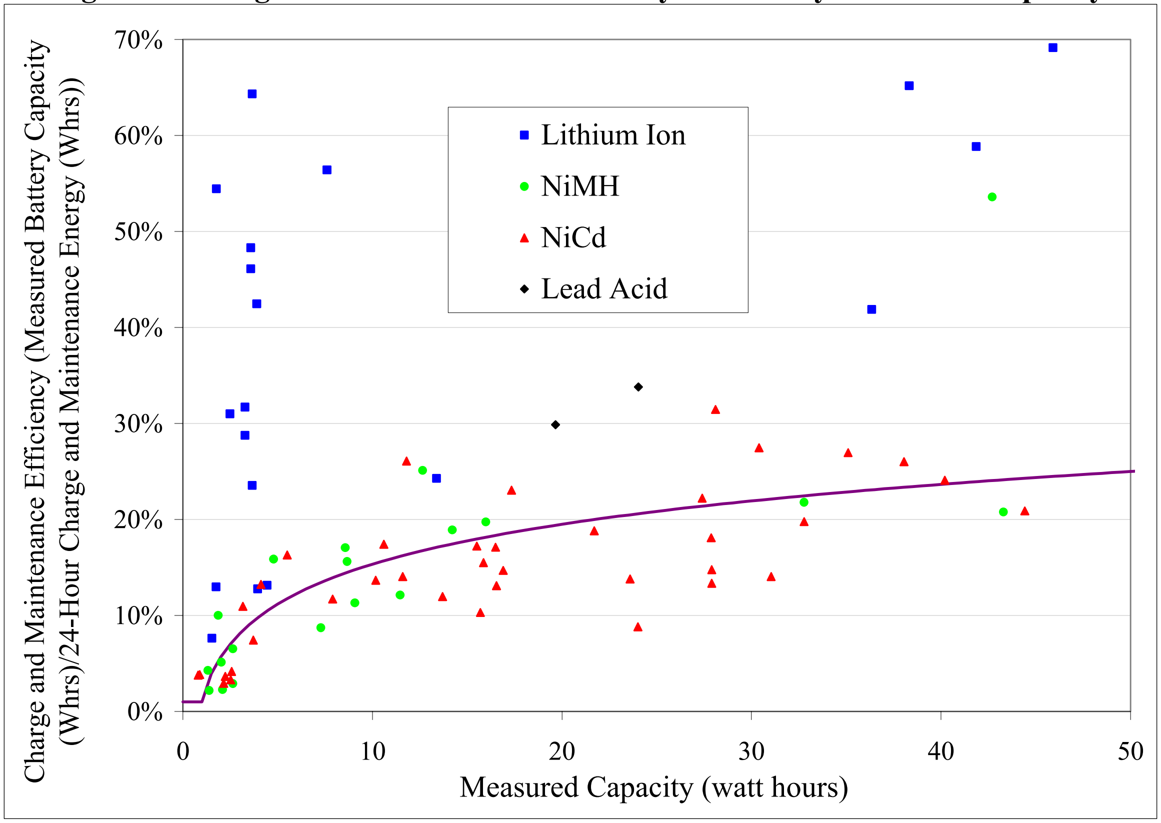


Source: Ecos Consulting 2006

Figure 5 below plots the 24-hour charge and maintenance efficiency against the measured battery capacity of all chargers in our data set. For any specific measured capacity, there is a range of charge and maintenance efficiencies. For example, at roughly 2.5 watt-hours, efficiencies vary from less than 5% to greater than 60%. It is possible that a line could be drawn through this data to indicate which products would be considered efficient for either a voluntary or mandatory program. We have drawn a hypothetical specification line to illustrate the concept. More product data needs to be collected before determining the exact shape or level of this 24-hour efficiency specification.

We have more data on no-battery mode power, which varies from nearly zero watts to roughly 11 watts, depending on the charger. Based on our technical research, this no battery mode power could be reduced to nearly zero (Geist et al. 2006). We propose that a flat specification line could be drawn to set an identical limit for no-battery mode for all battery chargers of all chemistries.

Figure 5. Charge and Maintenance Efficiency vs. Battery Measured Capacity



Source: Ecos Consulting 2006

Conclusion

Addressing the energy efficiency of battery charger systems is the next broad strategy to systematically reduce the energy consumption of electronics. We have removed some of the barriers of this approach by developing a near-complete battery charger energy efficiency test procedure, collecting and assembling data from a number of battery charger systems, estimating the energy savings opportunity, and analyzing these data to recommend an efficiency metric and policy approach. By building on the successful electronics initiatives of the ENERGY STAR program and the California Energy Commission, policymakers can further reduce the energy used by these products, without the complexity associated with product-specific policy approaches.

References

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

Cadmus Group 2005. "Battery Charger Data Spreadsheet." EPA ENERGY STAR.

Consumer Electronics Association 2005. "US Consumer Electronics Sales & Forecasts 2000-2005." Arlington, VA: Consumer Electronics Association.

Consumer Reports 2004. Cordless Drills: Power for Less. Consumer Reports. 69: 39-40.

ENERGY STAR 2005. "Test Methodology for Determining the Energy Performance of Battery Charging Systems." http://www.efficientproducts.org/reports/bchargers/ENERGY_STAR_Battery_Chargers_Test_Method.pdf

Foster Porter, S., H. Kameth, et al. 2006. "Draft 2 Energy Efficiency Battery Charger System Test Procedure." California Energy Commission.

Foster, S., C. Calwell, et al. 2004. If We're Only Snoozing, We're Losing: Opportunities to Save Energy by Improving the Active Mode Efficiency of Consumer Electronics and Office Equipment. ACEEE Summer Study 2004. Pacific Grove, CA, ACEEE.

Foster, S., C. Calwell, et al. 2005. "Power Supply Census." California Energy Commission.

Foster, S., A. McAllister, et al. 2003. "Proposed Test Protocol for Measuring the Energy Efficiency of Battery Charging Appliances." California Energy Commission. http://www.efficientpowersupplies.org/methods.asp

Geist, T., H. Kameth, et al. 2006. "Improving Battery Charger Efficiency: A Battery Charger Technical Primer."

Herb, K. 2006. "Battery Charger Market Characterization." Durango, CO.

Herb, K. Forthcoming. "2006 Battery Charger Energy Savings Analysis." Durango, CO: California Energy Commission.

Maloney, S. 2006. "Mobility Keynote." Presented at Spring 2006 Intel Developers Forum, San Francisco, March 7, 2006.

Robb, D. 2006. *Trends in Wireless Networking*. Accessed on March 16, 2006. Available online:http://www.smallbusinesscomputing.com/news/article.php/3591936.