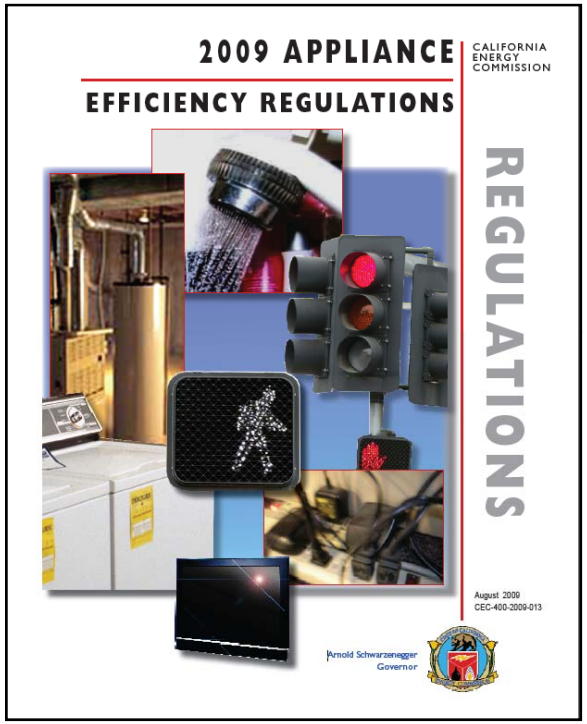

Proposed Title 20 California Efficiency Standards for Battery Charger Systems

March 3, 2011
California Energy Commission, Staff Workshop

Docket No. 09-AAER-2; RE: 2010 Rulemaking proceedings Phase II on Appliance Efficiency Regulations

Presentation by:
Suzanne Foster Porter and Philip Walters, Ecos

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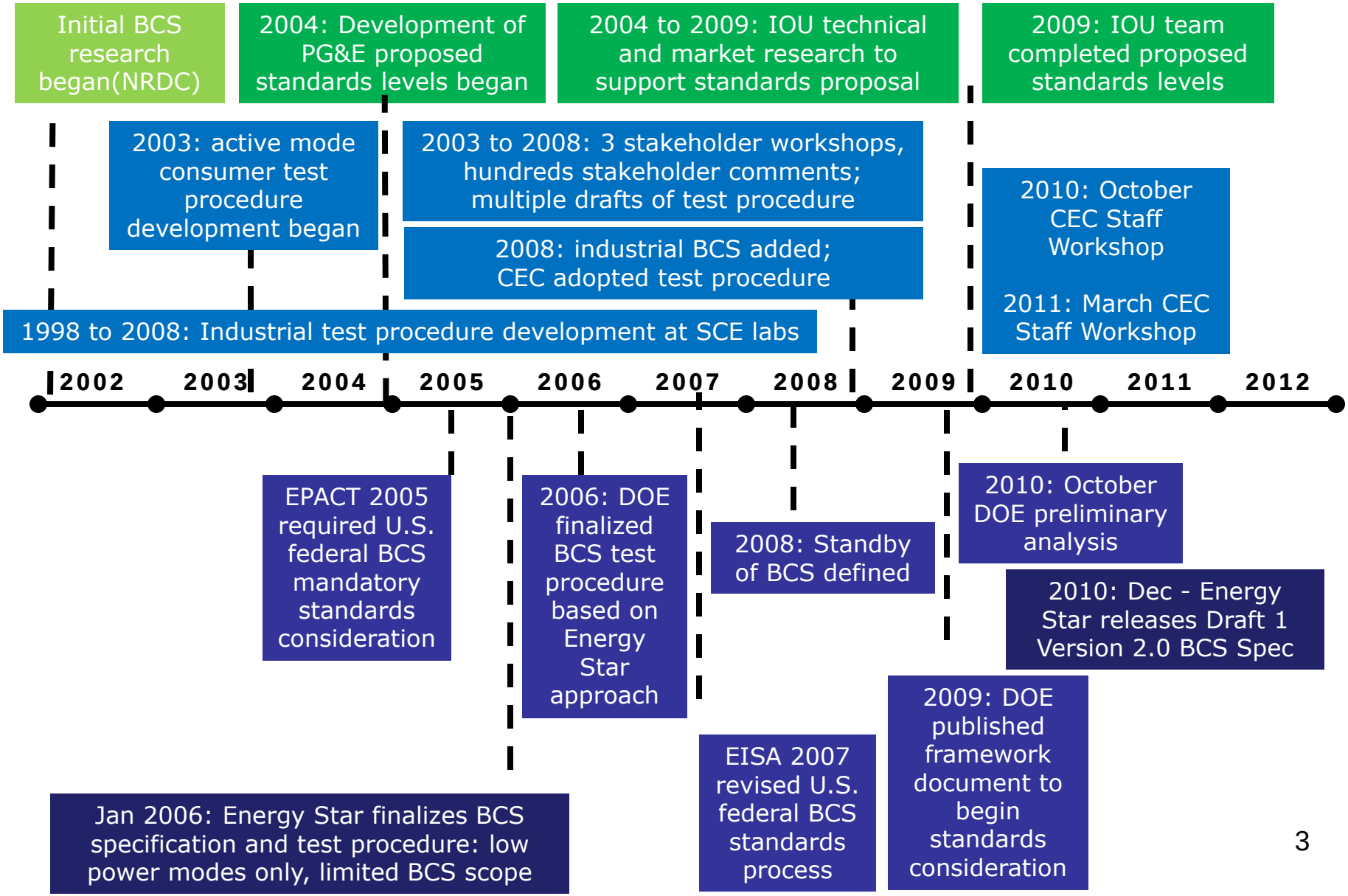
Acknowledgements

Thanks to the following institutions for technical contributions that made this work possible:

- Pacific Gas and Electric Company (PG&E) Applied Technology Services (ATS) Group
- California Energy Commission's Public Interest Energy Research Program (PIER)
- Southern California Edison (SCE)
- Electric Power Research Institute (EPRI)

California BCS efficiency efforts date back to 2002 (small) and 1998 (large)



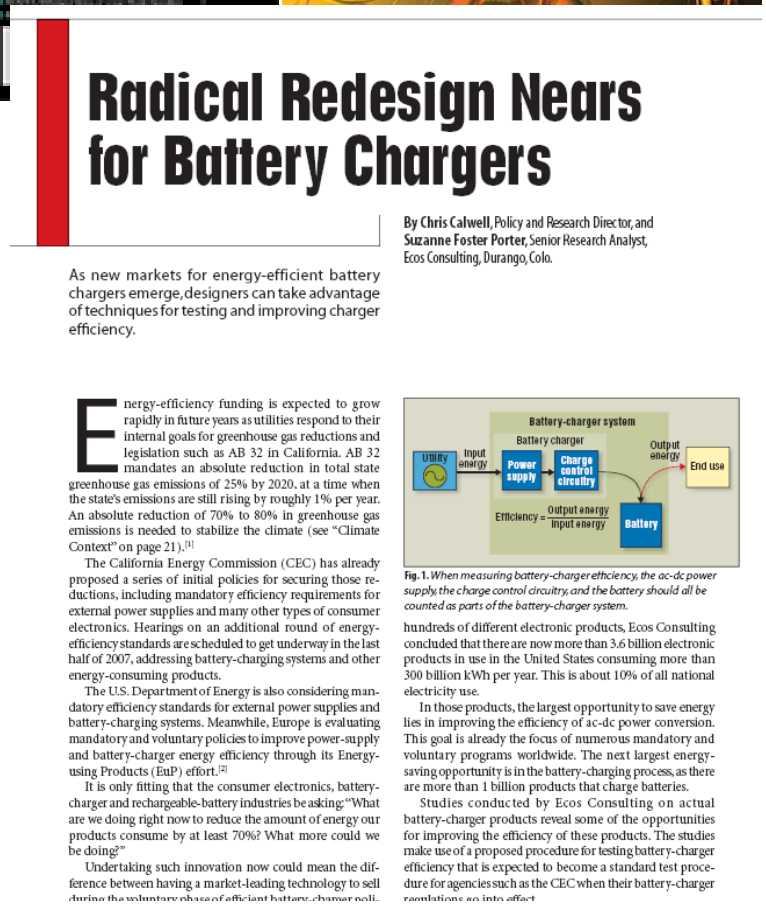
More than 100 products tested to inform standards development (small and large)

	A	B	C	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1	Line	ID		Test conditions			Conditioning				Preparation					Charge
2																
3	#		Product	Input V	Freq	Ports used	Conditioni	Date	Discharge 1	Discharge 2	Date	Start Time	End Time	Duration	Capacity	Date
4	3	BC200	2-way radio	115	60	1	Previous				10/10/07	11:40	14:40		61%	10/11/2007
5	4	BC200	2-way radio	115	60	2	Previous				11/05/07	11:00	16:20		110%	11/6/2007
6	5	BC201	2-way radio	115	60	1	N/A				10/10/07	11:40	14:40		57%	10/11/2007
7	6	BC201	2-way radio	115	60	2	N/A				11/05/07	11:00	16:00		103%	11/6/2007
8	7	BC245	CL Impact Driver	115	60	1	C/M/C	11/6/2007	993		11/06/07	13:17	18:20	303	101%	11/7/2007
9	8	BC246	CL Driver-Drill	115	60	1	C/M/C	11/6/2007	1107		11/06/07	13:20	18:48	328	109%	11/7/2007
10	9	BC237	Drill-Driver	115	60	1	C/M/C	11/6/2007	1070		11/06/07	17:30	23:00	328	109%	11/8/2007
11	10	BC242	CL Drill	115	60	1	C/M/C/D/C	11/6/2007	1236	1168	11/20/07	13:20	17:20	242	80%	11/21/2007
12	11	BC239	AA/AAA Charger	115	60	1	C/D/C/D/C	11/5/2007			11/06/07	17:30	21:15	224	74%	11/7/2007
13	12	BC239	AA/AAA Charger	115	60	1	Prev(18)				Disch (18)		15:40	270	90%	11/25/2007
14	13	BC239	AA/AAA Charger	230	50	1	Prev(11)/C	11/22/2007			11/22/07	9:45	14:10	265	88%	11/23/2007
15	15	BC238	AA/AAA Charger	115	60	1	Prev(13)				Disch (13)		15:40	269	89%	11/25/2007
16	16	BC238	AA/AAA Charger	115	60	2	C/D/C/D/C	11/5/2007			11/20/07	13:20	17:20	239&236	79%	11/21/2007
17	18	BC238	AA/AAA Charger	230	50	2	prev(16)				Disch (16)			270&270	90%	11/23/2007
18	19	BC241	CL Tools (3)	115	60	1	C/D/C/D/C	11/6/2007	2522	2565	11/21/07	9:35	14:00	263	87%	11/22/2007
19	20	BC240	Universal Battery	115	60	1	C/D/C/D/C	11/6/2007	480	496	11/20/07	13:20	14:50	87	28%	11/21/2007

- Includes wide array of consumer and industrial chargers: cell phones, cordless phones, AA chargers, power tools, personal care devices, mp3 players, lawnmowers, digital cameras, forklifts, and more
- Tests cover broad range of battery capacities, voltages, chemistries, and charger topologies

Significant outreach to manufacturers through trade media and web

- Battery Power Products and Technology Conference presentations last 5 of 8 years ('03, '04, '05, '06, '10)
- Article in trade press (Power Electronics Technology): expected policy action and pressing climate need ('07)
- Website continuously documenting research and policy measures since '05



Radical Redesign Nears for Battery Chargers

By Chris Calwell, Policy and Research Director, and Suzanne Foster Porter, Senior Research Analyst, Ecos Consulting, Durango, Colo.

As new markets for energy-efficient battery chargers emerge, designers can take advantage of techniques for testing and improving charger efficiency.

Energy-efficiency funding is expected to grow rapidly in future years as utilities respond to their internal goals for greenhouse gas reductions and legislation such as AB 32 in California. AB 32 mandates an absolute reduction in total state greenhouse gas emissions of 25% by 2020, at a time when the state's emissions are still rising by roughly 1% per year. An absolute reduction of 70% to 80% in greenhouse gas emissions is needed to stabilize the climate (see "Climate Context" on page 21).[1]

The California Energy Commission (CEC) has already proposed a series of initial policies for securing those reductions, including mandatory efficiency requirements for external power supplies and many other types of consumer electronics. Hearings on an additional round of energy-efficiency standards are scheduled to get underway in the last half of 2007, addressing battery-charging systems and other energy-consuming products.

The U.S. Department of Energy is also considering mandatory efficiency standards for external power supplies and battery-charging systems. Meanwhile, Europe is evaluating mandatory and voluntary policies to improve power-supply and battery-charger energy efficiency through its Energy-using Products (EuP) effort.[2]

It is only fitting that the consumer electronics, battery-charger and rechargeable-battery industries be asking: "What are we doing right now to reduce the amount of energy our products consume by at least 70%? What more could we be doing?"

Undertaking such innovation now could mean the difference between having a market-leading technology to sell during the voluntary phase of efficient battery-charger poli-

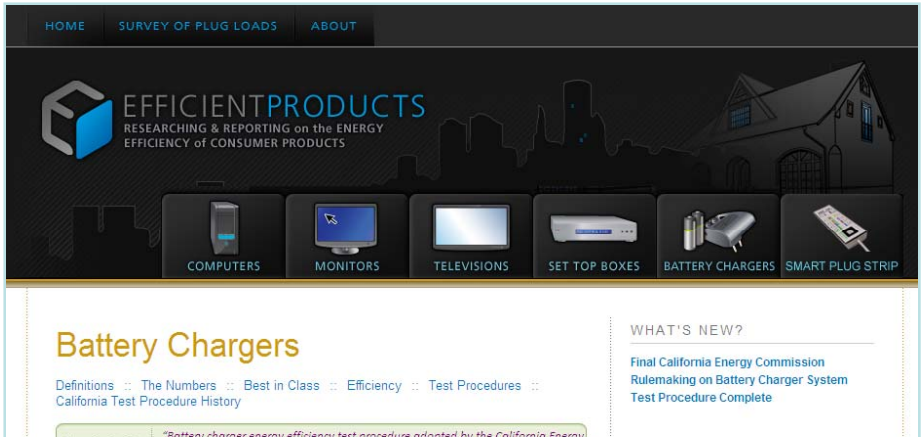
Battery-charger system
Utility
Input energy
Battery charger
Power supply
Charge control circuitry
Output energy
End use
Efficiency = Output energy / Input energy
Battery

Fig. 1. When measuring battery-charger efficiency, the ac-dc power supply, the charge control circuitry, and the battery should all be counted as parts of the battery-charger system.

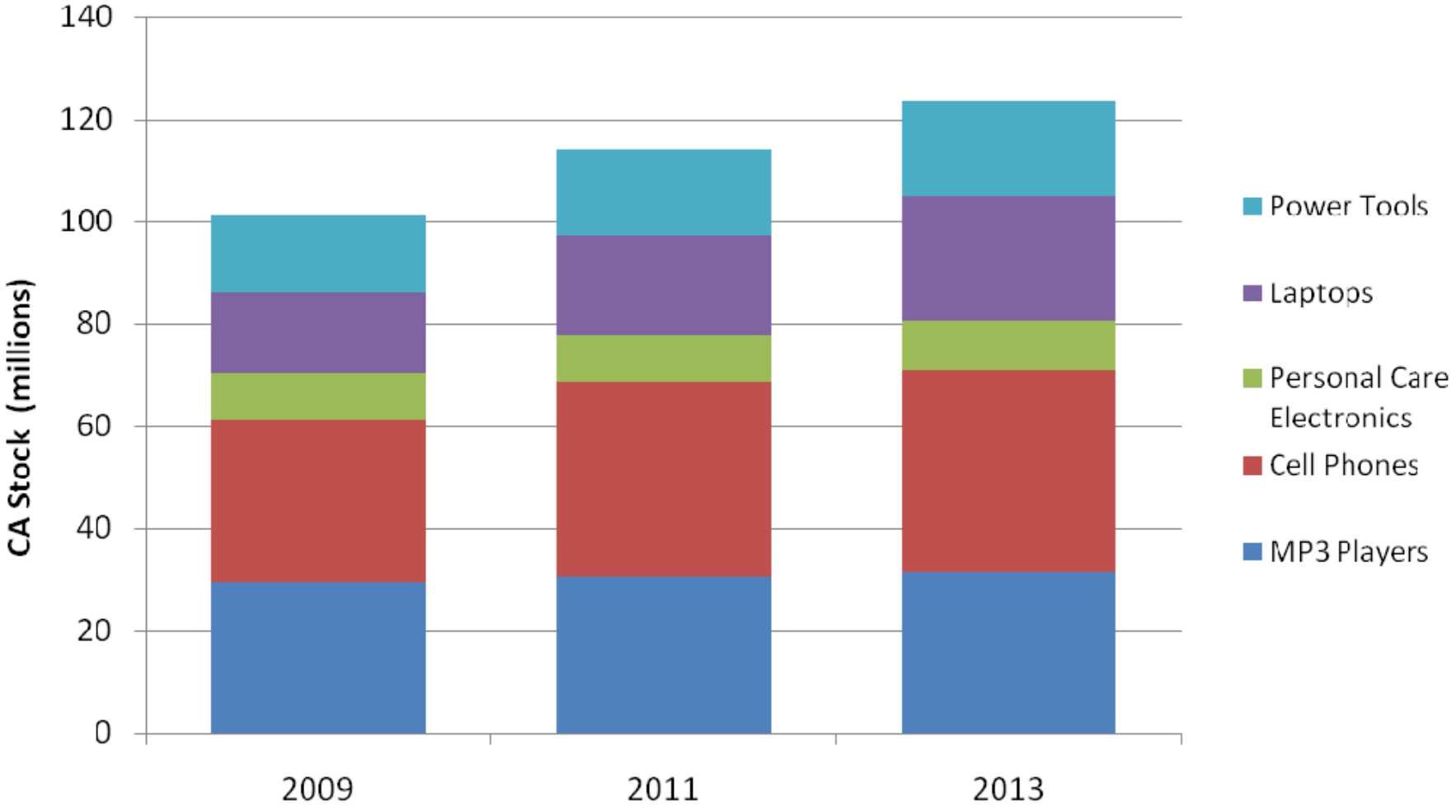
hundreds of different electronic products, Ecos Consulting concluded that there are now more than 3.6 billion electronic products in use in the United States consuming more than 300 billion kWh per year. This is about 10% of all national electricity use.

In those products, the largest opportunity to save energy lies in improving the efficiency of ac-dc power conversion. This goal is already the focus of numerous mandatory and voluntary programs worldwide. The next largest energy-saving opportunity is in the battery-charging process, as there are more than 1 billion products that charge batteries.

Studies conducted by Ecos Consulting on actual battery-charger products reveal some of the opportunities for improving the efficiency of these products. The studies make use of a proposed procedure for testing battery-charger efficiency that is expected to become a standard test procedure for agencies such as the CEC when their battery-charger regulations go into effect.



Number of consumer chargers continues to increase; new products routinely added

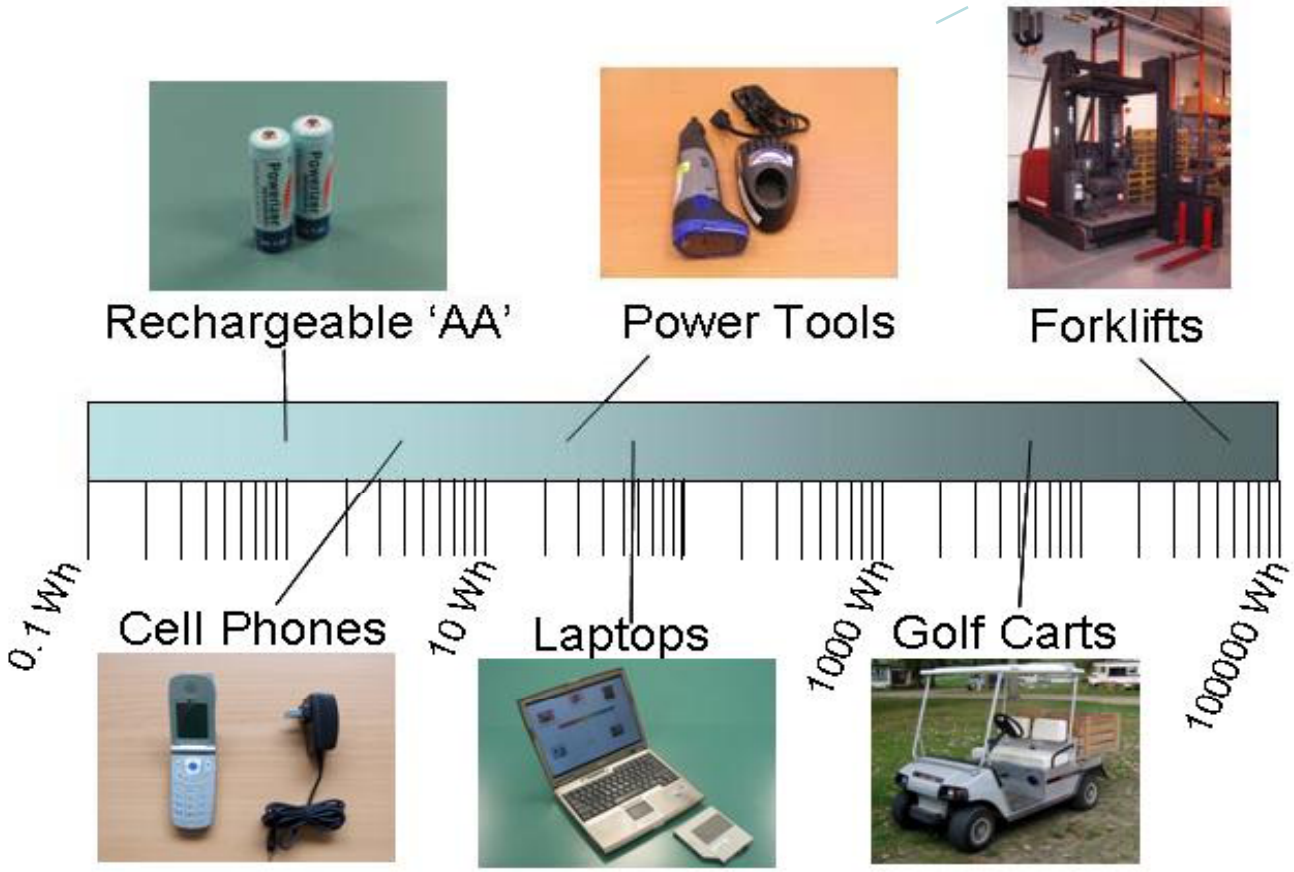


Data Source: (Porter et al. 2010)

Battery size from watt hours to 1000s watt hours, but all have same function

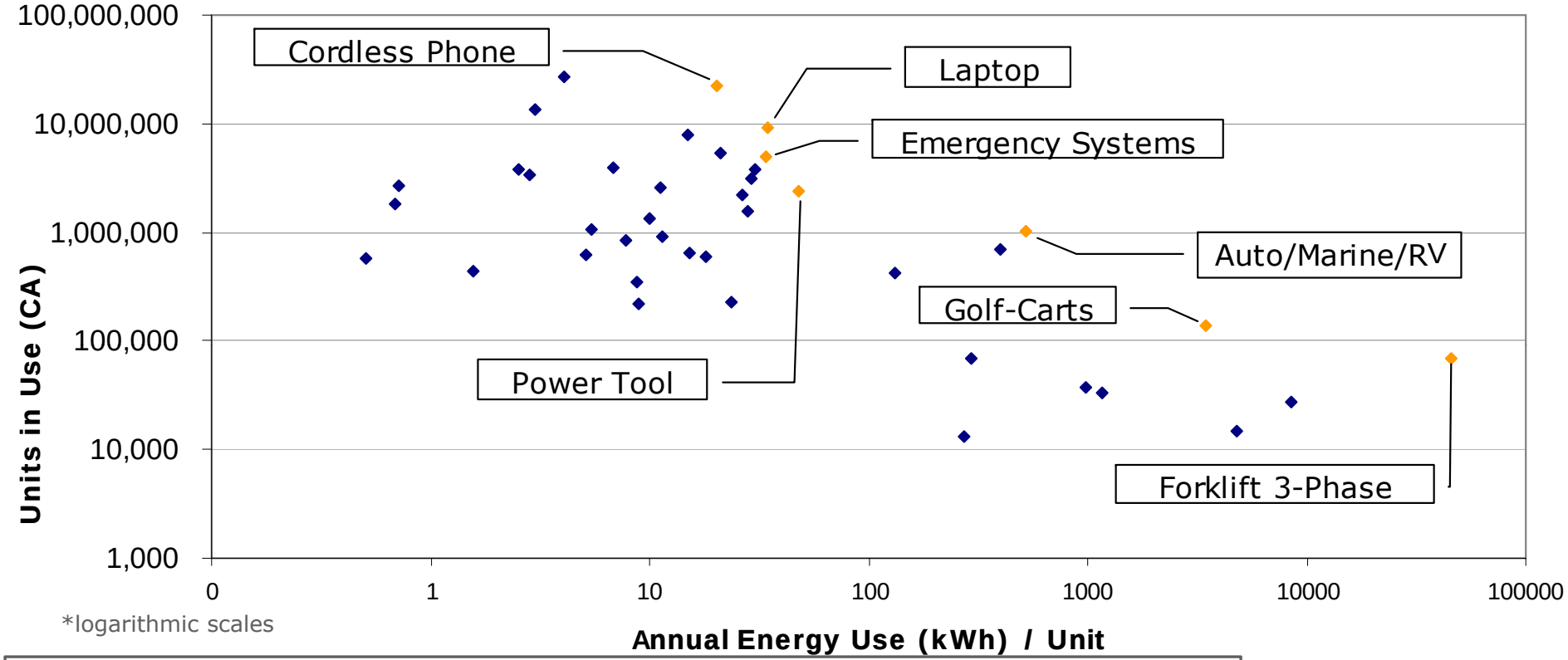
All BCS include:

1. A power supply to convert high voltage ac to low voltage dc
2. Charge control to regulate current going to the battery
3. A battery that stores energy



Graphic: *Designing battery Charger Systems for Improved Efficiency* Geist,Kameth, 2006

Energy use by product category & CA stock



*logarithmic scales

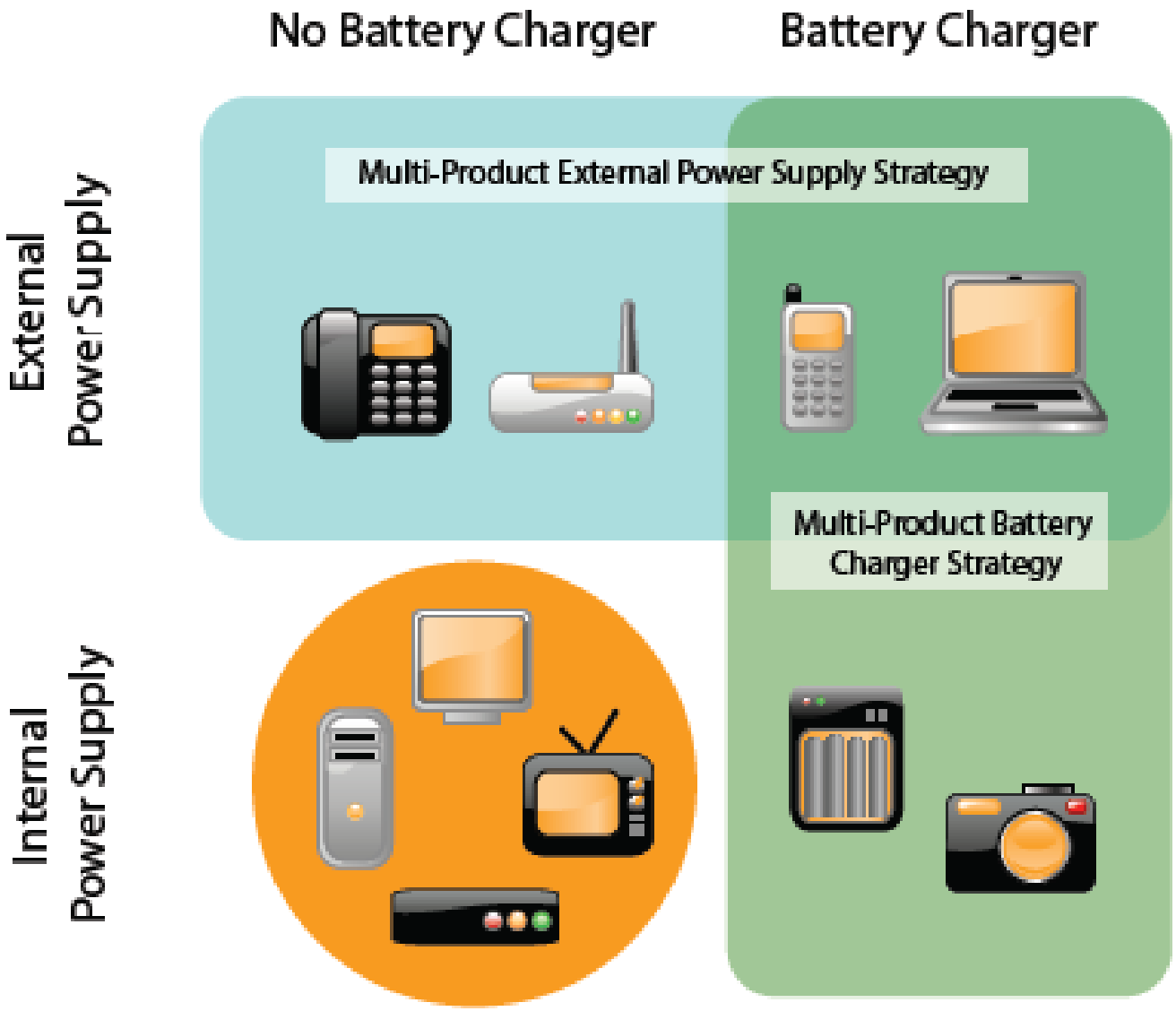
California Battery Charger Major Energy Use Contributors

- 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%)

*Orange diamonds represent outliers in terms of stock and energy use

*Blue diamonds are other battery chargers that compose the stock

Over 170 million battery chargers in use in California today, suggests a "phase two" multi-product approach



Source: PIER, *Tapping into Plug Load Savings available* www.efficientproducts.org/

Functional components sometimes in same housing, but more often separated

Form Factor 1

The power supply, the charge control circuitry and the battery are contained in separate housings.

Form Factor 2

The power supply and the battery charge control circuitry is contained in a single housing. The battery is contained in a separate housing.

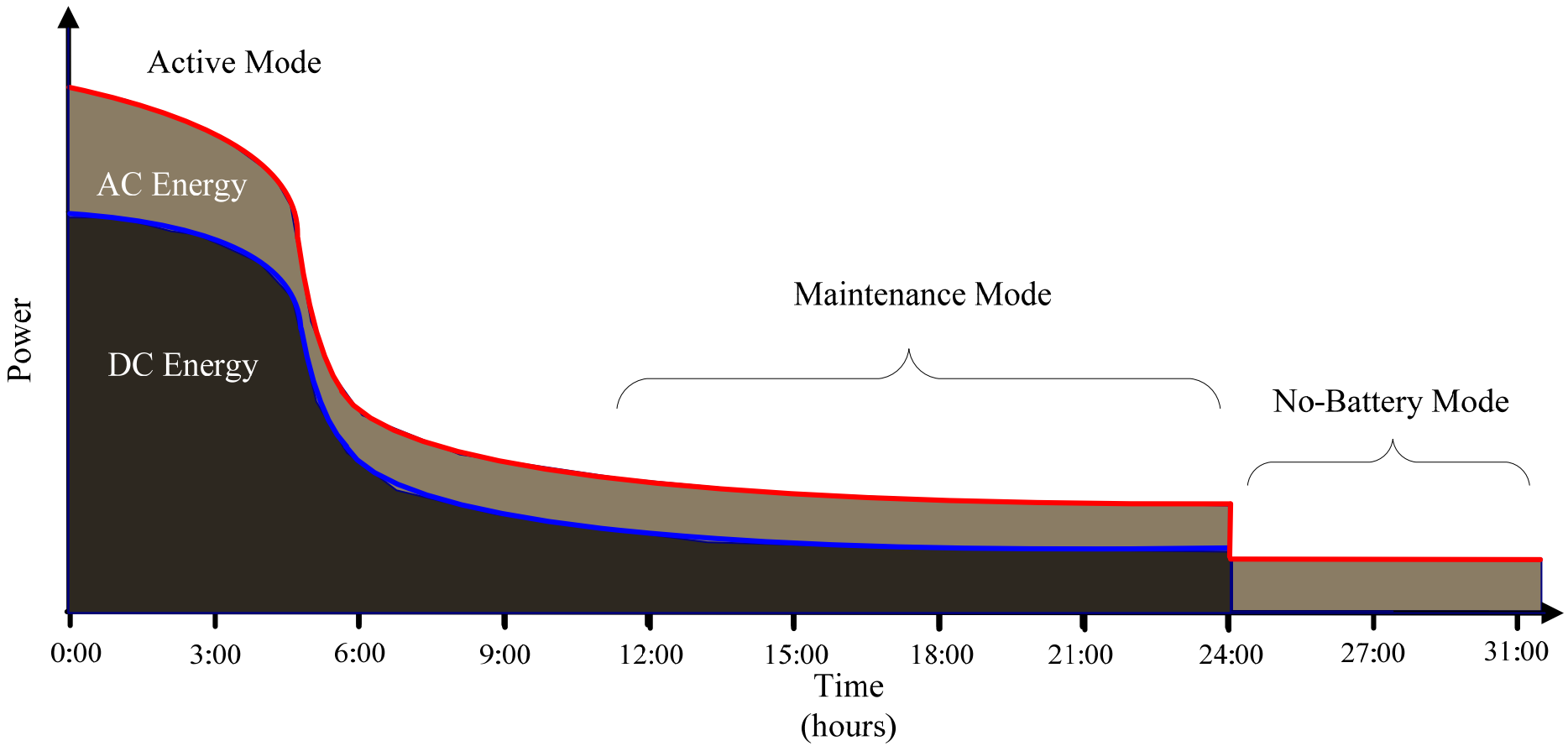
Form Factor 3

The charge control circuitry and battery are inside of the cell phone. The power supply is contained in a separate housing.

Form Factor 4

The power supply, the charge control circuitry and the battery are contained in a single housing.

Battery Chargers have three primary modes of operation: active (charge) mode, maintenance mode, and no battery mode



Four dominant battery chemistries

	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

Efficiencies can vary widely, even within similar product end uses and identical battery chemistries

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

Product utility and consumer features do not necessarily trend with efficiency

Slow Charge Time & Less Efficient

- Product: 18 Volt Drill Charger
- Charge Time: approx. 24 Hours
- 24h Efficiency: 6.6%
- Maintenance Mode: 10.4 watts
- No Battery Mode: 1.8 watts

Fast Charge Time & Higher Efficiency

- Product: 18 Volt Drill Charger
- Charge Time: approx. 1 Hour
- 24h Efficiency: 57.2%
- Maintenance Mode: 0.8 watts
- No Battery Mode: 0.6 watts

In data set, there are also examples of slow chargers that are quite efficient, examples of fast chargers that are inefficient

Consumer and non-consumer energy usage and trends

	Product types	Dominate charger technology	Key efficiency metrics	California stock of products	California annual energy use
Small battery chargers	Laptops, cell phones, power tools, auto/marine/RV, cordless phones, golf carts*	Linear, switch-mode	24-hr efficiency, maintenance mode	169 million	3,500 GWh
Large battery chargers	Forklifts, electric carts	Ferroresonant, silicon controlled rectifier (SCR)	Power conversion efficiency, charge return factor	0.10 million	3,600 GWh

Small battery chargers

- Typically sold with battery
- Usage patterns differ significantly
- Price and portability drive market
- Significant savings potential in charge mode and maintenance mode

Large battery chargers

- Typically not sold with battery
- Used heavily
- Significant cost and energy usage provide market mechanism for some efficiency
- Cost effective savings in power conversion efficiency and charging behavior

* Golf carts are exception to trends in small category

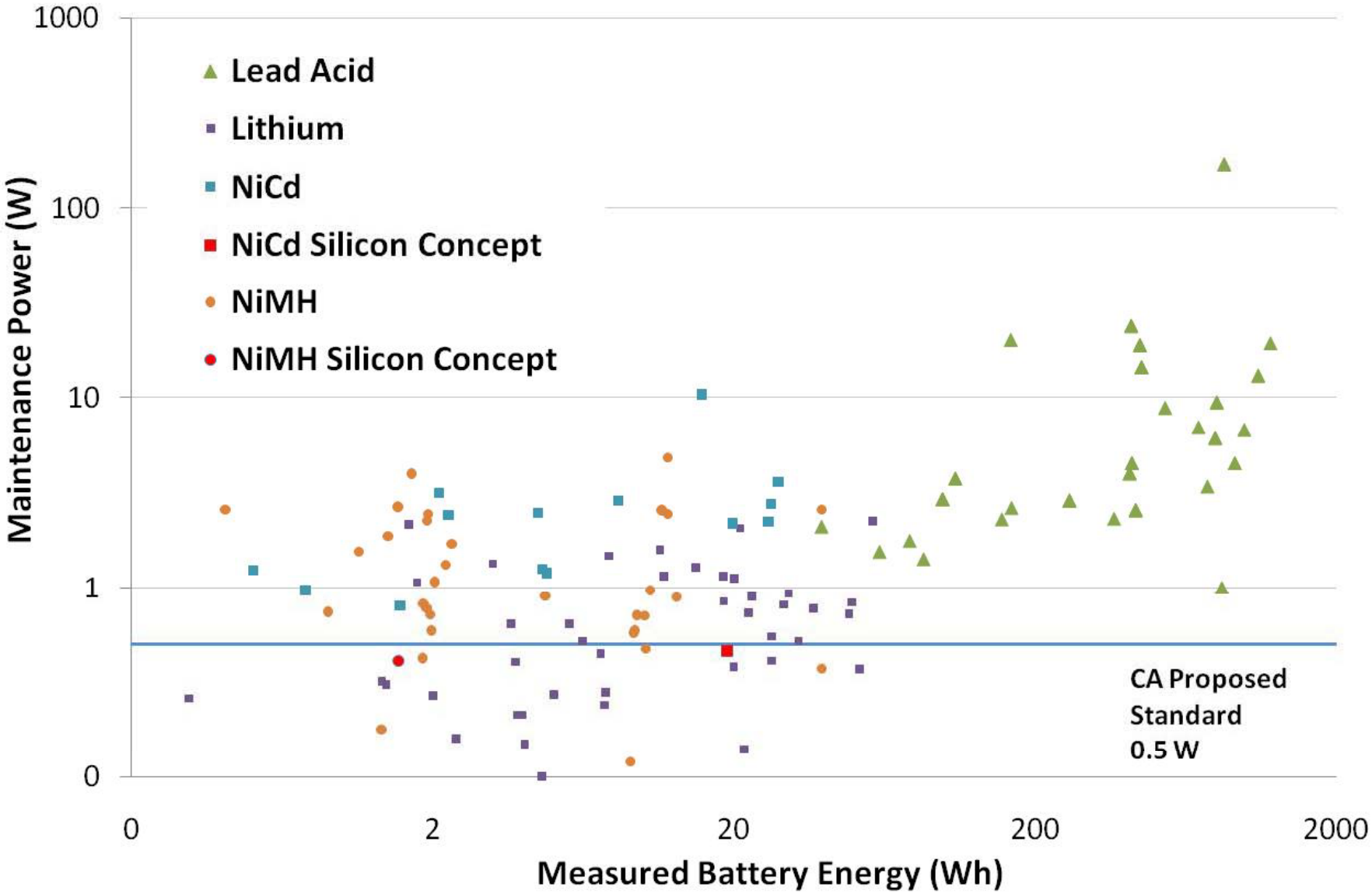
Counteracting battery self-discharge in maintenance mode possible, even for largest power tool battery chargers

- All batteries discharge slightly after the charge cycle
- Title 20 allows for trickle charge when needed

	24 hour self discharge	Ac power required to counteract self-discharge (W)	Maximum battery size observed (Wh)
Li-Ion	5%	0.29 (no immediate trickle needed)	96
NiCd	10%	0.35	48
NiMH	15%	0.36	40

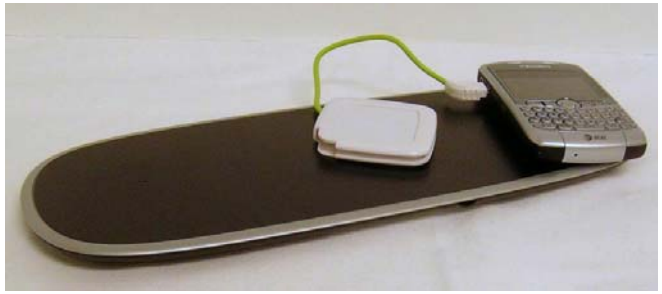
Isidor Buchman, Batteries in a Portable World, 2nd Edition, Cadex Electronics, 292 pp, 2001.

Battery maintenance mode level



Pad chargers: initially phones, but may extend to other products

- Emerging form factor enables consumer to place phones onto pad, rather than connect via cord
- Current generation products have external harness—future solutions could be incorporated into housing
- Recommend for inclusion in scope of Title 20 standard



Mission critical BCS can meet proposed standard

- Mission critical chargers are used charge radios carried by public emergency personnel
- Tested multiple rapid chargers of similar battery size that can meet the proposed standard
- Intrinsically safe circuitry to prevent electrical spark generation should not significantly increase energy consumption

Mission critical BCS can meet proposed standard

- LEDs for bright ambient conditions are 10 to 50 mW per LED
  - For six ports: 0.06 W to 0.3 W for battery maintenance
  - 0 W for no battery mode (no indication needed)
- Use LCD display with variable backlight control that responds to ambient room lighting (suggest specify that test is conducted in a bright room)
- Because efficiency test is conducted at normal room temperature, little to no energy associated with a cooling fan would be counted in test

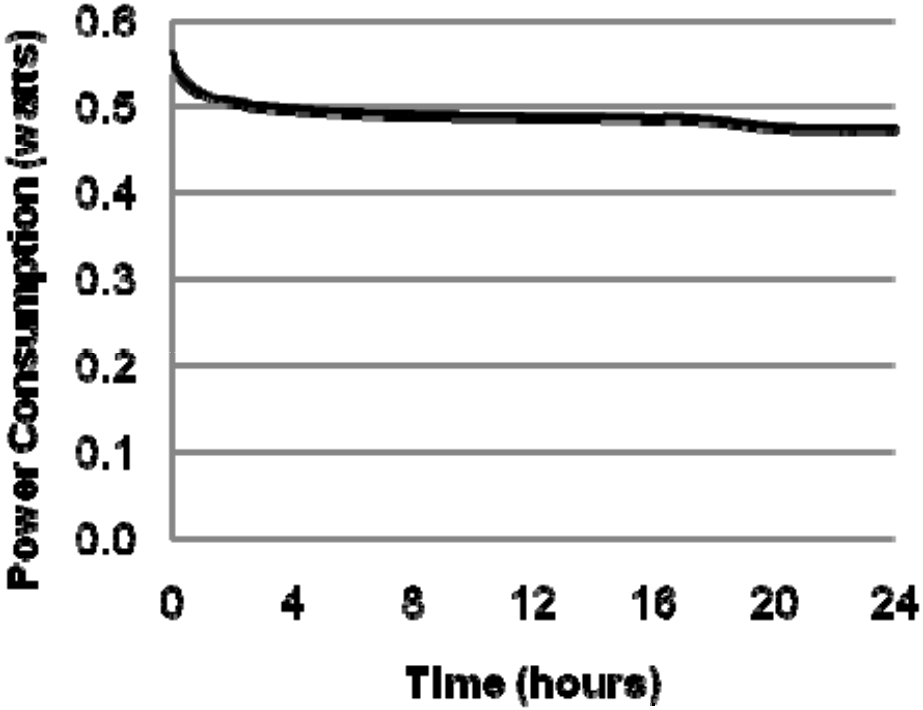
Proposed Title 20 BCS efficiency standard levels are cost effective: two detailed studies

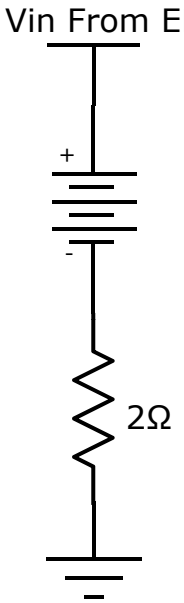
DIY 15 Wh NiCd power tool charger
Cost: $60 from Home Depot (Feb 2011)

1.5 Wh NiMH beard trimmer
Cost: $18 from Target (Jan 2011)

Products selected based on manufacturers' comments concerning cost effectiveness

Resistive charge control appropriate for low battery capacity products





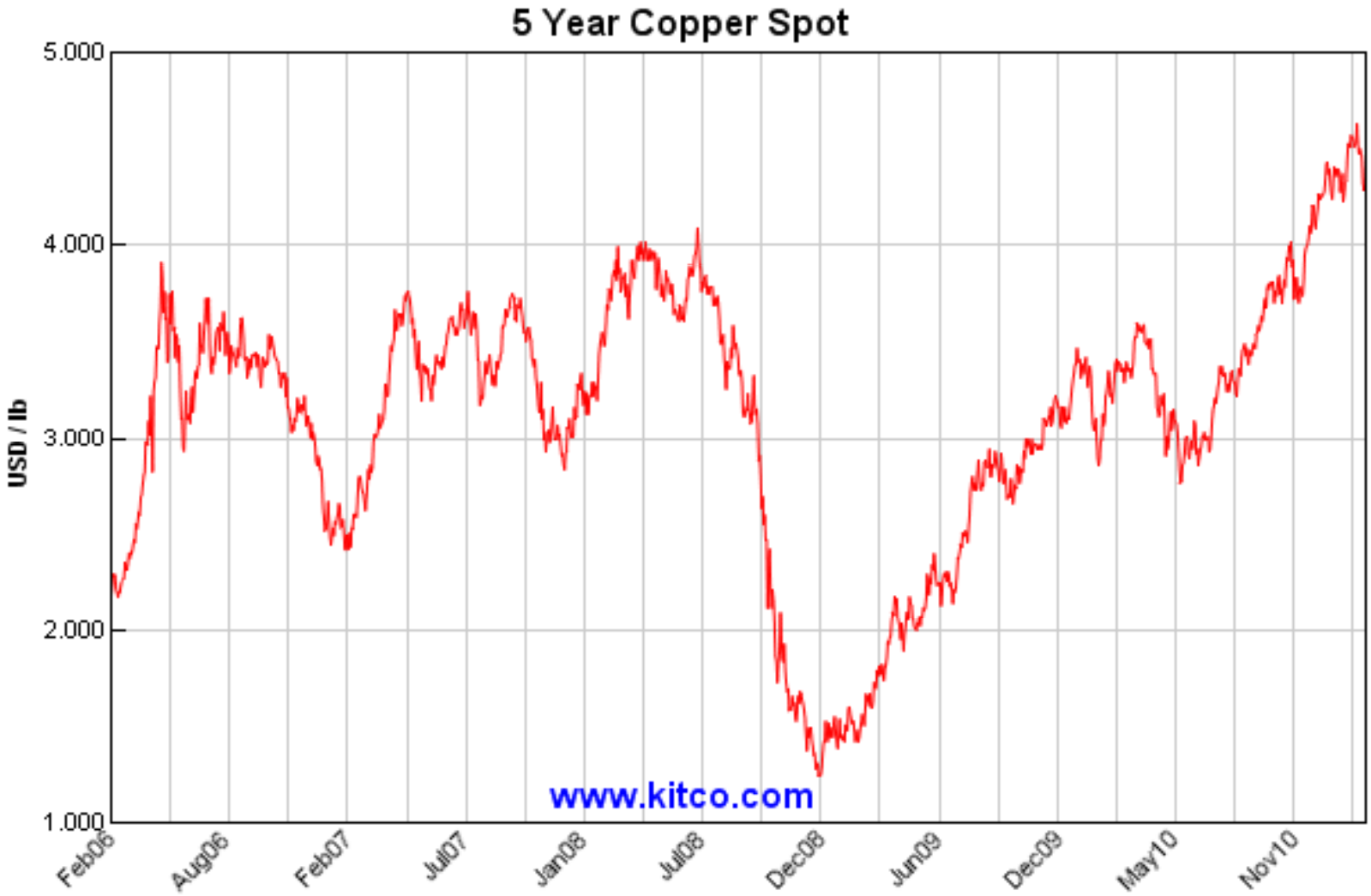
	24 hr efficiency	Maintenance	No-battery
Proposed Title 20	10.6%	0.5 W	0.3 W
As shipped	13.2%	0.47 W	0.31 W

No battery mode levels lowered by replacing level IV EPS with level V

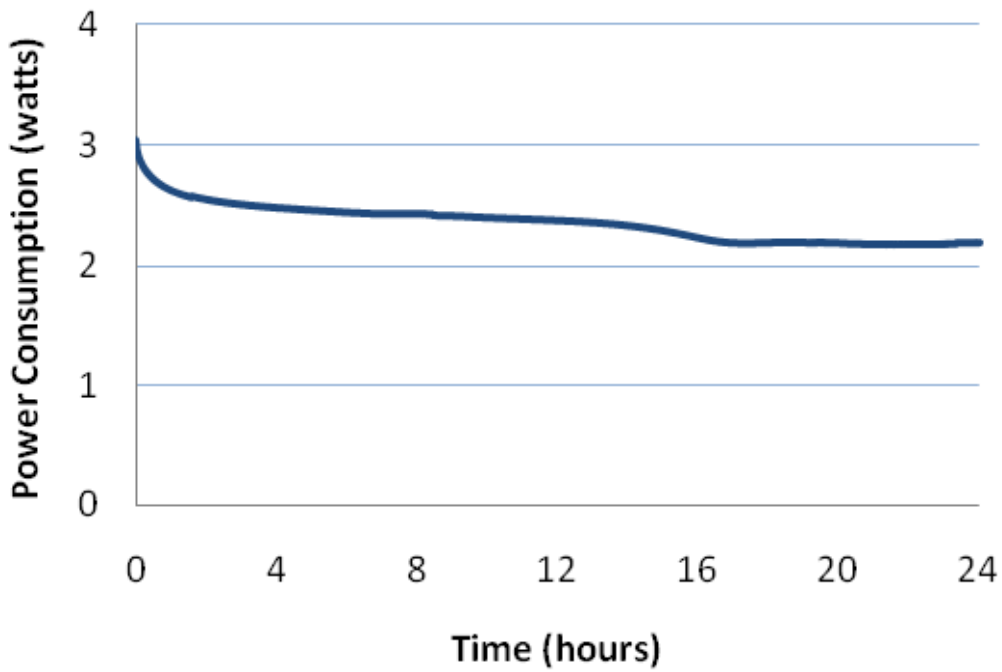
- DOE analysis of similar sized power supply (2.5 W) suggests incremental BOM cost of EPS IV to EPS V $0.10, so $0.15 incremental retail (with tax) (DOE TSD markup 1.45x)
- Benefit : cost = 1 : 2
- EPS available as "off the shelf" plug in from vendor, eliminating redesign costs

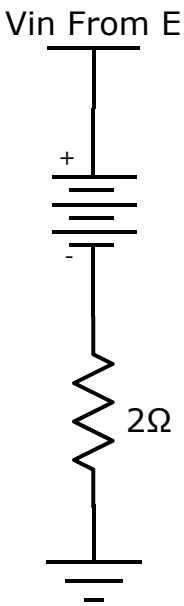
Mode	24 hr efficiency	Maintenance	No-battery
Proposed Title 20	10.6%	0.5 W	0.3 W
Modified: level V EPS	18.4%	0.41 W	0.30 W

As copper prices surpass pre-recession levels, incremental cost of level V EPS silicon solutions likely to lower further and possibly move negative



DIY power tool efficiency improvements needed: charge termination/maintenance

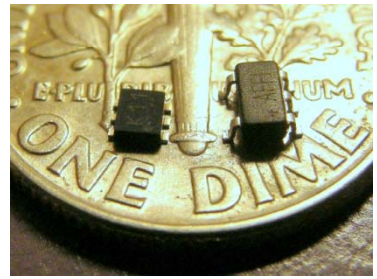




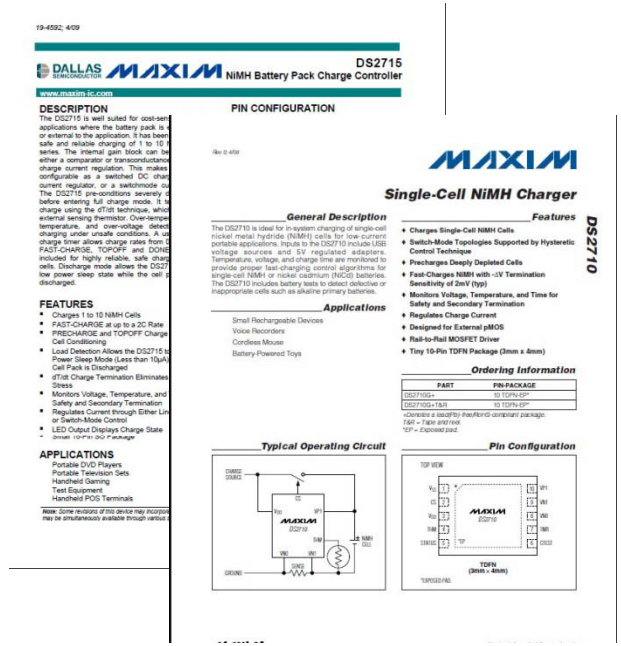
Mode	24-hour efficiency	Maintenance	No-battery
Proposed Title 20	45%	0.5 W	0.3 W
As shipped	35%	2.2 W	0.25 W

LiIon products already use Si control
“Off the shelf” Si solutions available for efficient battery management for Nickel

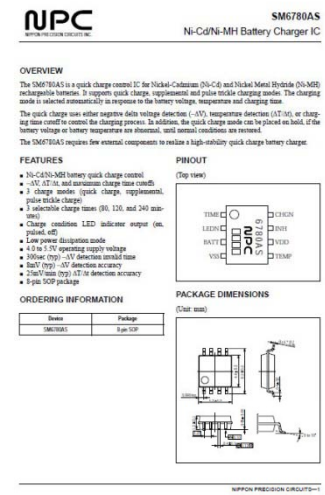
Comparators & comparators with references



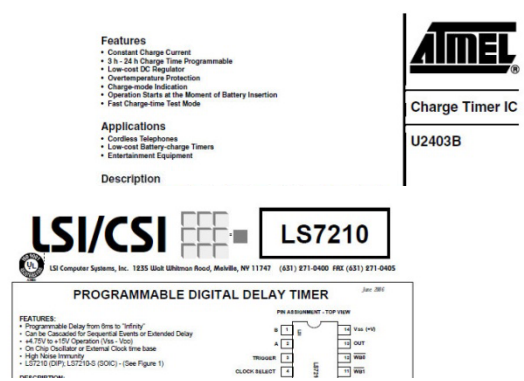
dT/dt with voltage comp. & timer



Neg.ΔV with *dT/dt* & timer

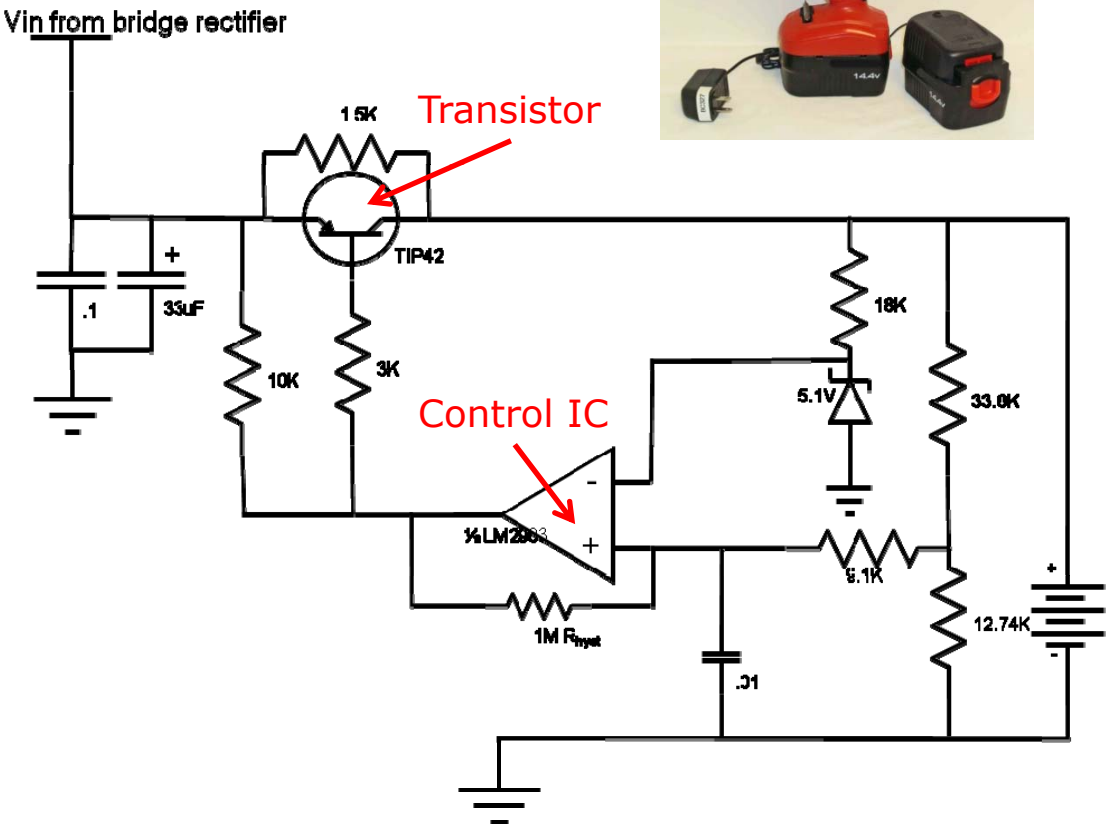


Timers

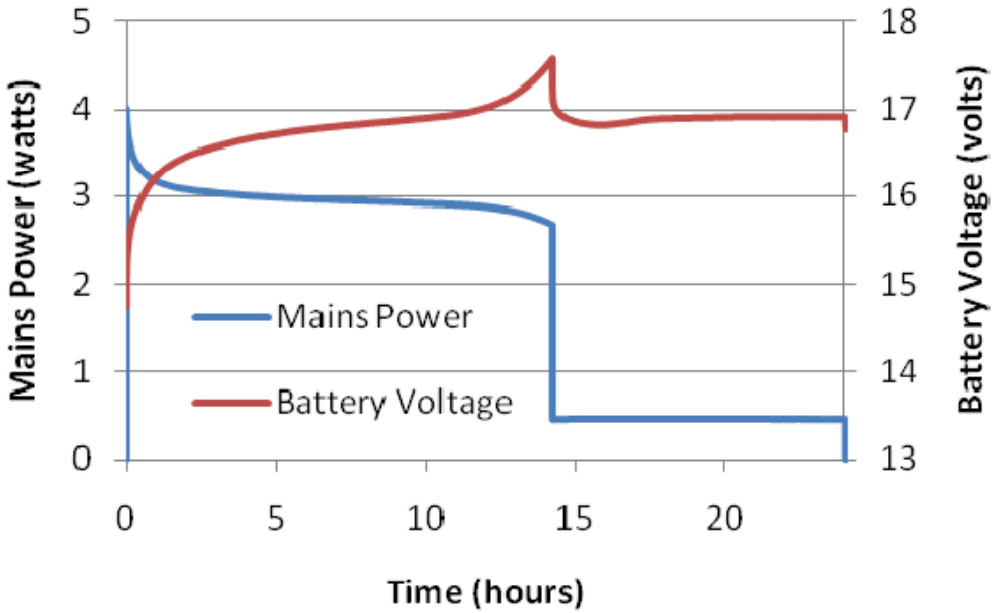


Simple charge control possible to improve charge and maintenance mode efficiency

- Replaced resistor as current regulator with a transistor controlled by a voltage comparator: reduced maintenance power
- Circuit can be converted to hysteresis charger by removing trickle resistor bypassing the transistor
- Incremental BOM cost for redesign (OEM quantity): ~$0.55



Charge efficiency and battery maintenance are improved



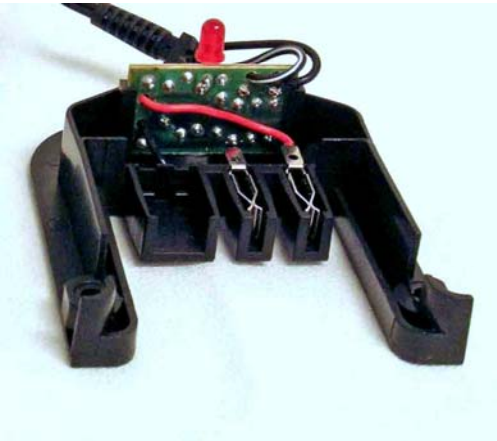
Mode	24-hour efficiency	Maintenance	No-battery
Proposed Title 20	45%	0.5 W	0.3 W
As shipped	35%	2.2 W	0.25 W
Modified: charge term.	41%	0.46 W	0.30 W

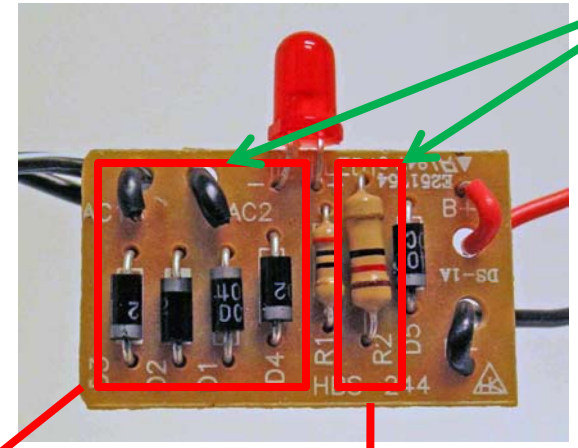
Add "off the shelf" level V EPS, and Title 20 proposed levels cost-effectively achieved

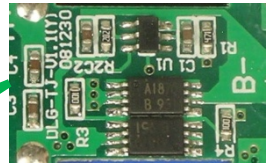
Mode	24-hour efficiency	Maintenance	No-battery
Proposed Title 20	45%	0.5 W	0.3 W
As shipped	35%	2.2 W	0.25 W
Modified: charge term. +V EPS	54%	0.40 W	0.30 W

- Incremental BOM cost for redesign (OEM quantity): ~$0.55
- Incremental cost for level V EPS: $0.10 (may go down as copper prices increase)
- Total with markup is $1.30 (2x in DOE method)
- Payback period: 0.6 years, 14 kWh/year annual savings

Plenty of room for Silicon charge control on existing circuit boards







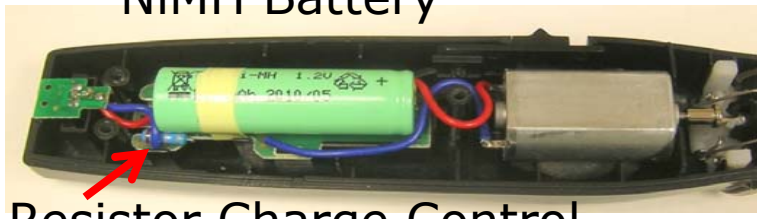
Surface mount Si charge control occupies vacated space

Rectifiers move into new EPS

Charge Resistor no longer needed

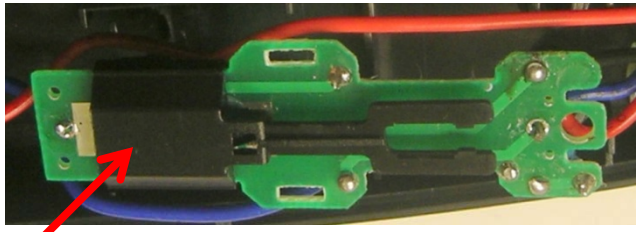
Wider adoption of LiIon has demonstrated that Si charge control can be implemented with little or no packaging impact

NiMH Battery



Resistor Charge Control

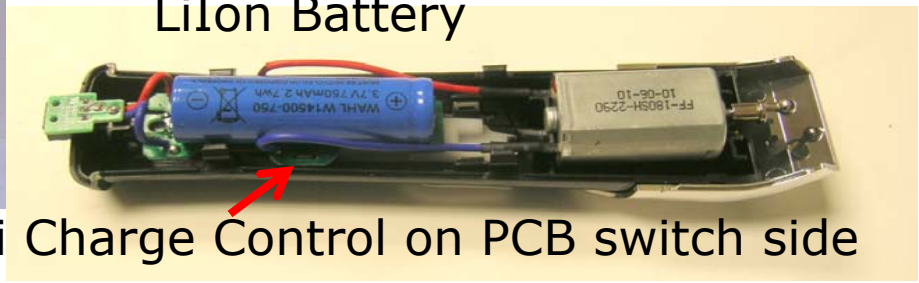
PCBs are same size & mount



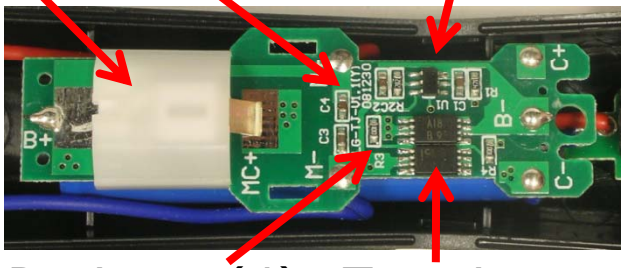
Switch Assy

Capacitors(4) Control IC

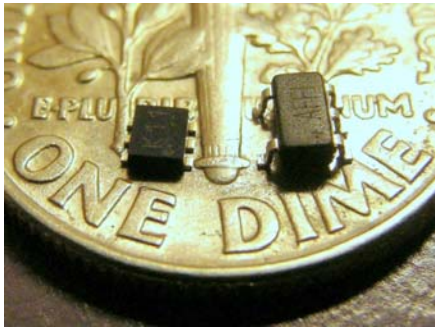
LiIon Battery



Si Charge Control on PCB switch side



Resistors(4) Transistors



- These small "off the shelf" packages allow Si based charge control to fit in existing PCB space

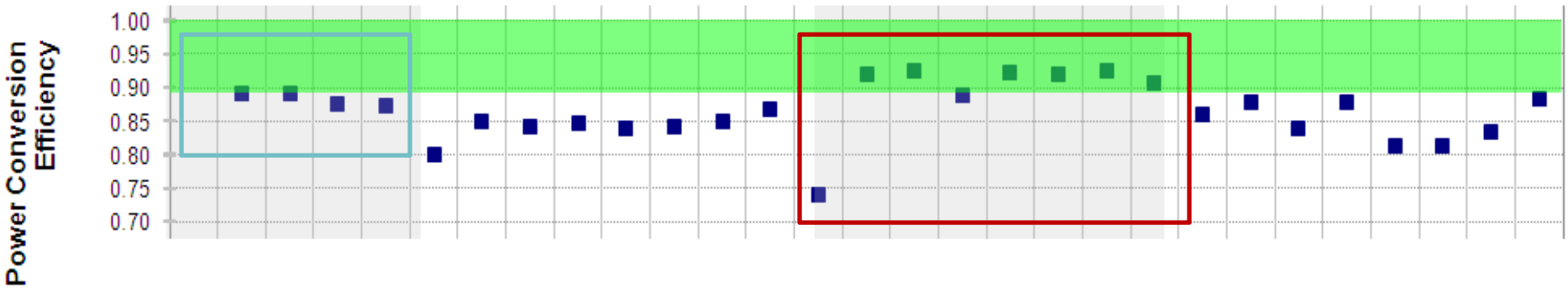
Few additional costs associated with redesign in one year

- Consumer products are regularly redesigned to encourage consumer upgrade to new models and to distinguish product in the market
- Circuit design and board design can be absorbed into regular OEM redesign schedules
- Changes to product molding not required, components required are small and fit on existing circuit board space
- Markup on extra components applied in the analysis (2x) easily covers these costs
- Full safety testing unlikely required with these changes
  - Using new EPS—no recertification required unless EPS interacts with battery charge circuits
  - Using new battery charger circuitry—retest for safety if outside standard ranges specified by battery manufacturer: estimate $2,000 to $3,000

Proposed standard not expected to increase sales of gasoline vehicles

- There is already price premium for electric versus gasoline vehicles
- Electric vehicles have a number of advantages over gasoline: no fumes, less noise, lower maintenance cost, lower operations cost
- More sophisticated commercial purchasers that evaluate life cycle cost for facilities would see a net reduction in total cost for compliant products
- Other residential users already paying a premium for the other benefits

89% power conversion efficiency (Tier 2) feasible for large chargers



- High frequency (switch mode) chargers can meet the standard
- If concerned about durability, one hybrid charger measured 88.3%, so small changes can be made to meet the standard such as:[1]
  - Better core steel (reducing magnetization losses)
  - Thicker copper conductors (transformer windings, circuit board, connector leads)

Power factor correction (PFC) justified only for large currents

Assessment of the Impacts of Power Factor Correction in Computer Power Supplies on Commercial Building Line Losses

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- Policy approach based on EPRI report that showed measurable energy savings from improved power factor
- For battery chargers, active PFC cost effective to consumer only for large currents

0.55 power factor cost effective for smaller chargers

Application	Incremental BOM cost	Wiring energy savings (kWh/yr)	Payback (yr)
Residential power tool (switch mode)	$0.02 (optimized capacitance)	0.3	0.9
Low power laptop	$0.75 (Silicon)	6	1.9

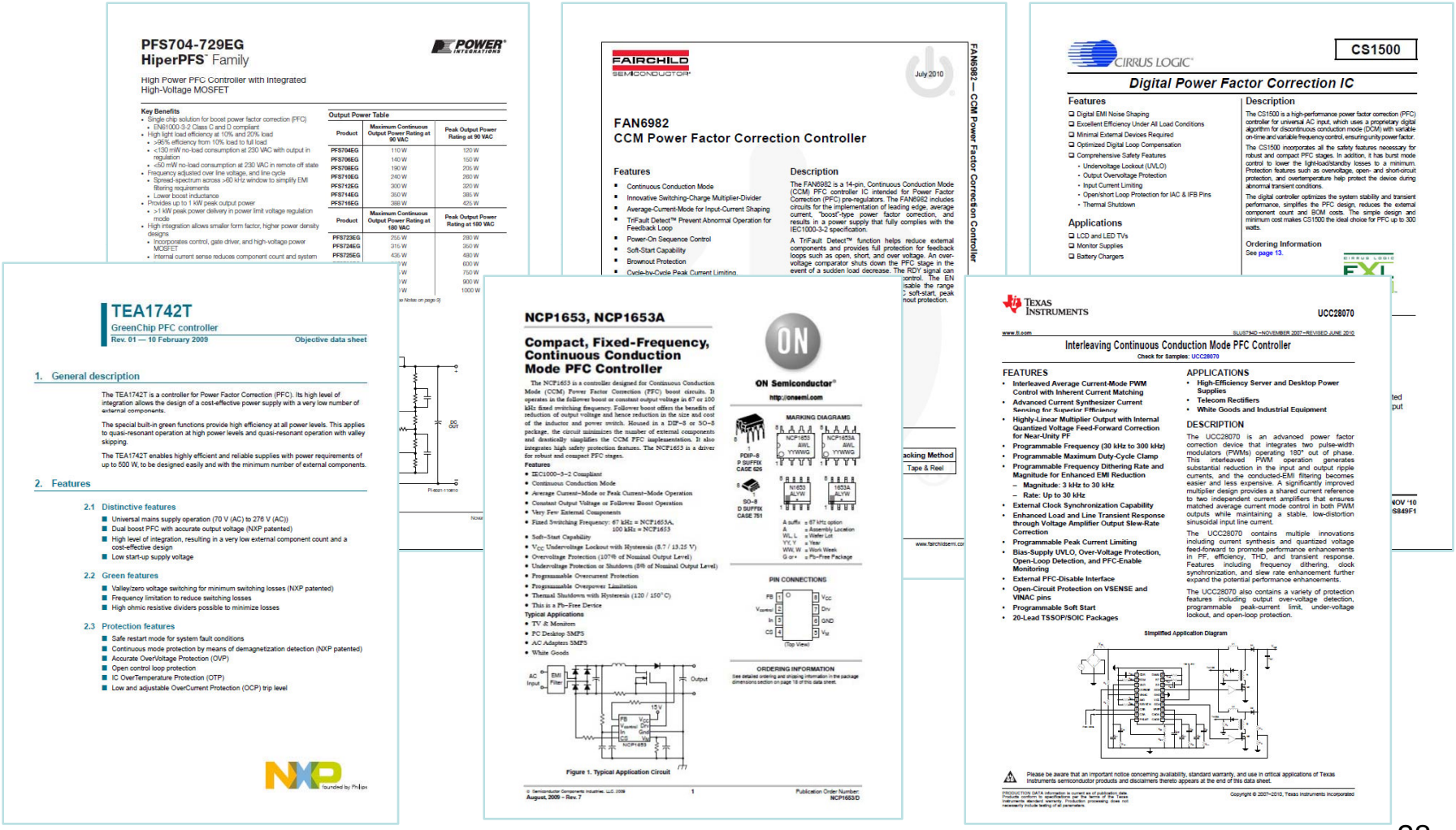
- Affects products 10 W to 60 W input power
- Switch mode dedicated battery chargers (residential power tool above): optimize capacitance value to improve PF, small total incremental cost
- BCS that are also power supplies (such as for laptops), another Silicon solution required
- Switch mode smaller than 10 W input would be cost effective as well
- BCS with linear rectification already meets standard
- 2x applied for markup

Active power factor correction to reach 0.9 power factor cost effective for higher currents

Application	Incremental BOM cost	Wiring energy savings (kWh/yr)	Payback (yr)
High power laptop	$0.90	13	1.0
Commercial fast charging power tool	$0.90	2.5	5
Auto/marine	$0.90	8	1.6
Personal electric vehicle	$0.90	53	0.2

Note: Laptop counts savings in power supply only mode
>60 W input power
Markup of 2x

Si Power Factor Correction solutions widely available



Summary for small chargers

- High-volume, high tech products have made efficient charging solution inexpensive and widely available
- PG&E research demonstrates feasibility of improving consumer chargers to 70% (current average is 10 to 15%)
- PG&E proposed standard for small chargers targets only about 40% efficiency
- Approximately 2/3 of energy used can be saved (60% to 70%)
- Proposed standard is based on simple 3-part metric of improving each operating mode

Summary for large chargers

- Metrics based on CEC test procedure part 2 measurements – accepted by industry and energy advocates
  - Power conversion efficiency
  - Charge return factor
  - Maintenance and no battery power
  - Power factor
- Incremental improvements sought in a mature marketplace, about 10% energy savings
- Improvements are about 4 MWh/yr per unit
- Added cost may be $100 to $400 in order to save $400/year of energy for 15 year life

Battery Charger Standards Savings

Small BCS energy savings	60 to 70% of current energy use 2,400 GWh per year after stock turnover
Large BCS energy savings	8% of current energy use 300 GWh per year (Tier 2) after stock turnover
All BCS energy savings	35% of current energy usage; $400 M per year
Rosenfeld	0.9
Equivalent household energy usage savings	390,000 homes

- Per product incremental cost $1.80, lifetime unit energy savings $14
- Benefit : cost = more than 7:1
- Net present value of consumer energy savings from first year of sales is $300 M, orders of magnitude greater than the cost of regulation

Extra material

Special exception made for exit signs, emergency egress included with small charger standard

- Exit sign efficacy covered by DOE lighting standards, BCS function not preempted
- Higher maintenance mode (0.8 W) allowed for constant illumination

- Emergency egress lighting covered by small BCS proposed standard

Energy savings may be lower than CASE report estimates because some emergency lighting is centrally powered, but same cost effectiveness