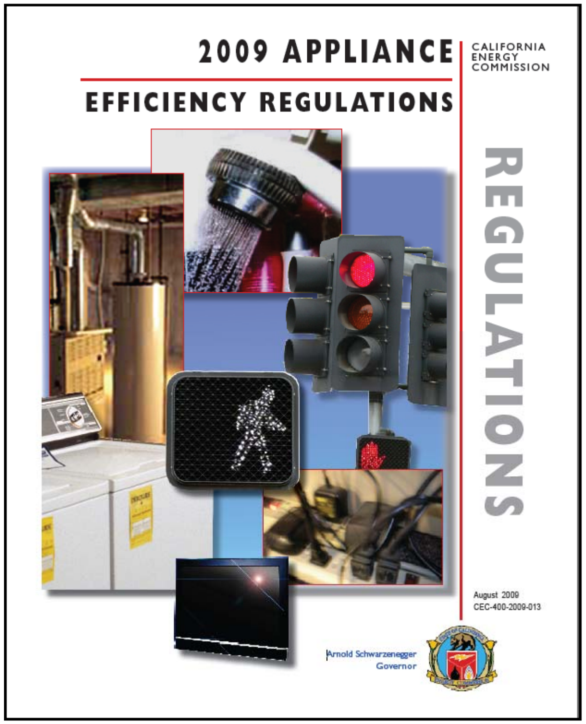

Proposed Title 20 California Efficiency Standards for Battery Charger Systems

October 11, 2010
California Energy Commission, Staff Workshop

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

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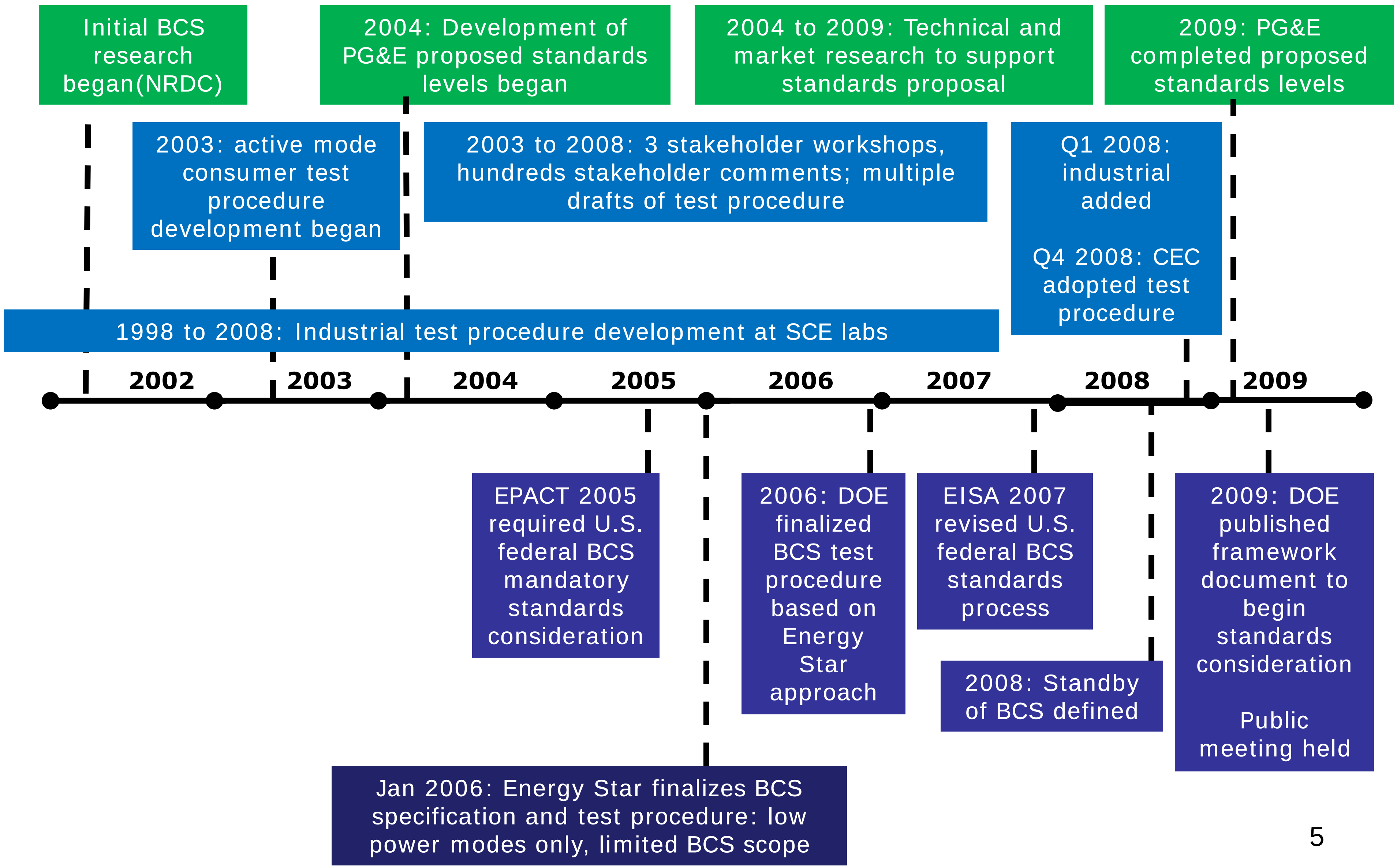
- Pacific Gas and Electric Company (PG&E) Applied Technology Services (ATS) Group
- California Energy Commission's Public Interest Energy Research Program (PIER)
- Southern California Edison (SCE)
- Electric Power Research Institute (EPRI)

Outline

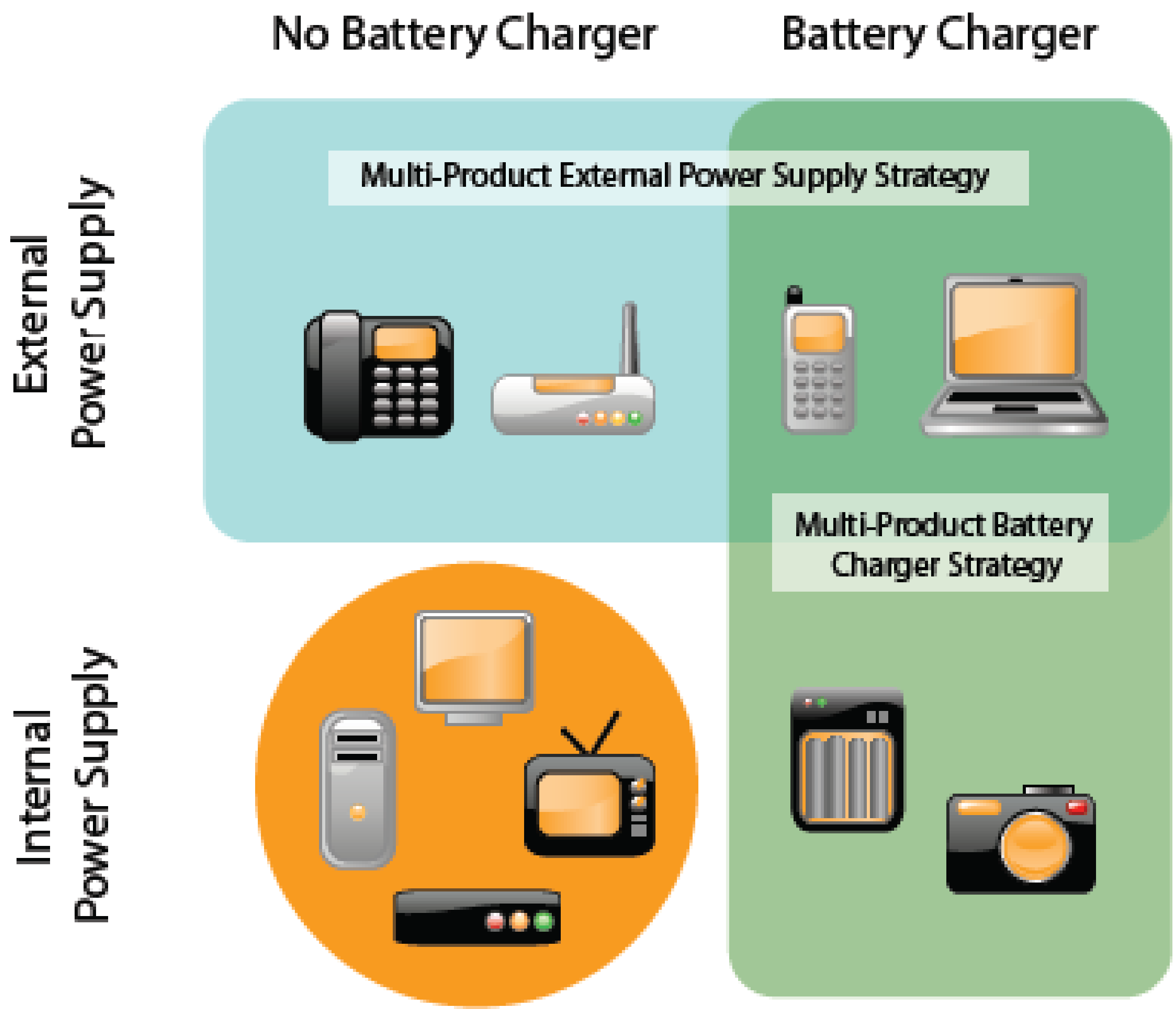
- Battery charger technical and market background
- Battery charger test data
- Technical strategies to improve battery charger system efficiency
- Proposed Title 20 standards
- Summary

Battery Charger Technical and Market Background

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

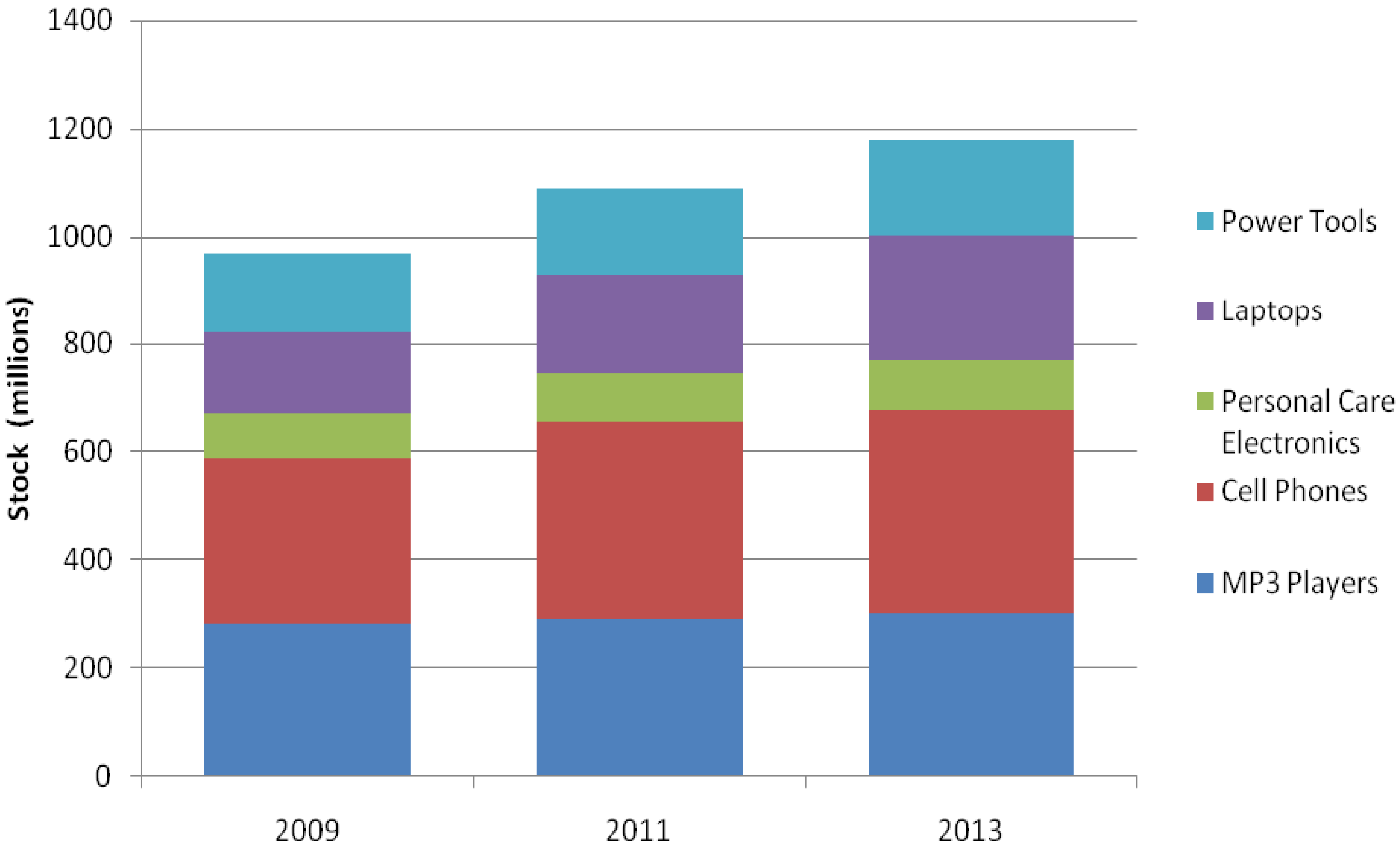


Over 170 million battery chargers in use in California today, suggests a “phase two” horizontal policy approach



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

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

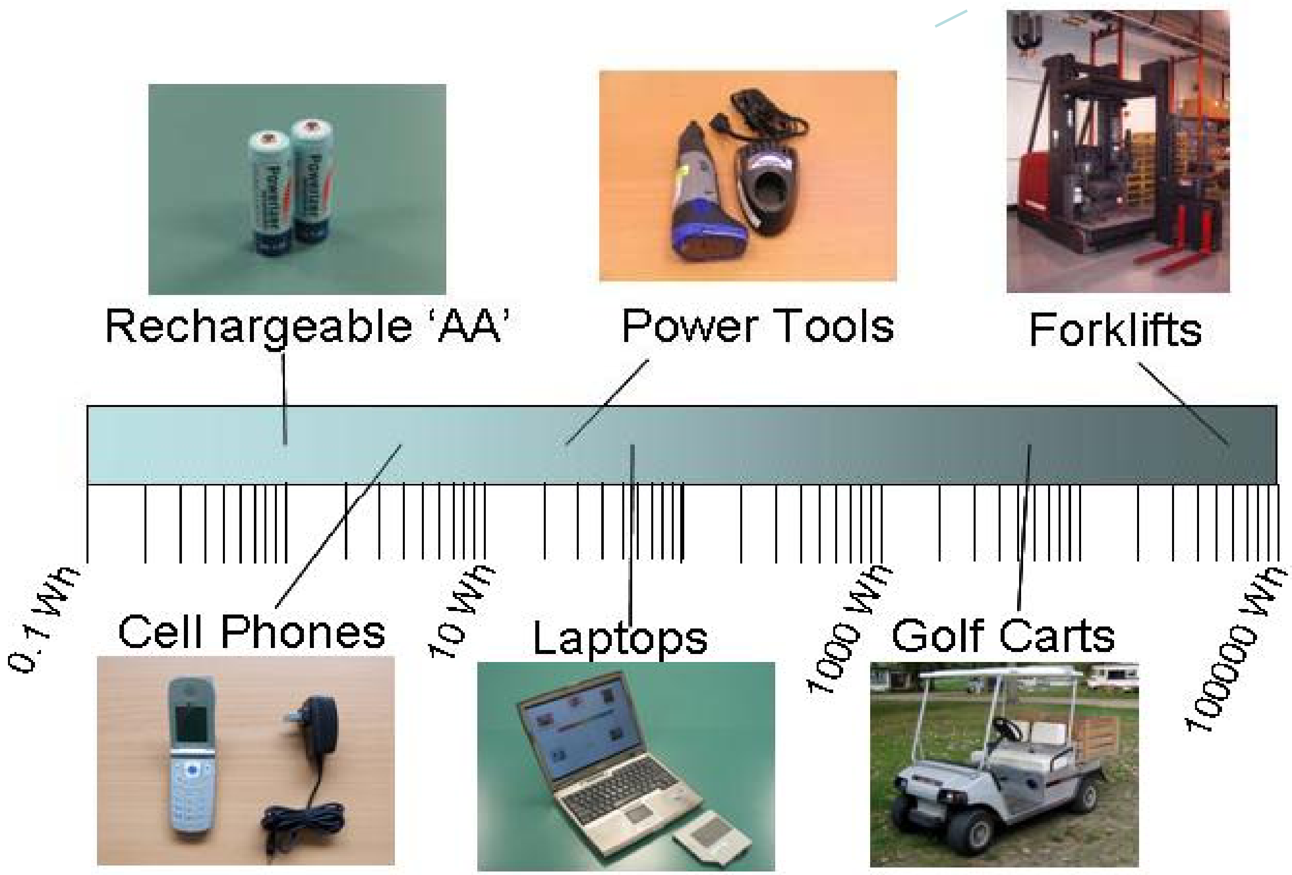


Data Source: (Porter et al. 2010)

Battery size from 10s of watt hours to 1000s watt hours, but all have same function

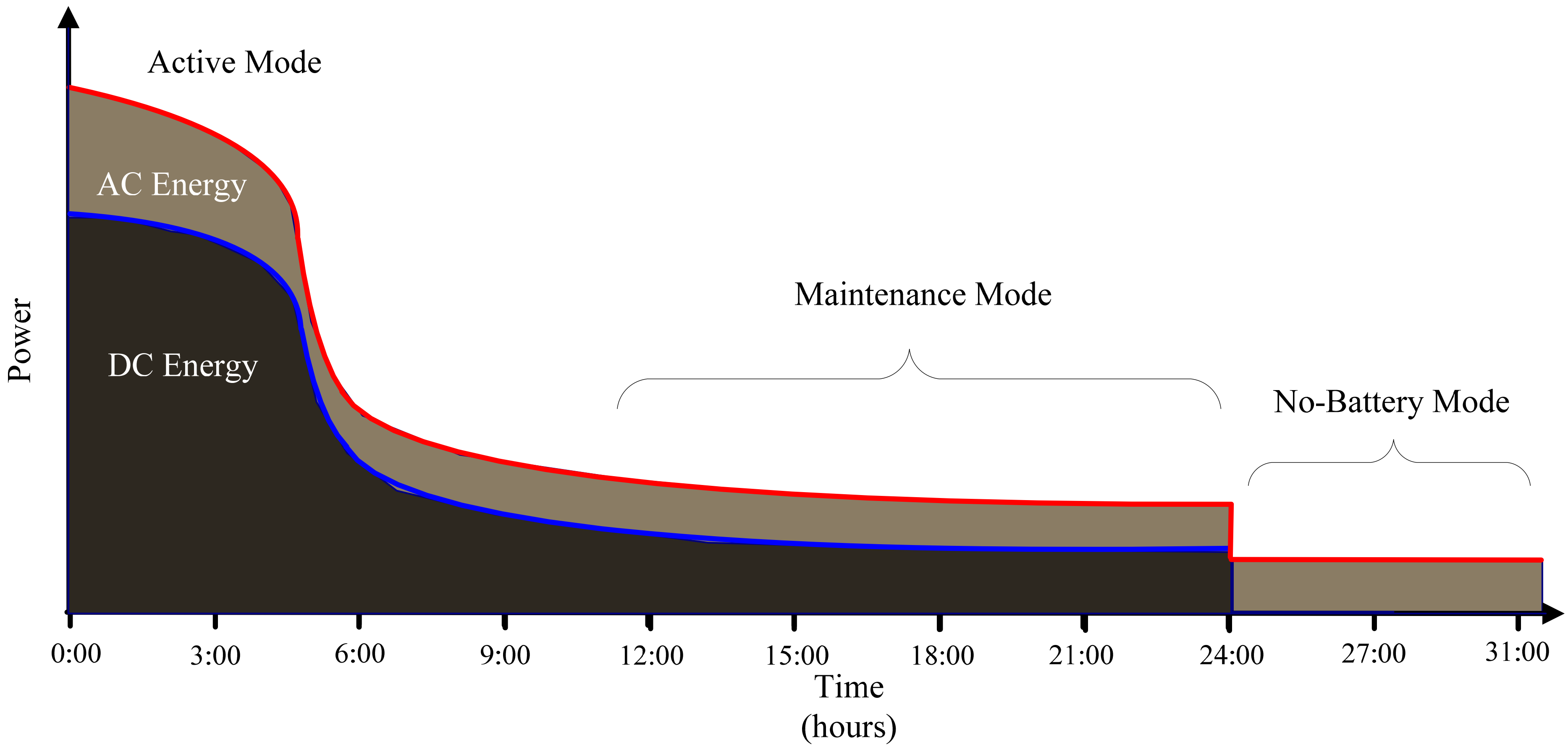
All battery charging Systems include:

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

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



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.

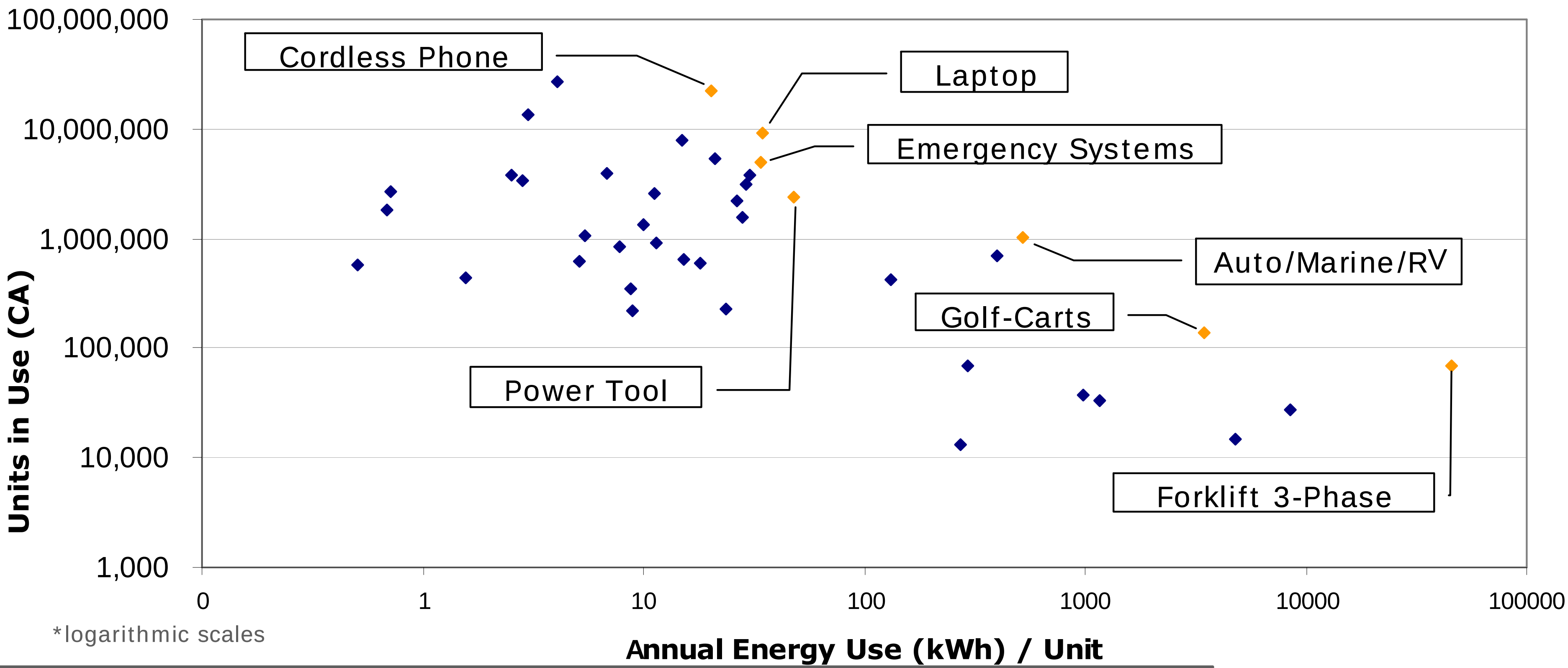
Form Factor 3

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.

Energy Use by Product Category & CA Stock



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

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, silicone 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

* Golf carts are exception to trends in small category

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

Battery Charger Systems: Consumer and Non-Consumer

- **Small Charger: consumer and non-consumer**
  - **Consumer**: cell phones, cordless phones, digital cameras, emergency systems, golf carts, lanterns, laptops, personal care products, personal electric vehicles, portable music players, power tools, toys, universal battery chargers.
  - **Non-consumer**: bar code scanners, emergency egress lighting, commercial 2-ways radios
- **Large Charger: non-consumer only**
  - Industrial lift trucks, bagging handling trucks, electric carts

Battery Charger Test Data

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	C
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 a 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 a broad range of battery capacities, voltages, chemistries, and charger topologies.

Current battery charger test procedures

Measured Quantities		Small Appliance Test Procedure * (ENERGY STAR, CSA, DOE)	DOE Electric Vehicle Charger	Air Resource Board Hybrid Electric Vehicles	Adopted CEC Method, Forthcoming DOE Method# (Small)	Adopted CEC Method (Large)
Power Conversion Efficiency			X	◊	◊	X
Modes (power)	Charge		X	◊	◊	X
	Maintenance	X			X	X
	No Battery	X			X	X
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

details of DOE method forthcoming. Table is based on DOE's last publically indicated direction

Results for Consumer Chargers Vary Over a Huge Range

- 24-hour efficiency
  - Range: 0.4% to 70+%
  - Tested products average 21%
  - Energy-weighted annual average: 10% efficiency
- Maintenance mode power
  - Range: 0.10 W to 170 W
  - Average: 5.1 W; median 2.0 W
- No-battery mode power
  - Range: <1 mW to 70 W
  - Average: 3.2 W; median 1.0 W
- Off mode (few products have an off mode)
  - Range: <1 mW to 2.7 W

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

Utility or consumer features do not necessarily trend with efficiency

Slow Charge Time & Less Efficient

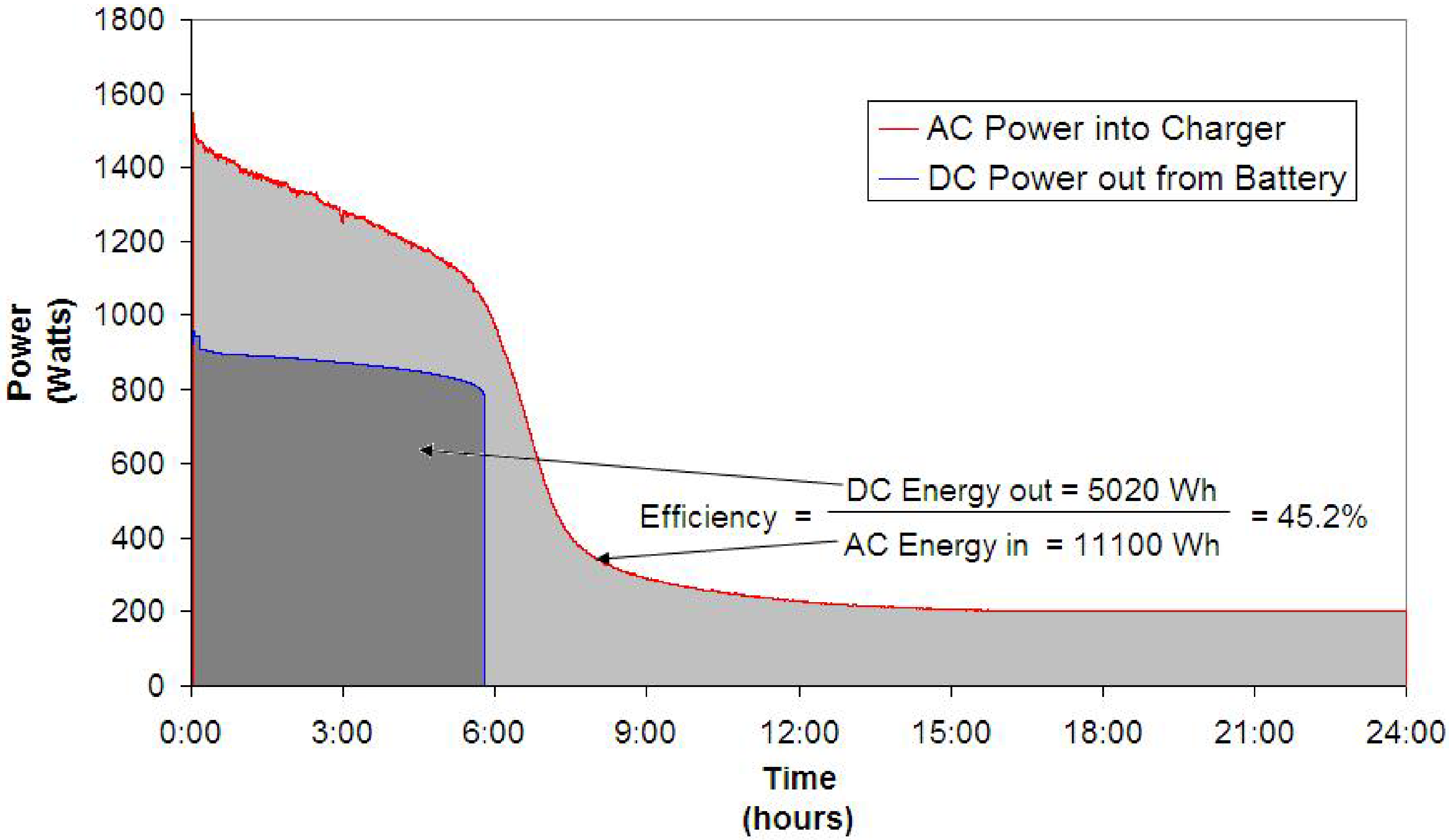
- Product: 18 Volt Drill Charger
- Charge Time: approx. 24 Hours
- 24h Efficiency: 6.6%
- Maintenance Mode: 10.4 watts
- No Battery Mode: 1.8 watts

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

High battery maintenance mode levels have more dramatic consequences for higher power chargers



Industrial Charger Test Results

- Have 47 tests on 15 chargers (performed by SCE, PG&E, and Ametek)
- Results vary over narrow range
  - About 20% variation in power conversion efficiency (74% to 93%)
  - About 30% variation in charge return ratio (1.05 to 1.35)
  - Small improvements are a lot of energy, each unit uses 40 MWh/yr
  - Significant variation in maintenance mode and no-battery mode power (0.4 W to 300 W) shows room for improvement
- Need more elaborate test to distinguish efficient chargers
  - Testing at 3 different depths of discharge
  - Separate measurement of power conversion efficiency and charge return ratio
  - Test is much longer than consumer procedure, requires additional equipment

Technical strategies to improve battery charger system efficiency

Technical improvements documented in EPRI study for CEC

Available at
www.efficientproducts.org

Geist, Tom, Haresh Kameth, et. all 2006. Designing Battery Charger Systems for Improved Energy Efficiency: A Technical Primer. Prepared for the California Energy Commission Contract # 500-04-030, Brad Meister, Contract Manager.

Designing Battery Charger Systems for Improved Energy Efficiency

A Technical Primer

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Prepared for the California Energy Commission
Contract # 500-04-030, Brad Meister, Contract Manager
September 28, 2006

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

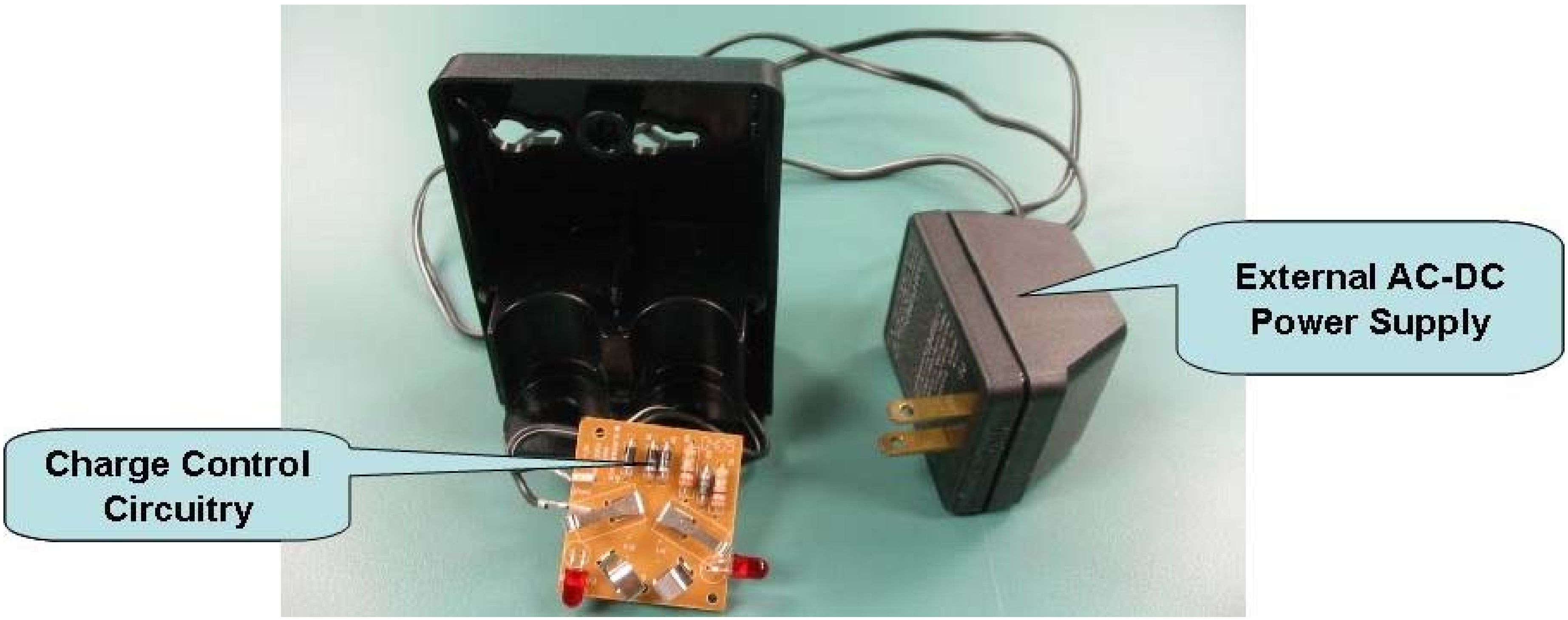
Four key battery charger technology types

Charging Technology	Typical Efficiency	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

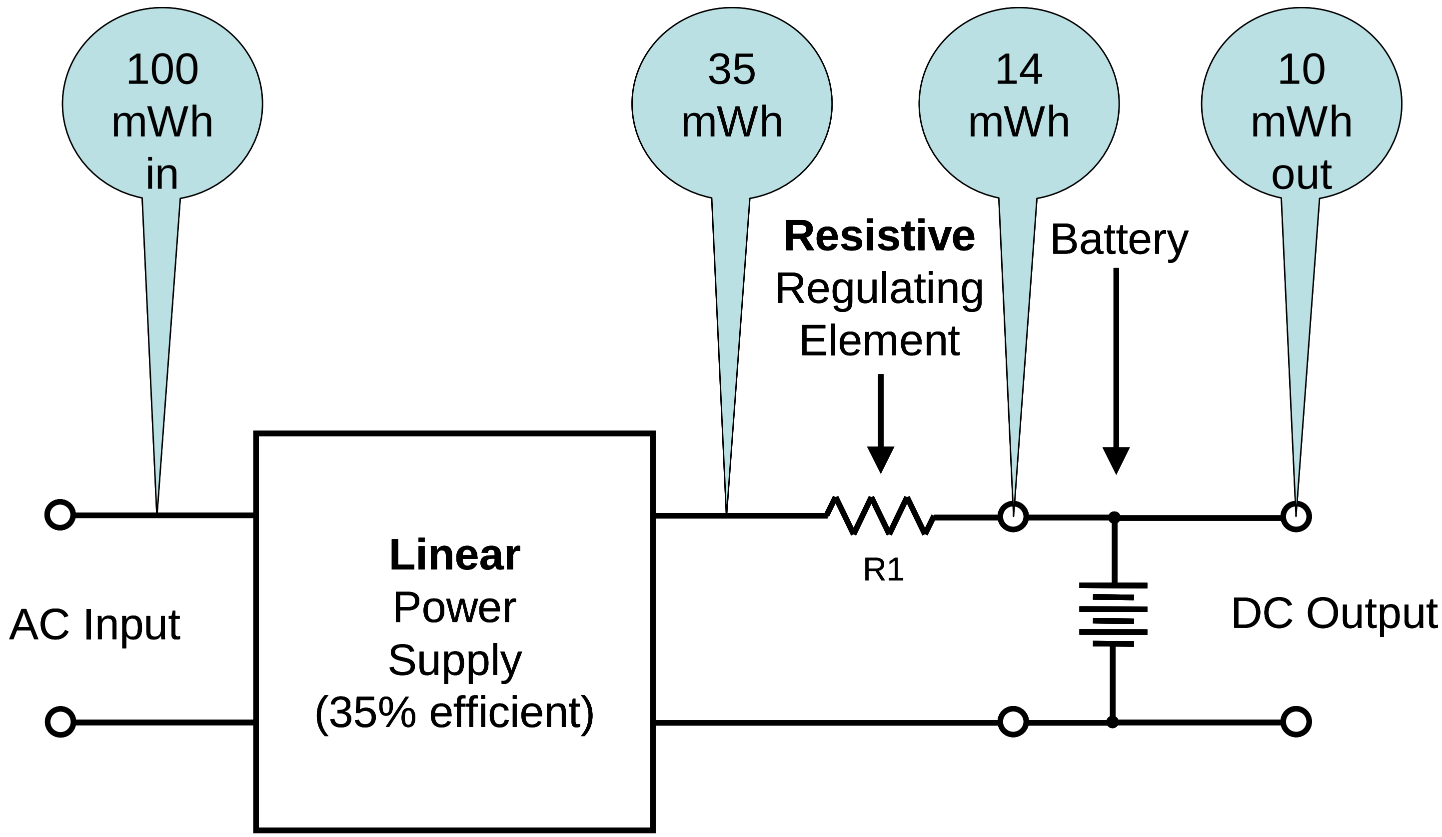
Approaches to improve linear charger efficiency

- Using full wave rectifiers instead of half wave rectifiers
- 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
- Substituting the entire linear battery charger with a switch mode design

Typical small charger where cost drives design: linear power supply, resistive current regulating element

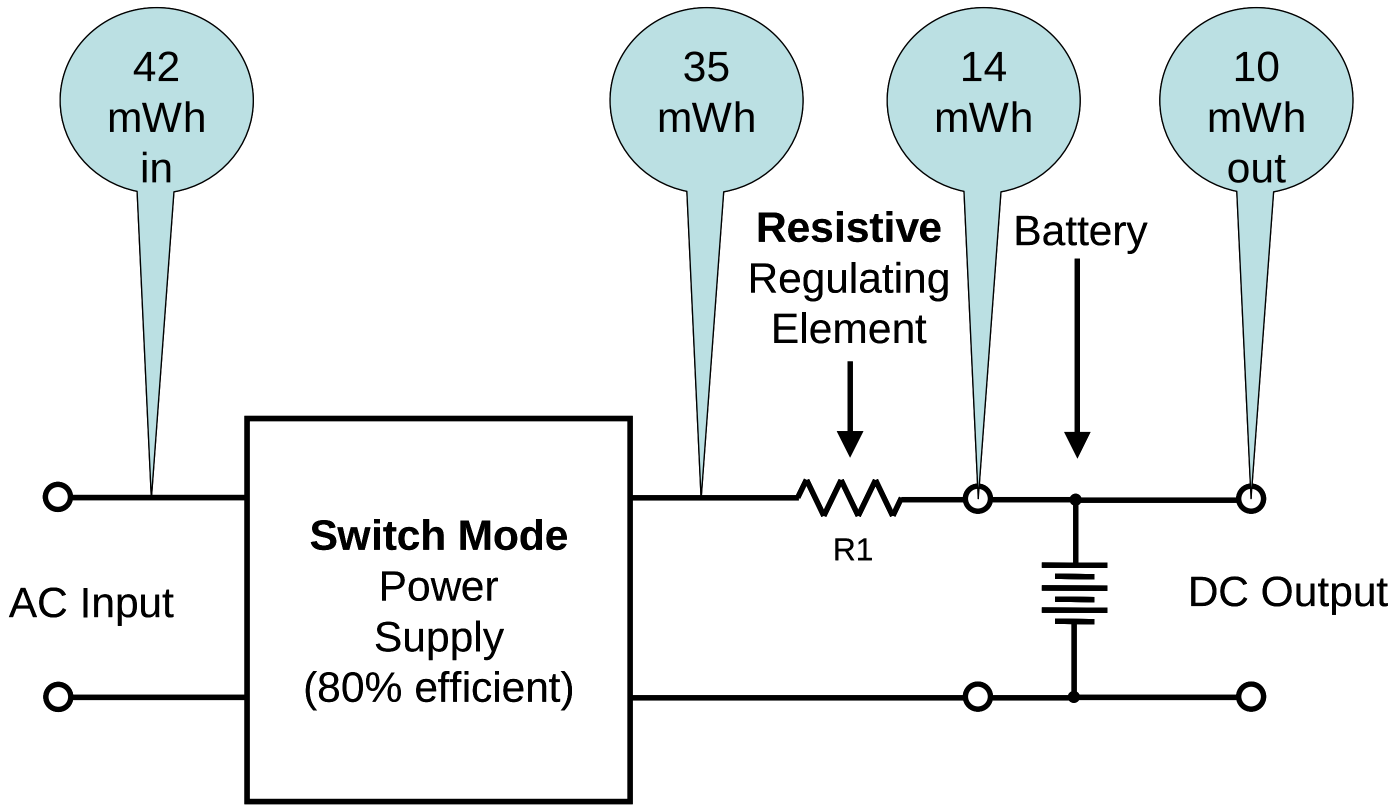


Simplified technical schematic for low-cost linear charger



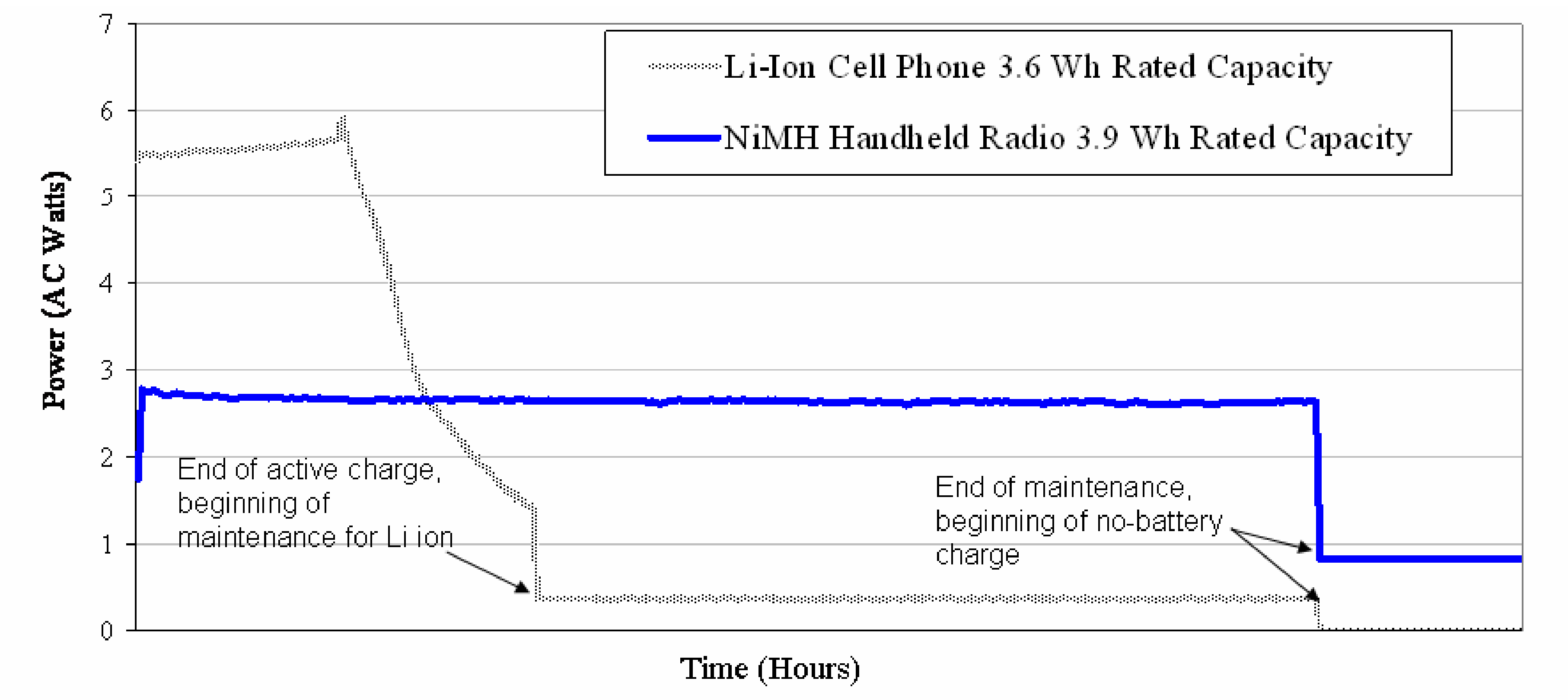
$$\textbf{Efficiency} = \frac{\textbf{10 mWh}}{\textbf{100 mWh}} = \textbf{10\%}$$

Replacing the linear power supply with a switch mode increases charge efficiency by 15 percentage points

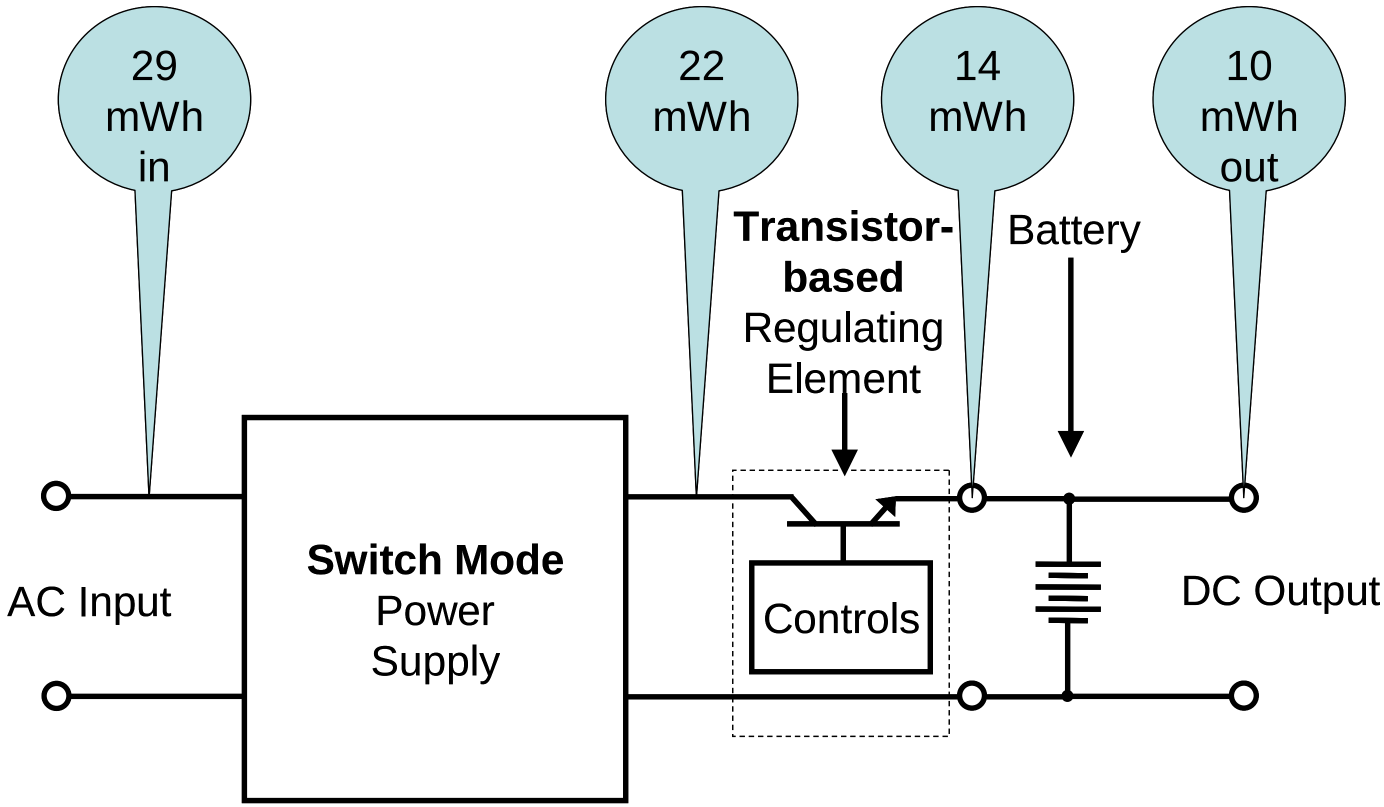


$$\textbf{Efficiency} = \frac{\textbf{10 mWh}}{\textbf{42 mWh}} = \textbf{24\%}$$

Efficiency variations evident, even for chargers with similar battery capacity

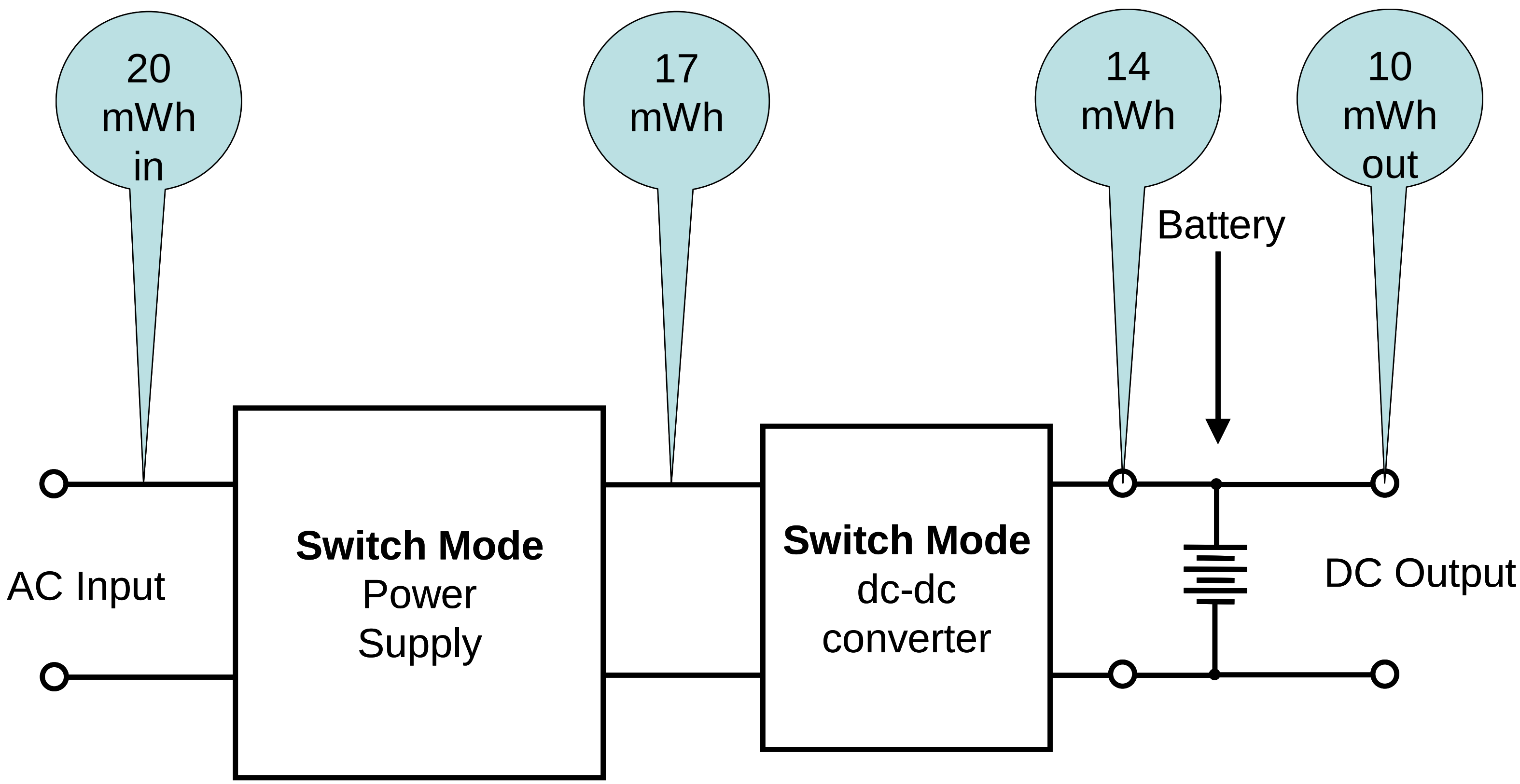


Moving to transistor-based regulating element with “smart” controls increases efficiency to 34%



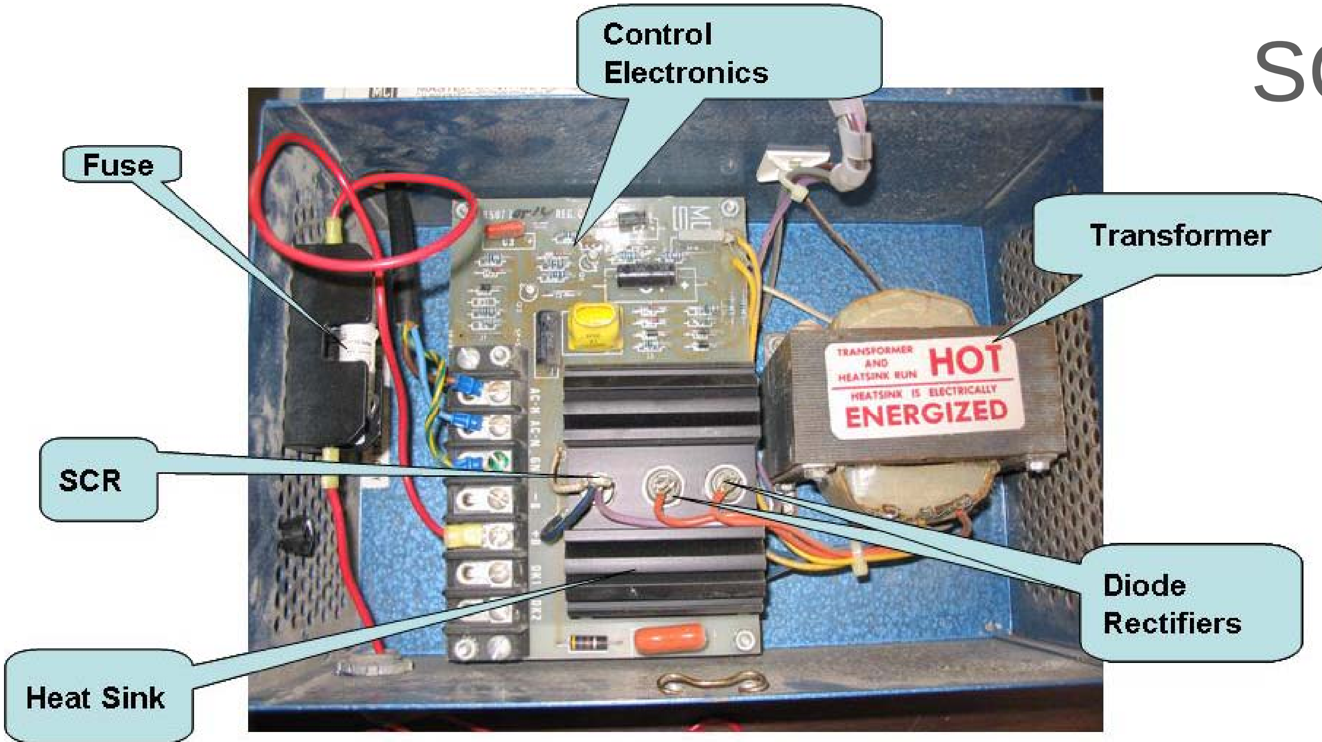
Efficiency = $\frac{\textbf{10 mWh}}{\textbf{29 mWh}}$ **= 34%**

Switch mode power supply and dc-dc convertor: 50% efficiency



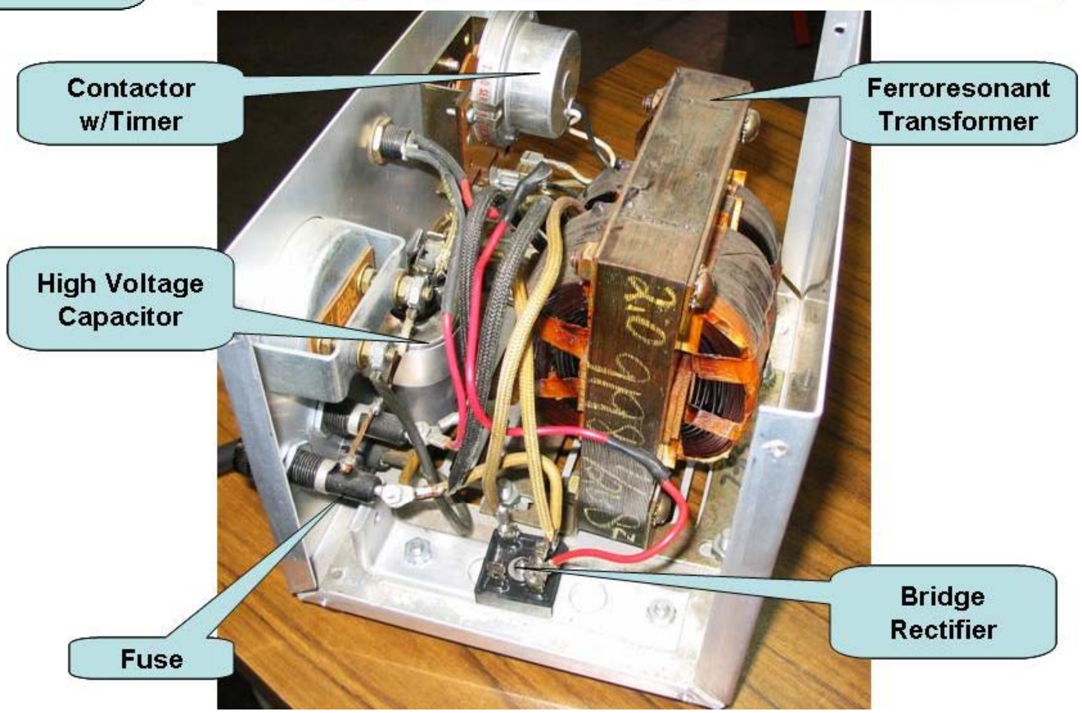
$$\textbf{Efficiency} = \frac{\textbf{10 mWh}}{\textbf{20 mWh}} = \textbf{50\%}$$

50% efficient switch mode charger in products where portability and size drive the design parameters



SCR charger

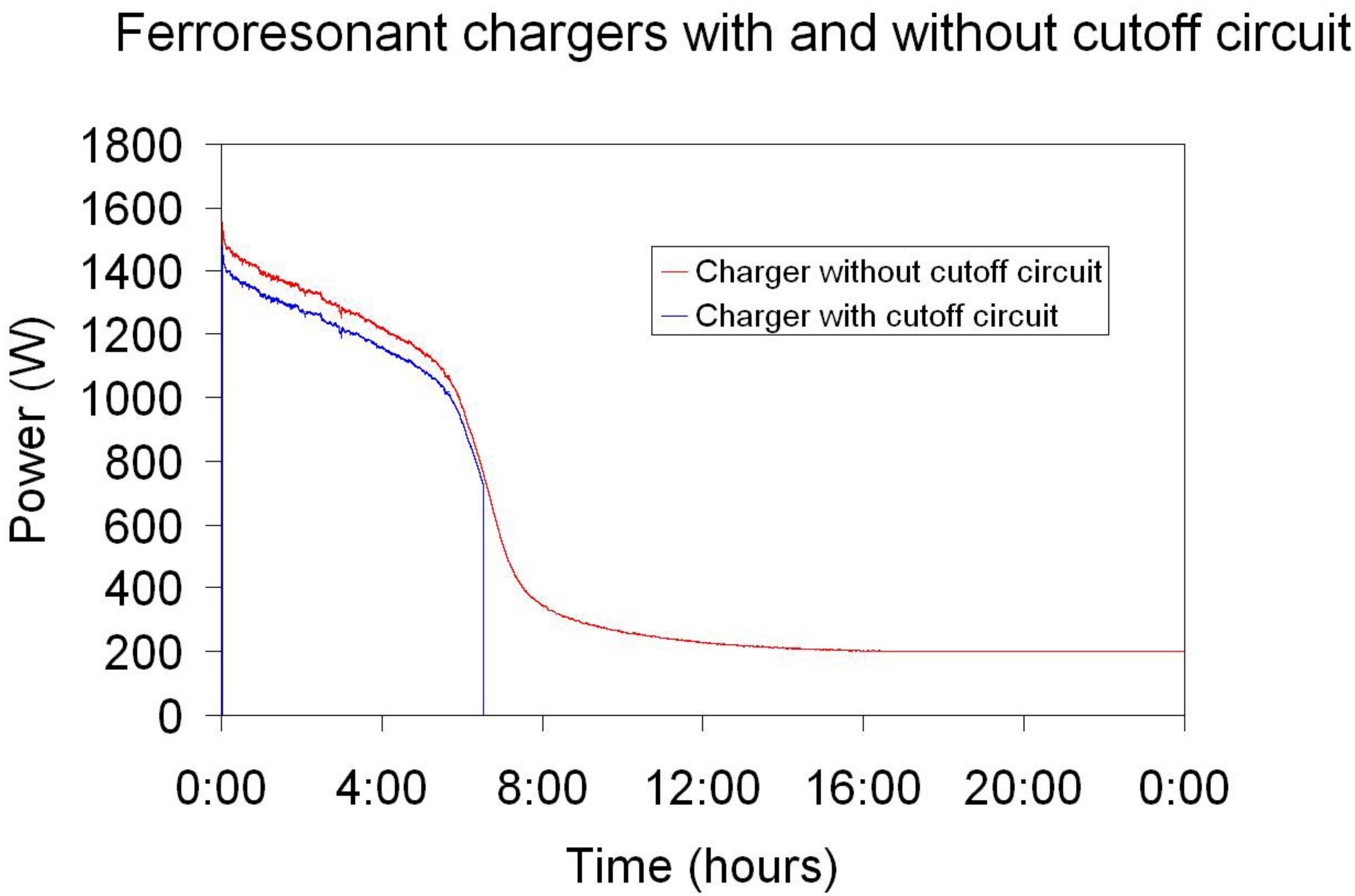
More advanced SCRs: can reduce switching losses by supporting higher switching frequencies.



Ferroresonant charger

Efficiency opportunity in hybrid technology: can optimize the magnetic flux coupling in the transformer to improve power conversion efficiency.

Opportunity to reduce battery maintenance mode for ferroresonant chargers

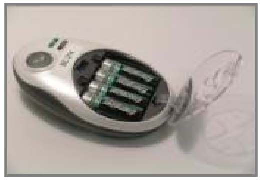


EPRI Summary of Efficiency Improvements in Charger Topologies

Topology	*Typical Efficiency (%)*	*Estimated Improved*
Linear	2% - 30%	20% - 40%
Switch Mode	40% - 60%	50% - 70%
Ferroresonant	25% - 50%	45% - 55%
SCR	30% - 55%	45% - 60%

Proposed Title 20 Standards

Battery Charger System Standards






Scope: Consumer and non-consumer, large and small battery charger systems.

Proposed Standard: Use two-tiered approach to set standards for large charger; single standard for small chargers

Small Battery Chargers: Standards for 24-hour charge-and-maintenance energy, maintenance power, no battery power, and power factor.

Large Battery Chargers: Standards for charge return factor, power conversion efficiency, power factor, maintenance power, and no battery power.

Utilize the Battery Charger Systems test procedure developed through funding by PG&E and CEC-PIER, authored by Ecos, EPRI and SCE.

Potential Effective Date: 2012 (small and large Tier 1) and 2013 (Large Tier 2)

Multiple efficiency metrics preferred over annual energy use metric

- Little to no data on duty cycle of battery charger systems
- Even if data were available, standard deviation likely to be very high
- Annual energy use metric, if employed, likely to represent small fraction of products
- Multiple metrics ensures that each mode is efficient
  - Charge (1 metric for small, 2 for large)
  - Maintenance
  - Standby (no battery)
  - Power factor

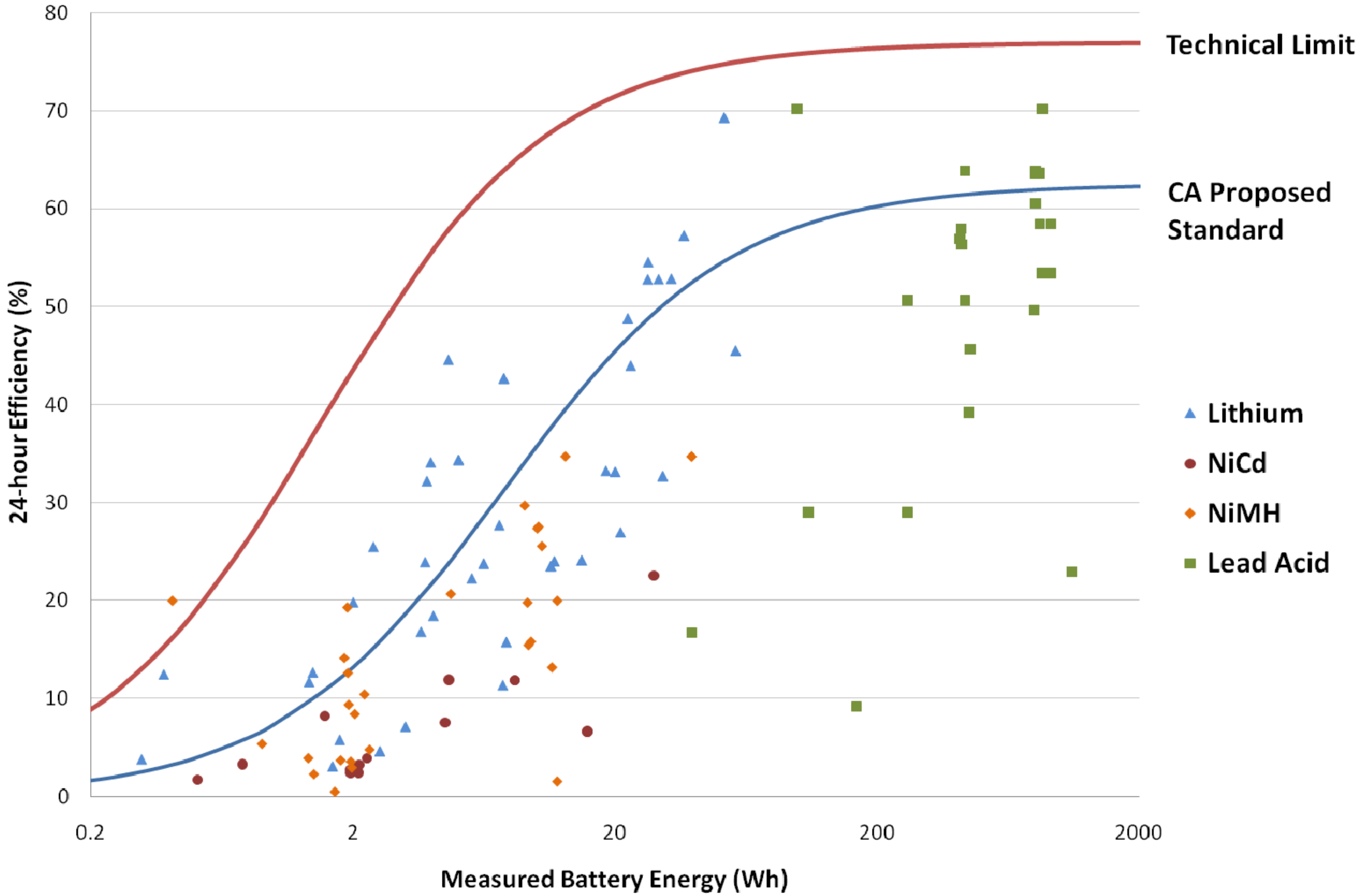
Small charger standards proposal overview

- Three “classes” of small chargers: General, emergency exit signs and inductive chargers
- Emergency exit signs special safety consideration: lights must be continuously on (may be federally preempted)
- Inductive chargers special utility/safety consideration: corrosion of metal contacts in wet environment, safety
- All other chargers should be able to meet any dual functions within small standards proposal (e.g. LED lights, charge indication, clocks, etc.)
- Focus on general small charger standards: same for consumer and non-consumer chargers

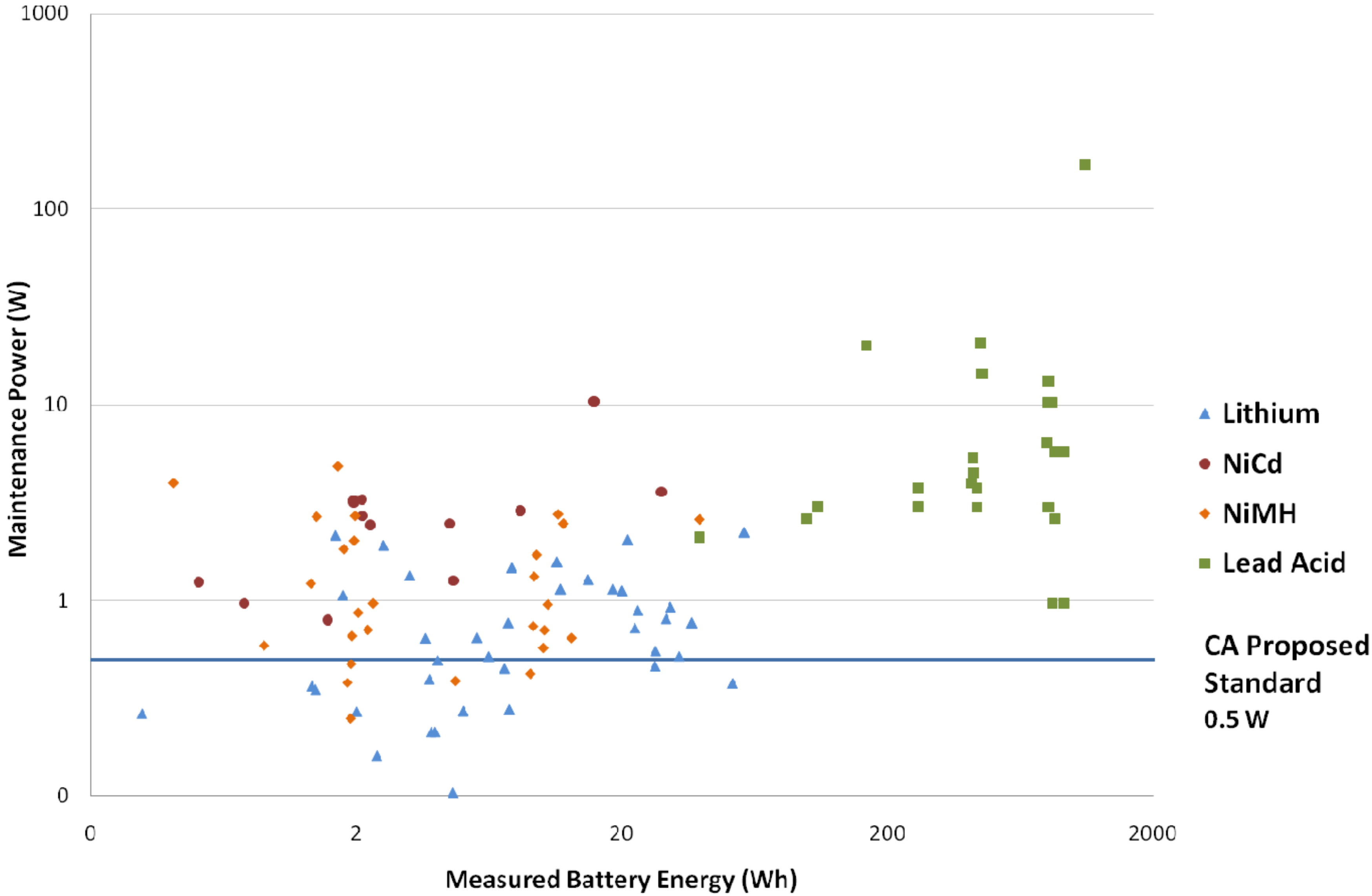
Small Charger Standards Proposal (consumer and non-consumer)

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 Power	Less than or equal to : **0.3 W**
Power Factor	Depends on input current

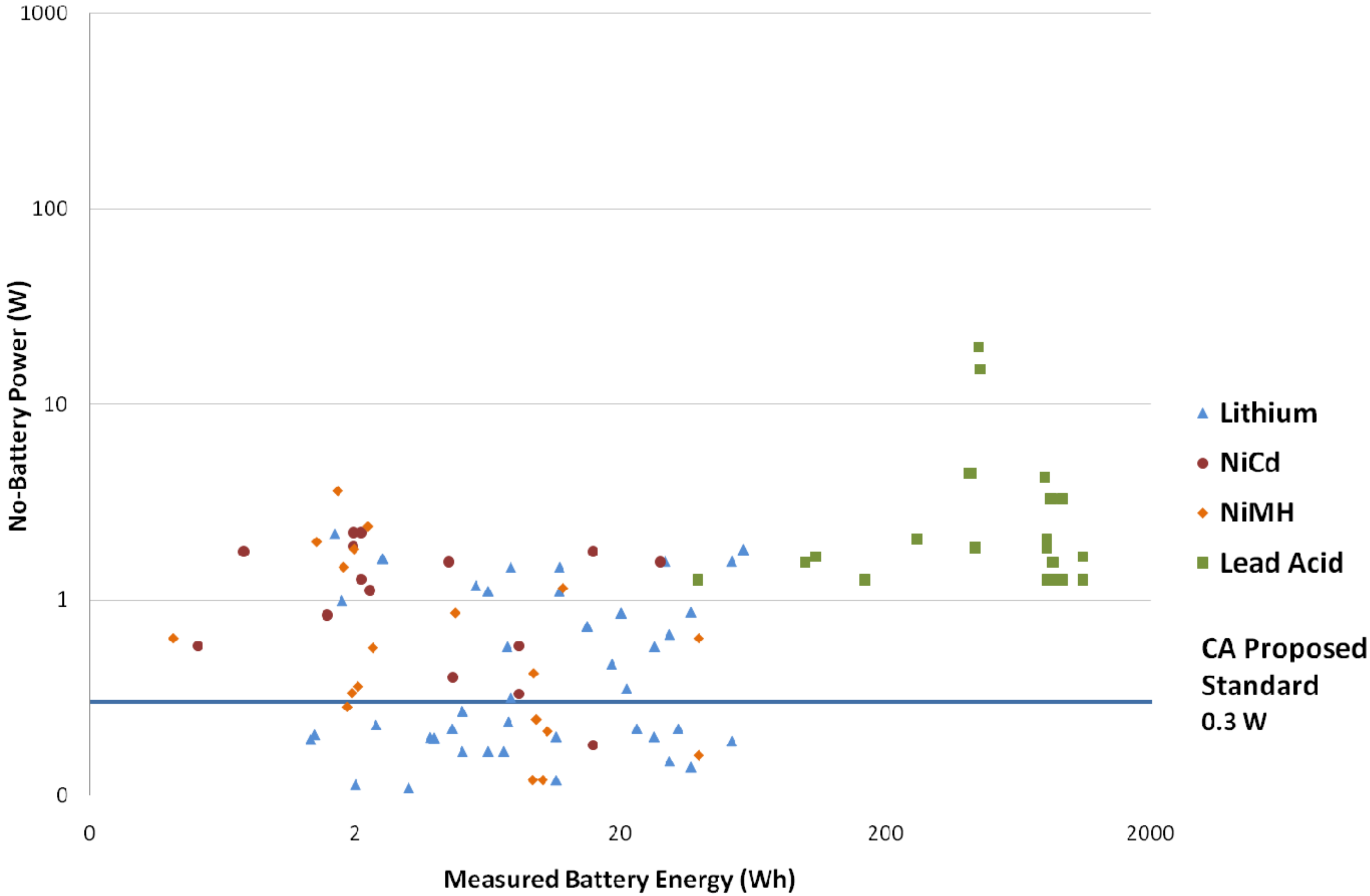
Active Mode Efficiency



Battery Maintenance Mode Level



No Battery Mode Level



Emergency Exit Sign Standards Proposal (non-consumer)

Metric	Requirement
24 hour charge and maintenance energy (Wh)	Less than or equal to: **$20 + 1.6E_b$** (E_b = battery capacity)
Maintenance Power	Less than or equal to: **0.8 W**
No Power	Not applicable
Power Factor	0.9 for currents > 1.0 A

Inductive Charger Standards Proposal

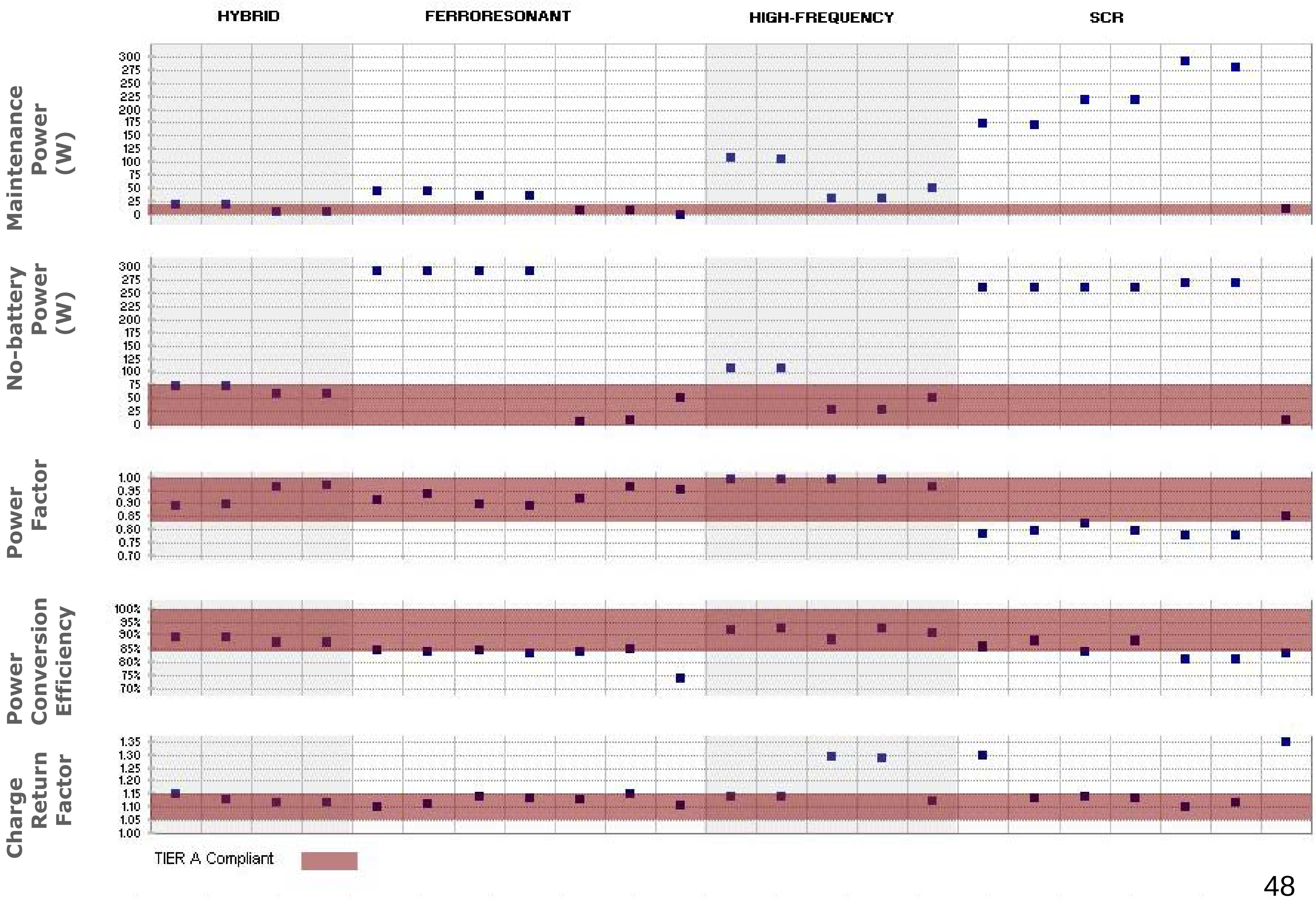
- Developed with feedback from industry
- Meet either the small standards proposal or the 1.0 W “all the time” standard (below)

Metric	Requirement
24 hour charge and maintenance energy (Wh)	Less than or equal to: **24**
Maintenance Power	Less than or equal to: **1.0 W**
No Power	Less than or equal to: **1.0 W**

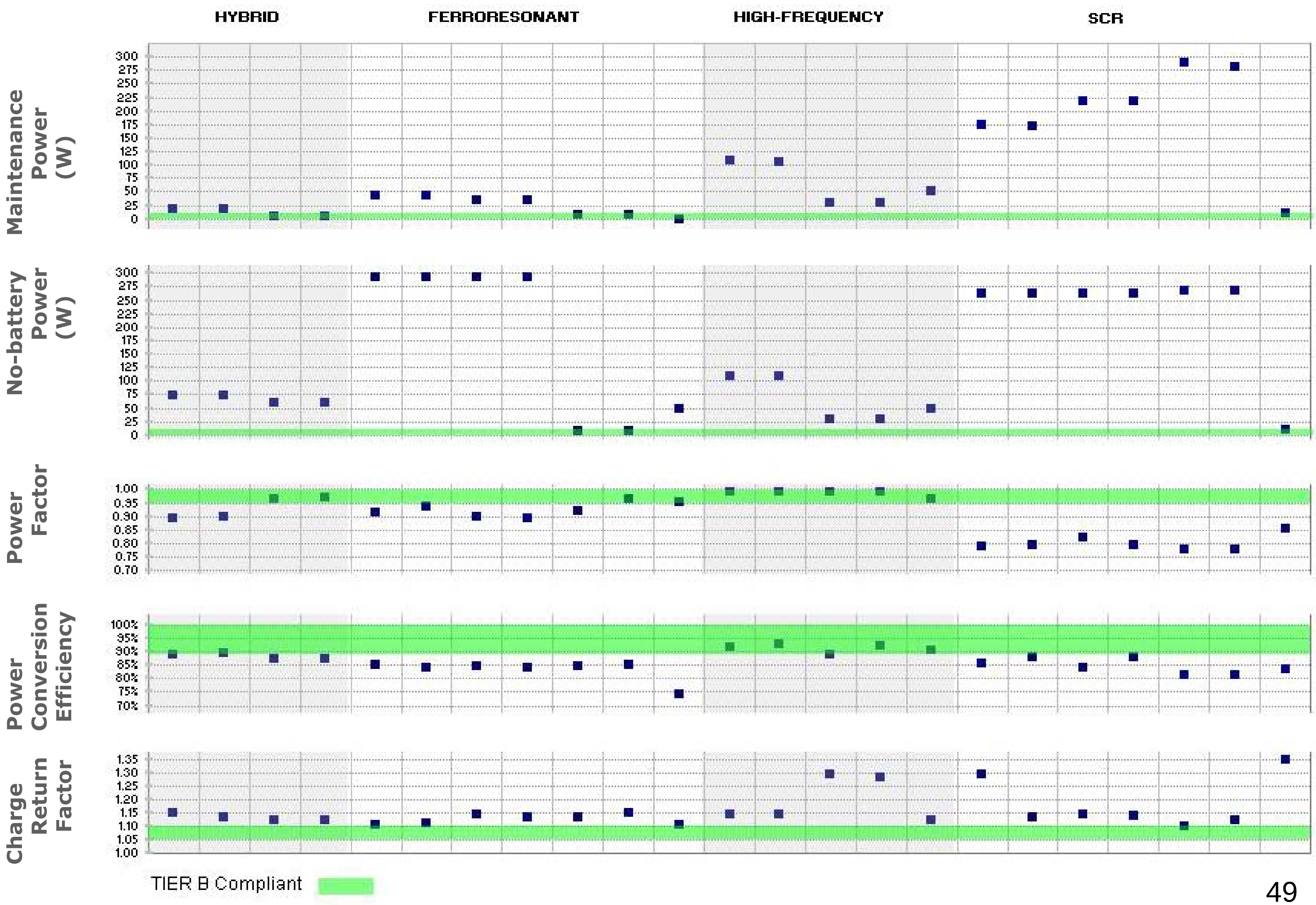
Large Battery Charger System Proposal

		Tier 1	Tier 2
Charge Return Factor (C_{rf})	**100% & 80% Depth of Discharge**	**$1.05 \leq C_{rf} \leq 1.15$**	**$1.05 \leq C_{rf} \leq 1.10$**
	40% Depth of Discharge	**$1.05 \leq C_{rf} \leq 1.20$**	**$1.05 \leq C_{rf} \leq 1.15$**
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**

Tier 1: Large Battery Charger System Testing



Tier 2: Large Battery Charger System Testing



Incremental Cost of Efficiency Improvements for for Small Battery Charger Systems

- Of 170 M BCS in California, about 42% already comply
- Of nearly 100 M that need improvement, average unit lifetime savings is over 11 kWh/yr
- High-tech products (cell phones, mp3, netbooks) have brought efficient chargers into the mass marketplace
- Advanced BCS controller IC's sell for less than $0.05 in OEM quantities
- Some products might be required to have high efficiency in rarely-used modes
  - When a charger is being designed to be efficient, the additional cost of improving that mode is very small
- Added cost is on average $0.30 to save $0.78 per year over product lifetime (present costs)

Incremental Cost of Efficiency Improvements, Large BCS

- Tier 1:
  - Smarter charge control electronics available as modularized add-ons ($100 to $150)
- Tier 2:
  - power conversion efficiency technologies needed to achieve Tier 2 levels require newer technology that is currently more expensive ($100 to $400)
  - Incremental cost of the more efficient chargers recovered in first year of operation and certainly within the lifetime of the charger

Power Factor Correction Justified Only for Large Currents

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

EPRI SOLUTIONS

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- Policy approach based on EPRI report that showed measurable energy savings from improved power factor
- For battery chargers, cost effective to consumer only for large currents (>1A)
- 7.5% of usage attributable to losses associated with poor power factor

Test protocol recommendation

- CEC utilize 2008 CEC test procedure for standards development: part 1 and part 2
  - Part 1: small chargers
  - Part 2: large chargers
- Adopt DOE consumer battery charger test procedure for small standard once finalized (12/2010, 1/2011)
- Part 2 of CEC test procedure freestanding protocol used after DOE final test procedure rule—can test large non-consumer chargers

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)
All BCS Energy Savings	35% of current energy usage
rosenfeld	0.9
Equivalent household electricity usage savings	390,000 homes

- Net present value of all energy savings is $450 M in first year and 2.4 B after stock turnover
- All cost-effective savings opportunity is considerably greater

Summary

Summary for Small Chargers

- High-volume, high tech products have made efficient charging solution inexpensive and widely available
- PG&E research demonstrates the 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 ratio
  - 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

References

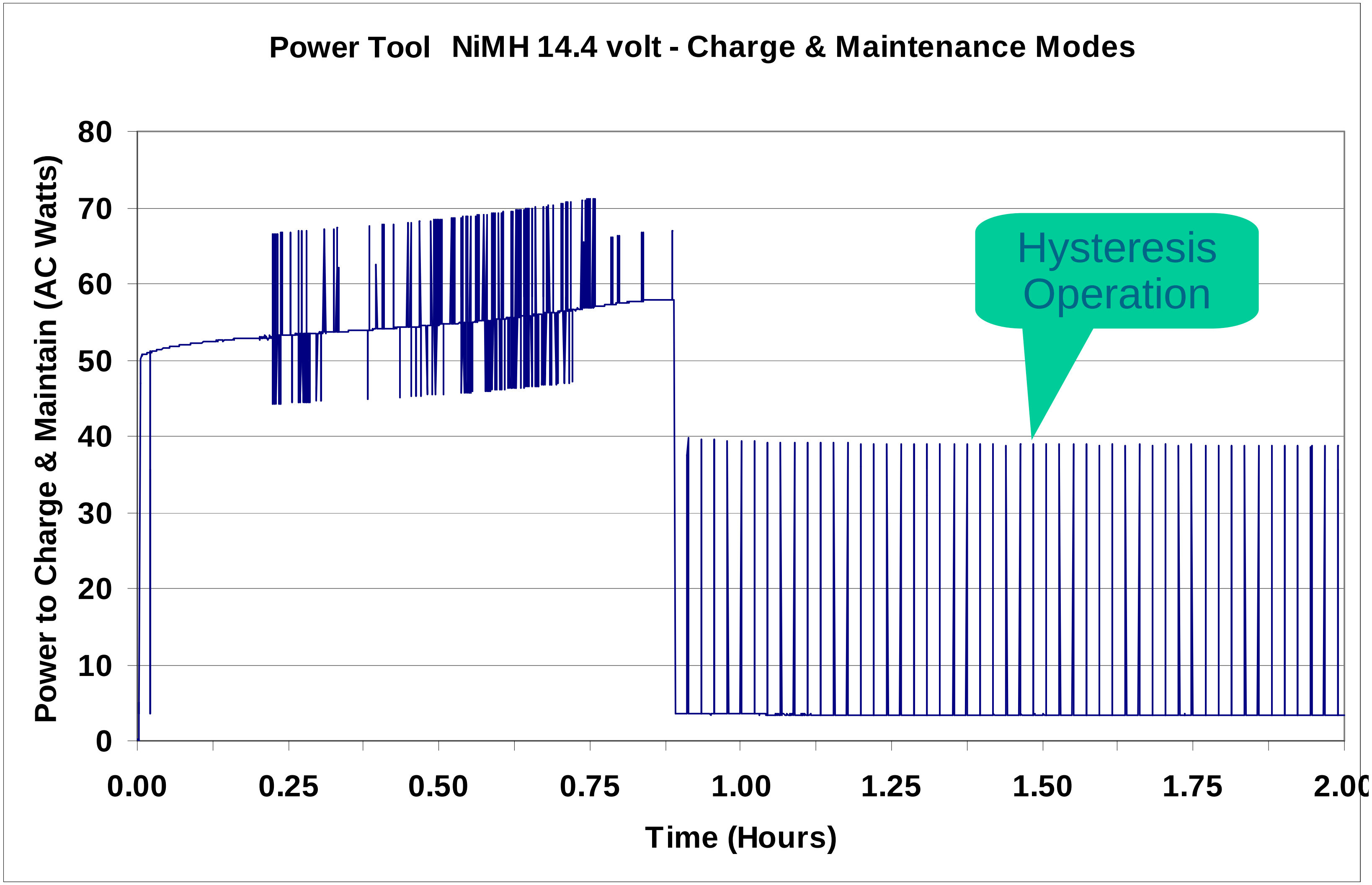
Geist, Tom, Haresh Kameth, and Peter May-Ostendorp. 2006. Designing Battery Charger Systems for Improved Energy Efficiency: A Technical Primer. Prepared for the California Energy Commission Contract # 500-04-030, Brad Meister, Contract Manager.

Porter, Suzanne Foster, Paul Bendt, Haresh Kamath, Tom Geist, Jordan Smith, Loïc Gaillac, and José Salazar. 2009. Energy Efficiency Battery Charger System Test Procedure Version 2.2.

Porter, Suzanne Foster, Paul Bendt, Jeffrey Swofford, and Jonathan Carter Hebert. 2010. Analysis of Standards Options for Battery Charger Systems. In *Codes and Standards Enhancement (CASE) Initiative For PY2009: Title 20 Standards Development: prepared for Pacific Gas and Electric Company.*

Additional Material

Hysteresis operation: reduces battery maintenance mode power



Summary of techniques to improve switch mode battery charger designs further

- **Resonant switching configuration**: can reduce switching losses in larger switch mode battery chargers when operating in charge mode.

- **Synchronous rectification**: can reduce voltage drop and thus power losses in the power supply by using a transistor instead of a diode to conduct during certain cycles of operation.

- **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.

Approaches to improve charge control for all topology types

- **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
- **Reduced fixed energy consumption**: may reduce no-battery mode power and energy usage overall