Batteries

Energy
ITP / NYU / Feddersen

Batteries

Electrochemical energy storage devices. How do they work?

http://www.youtube.com/watch?v=CJK2kwF6Am4

(or https://www.youtube.com/watch?v=9OVtk6G2TnQ if you prefer this style)

No matter how they work, the same considerations apply as for any energy storage:

- Energy per unit volume and mass
- Power per unit volume and mass
- Efficiency – ratio of energy in to energy out

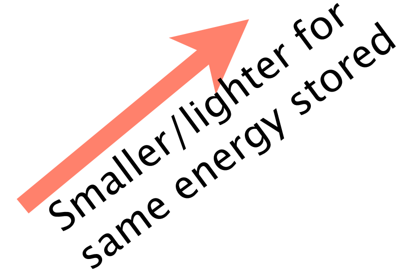
General battery concepts

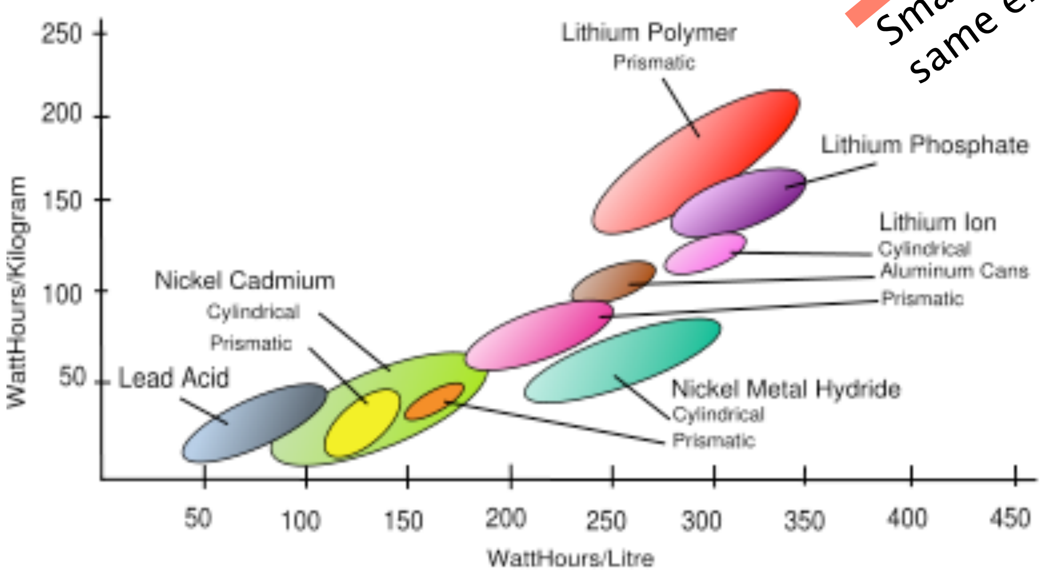
- “**Cell**” refers to single electrochemical unit; “**battery**” to an array of cells.
- **Voltage** of a cell is intrinsic to chemistry involved; maximum current depends on amount of material (like PV).
- Cells can be arranged in **parallel** to increase maximum **current**.
- Cells can be arranged in **series** to increase **voltage**.
- “**Primary**” = non-rechargeable, “**secondary**” = rechargeable.
- Exceeding maximum or minimum cell voltage will damage the cell (potentially hazardously).

Chemistry – what is the battery made of?

Effects energy density, charging methods, safety considerations, etc. Some common types are:

- Lead acid
- Nickel Cadmium (NiCad)
- Nickel Metal Hydride (NiMh)
- Lithium



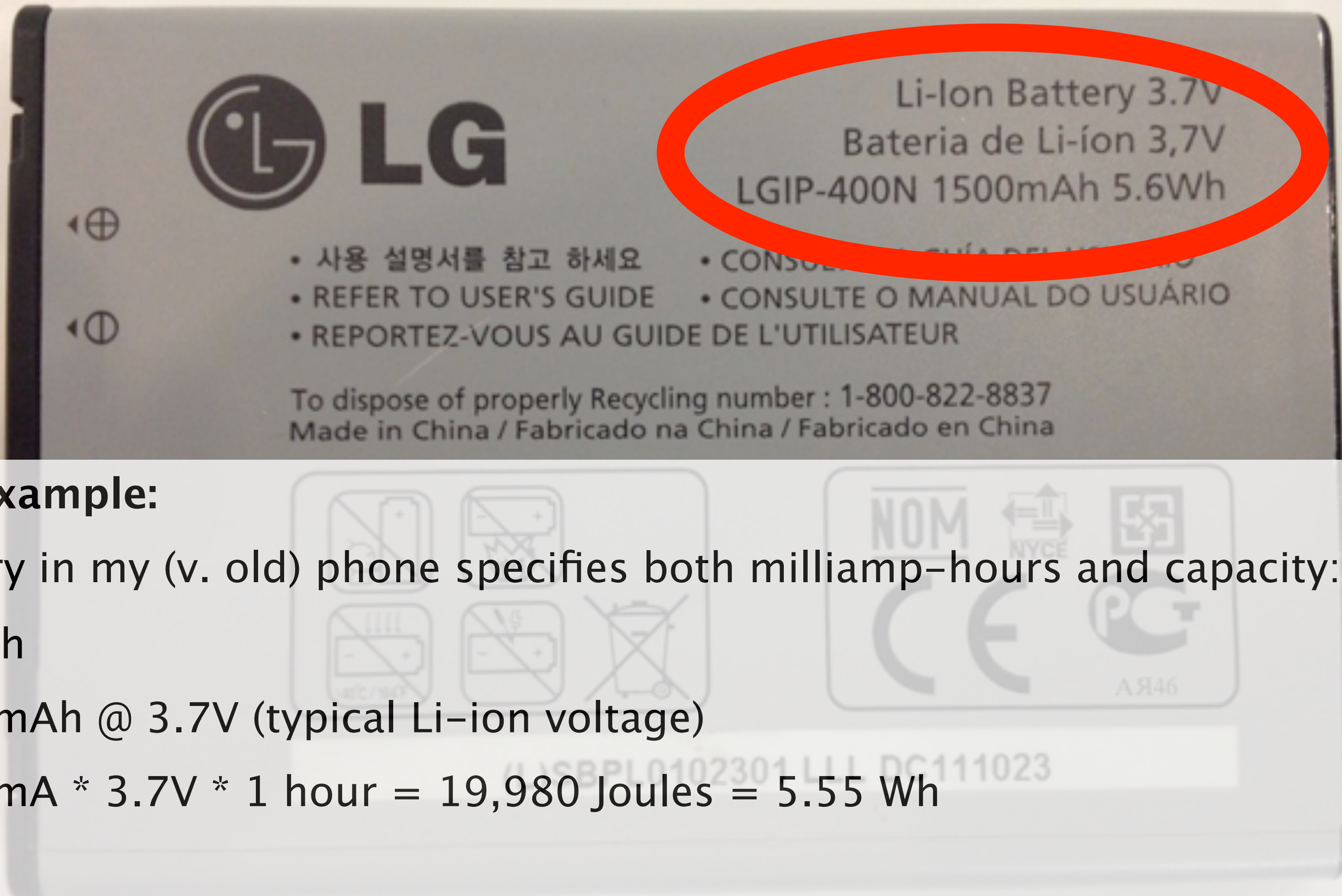


Capacity - how much can the battery hold?

Typically specified in **amp-hours** (or milliamp-hours), abbreviated Ah or mAh.

Can be roughly converted to joules by multiplying amps * 1 hour * nominal voltage.

Capacity – how much can the battery hold?



For example:

Battery in my (v. old) phone specifies both milliamp-hours and capacity:

5.6 Wh

1500mAh @ 3.7V (typical Li-ion voltage)

1500mA * 3.7V * 1 hour = 19,980 Joules = 5.55 Wh

C-Rate

Battery charge/discharge currents are typically given as a **ratio to total capacity** called the **C-Rate.**

For example, for a 750 mA-hour battery:

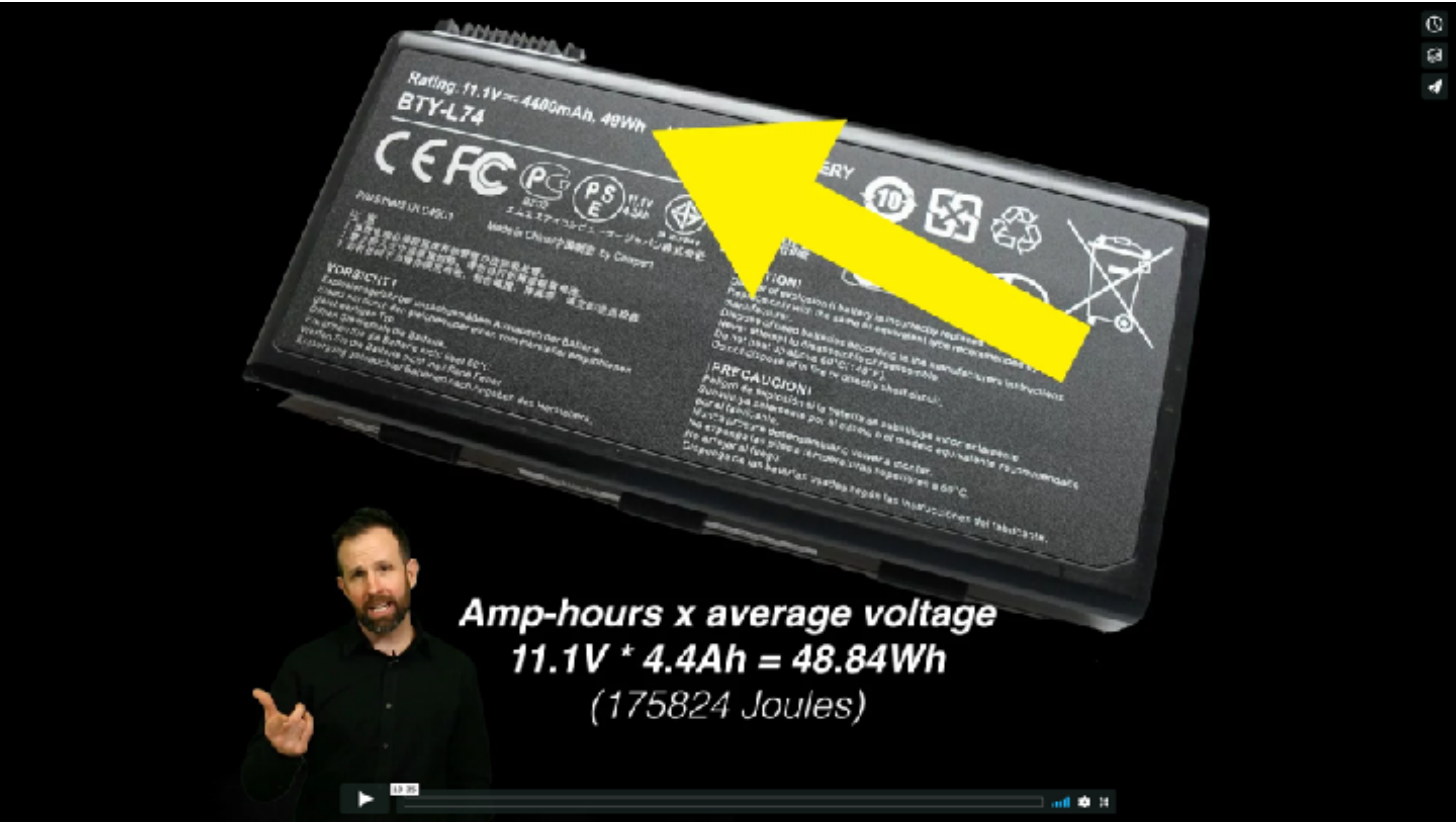
1C = 750mA

2C = 1500mA

.5C = 375 mA

A very important battery specification will be its **maximum safe discharge current**. This will vary widely depending on battery type.

The rated capacity of a battery is (usually) specified for its **C/20 (1/20 C) discharge rate**. Higher or lower rates of discharge may decrease realized capacity.



ITP Energy channel has detailed lecture on Amp-hours and C-Rate

Capacity – technical note

Technical Detail:

Actual capacity depends on how fast the battery is discharged. Discharging a battery very quickly, or slowly, can reduce the realized capacity.

The capacity figure is given for 20-hour discharge rate (C/20)

For example:

A 12 volt battery (~14-10V during use) with a rated capacity of 10 amp-hours could average 12V while supplying 1/2 amp (500 mA) for 20 hours:

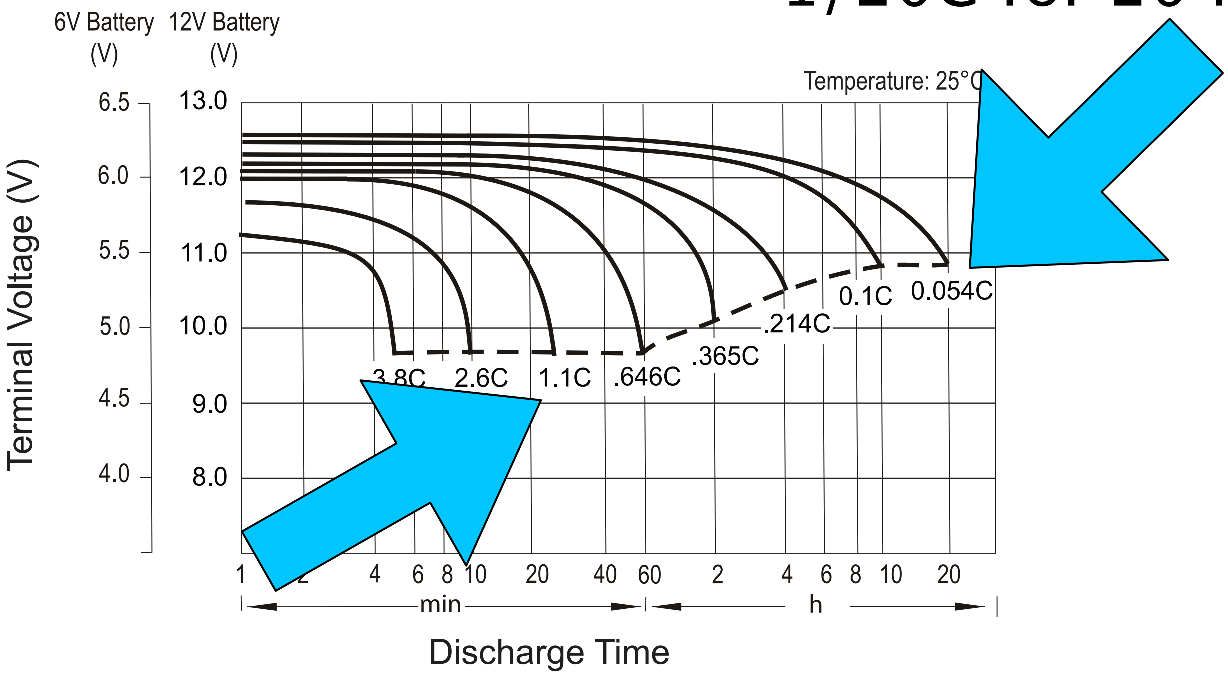
(12 volts) * (500 milliamperes) * (20 hours) = 432 000 joules

More about calculator.

PDC-121100	12	107	100.0	12.99	330	6.81	173	8.46	215	8.66	220	
PDC-122000	12	214	200.0	20.55	522	9.45	240	8.58	218	8.82	224	

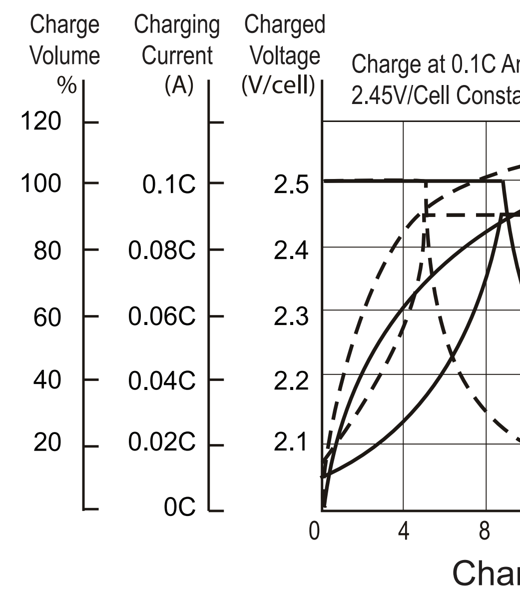
Discharge Characteristics

1/20C for 20 hours OK!



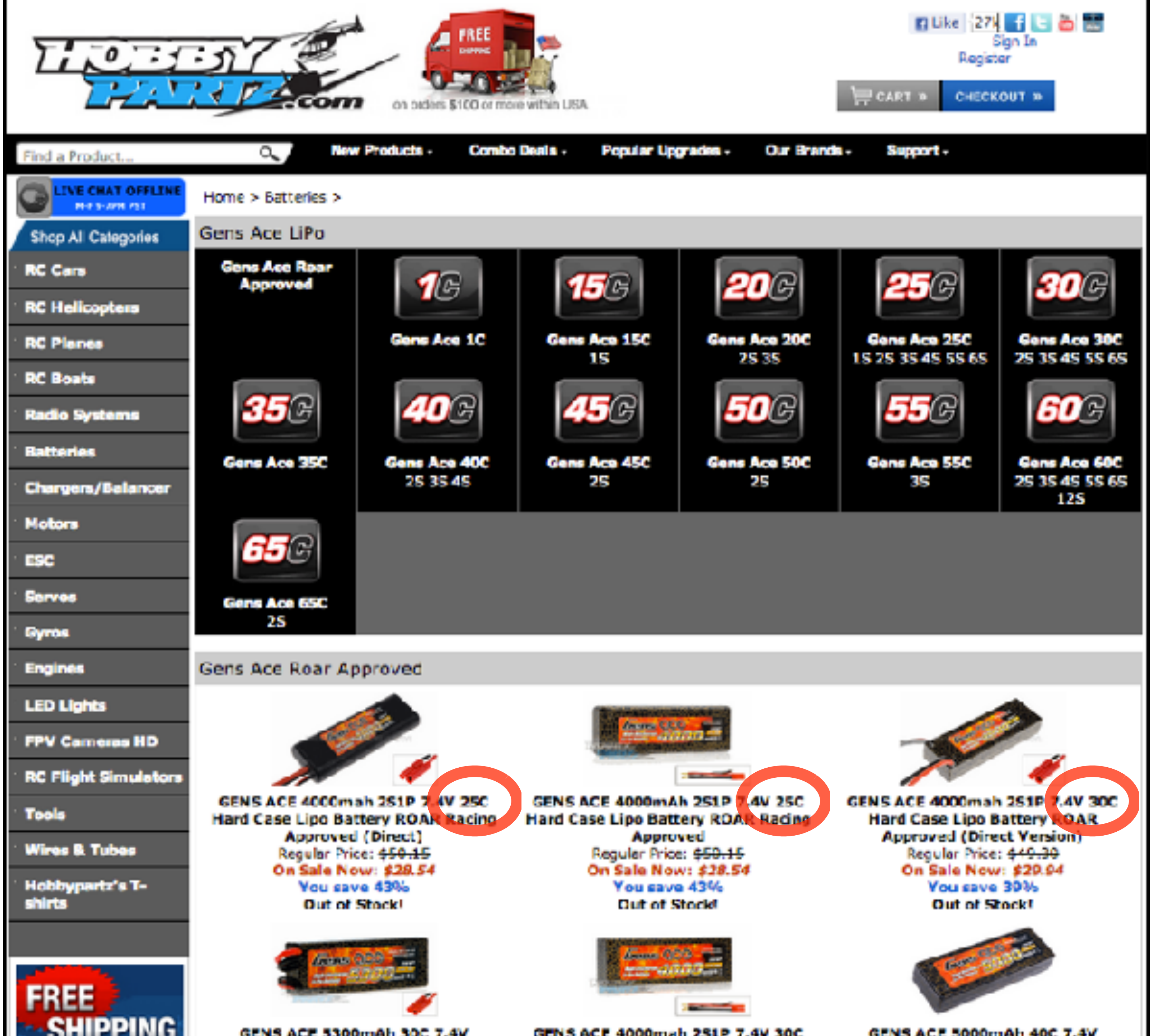
1C for only ~20 minutes, NOT 1 hour

Float Charging Character



Temperature Effects in Relation to Capacity

Cycle Life in Relation to D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Gens Ace 15C
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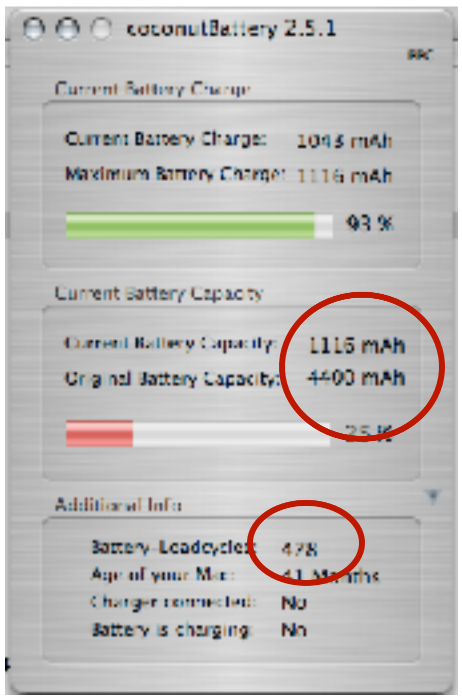
Regular Price: $40.30
On Sale Now: $28.04
You save 30%
Out of Stock!

Other considerations:

Battery life – how many times a battery can be charged and discharged. Varies widely by type.

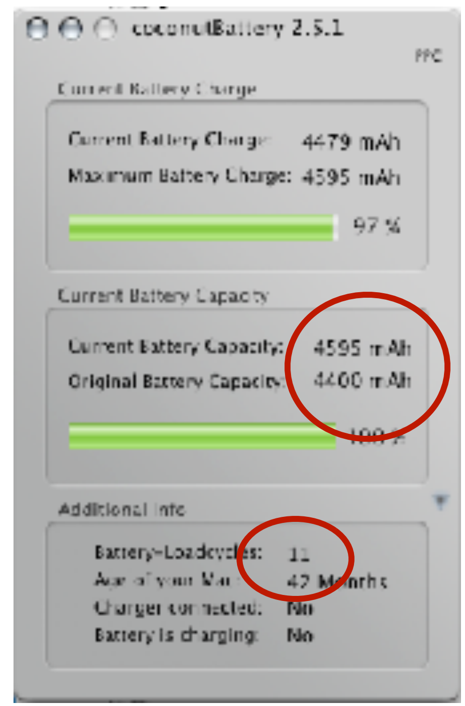
Depth of discharge – how deeply can it be discharged? Decreasing DOD increased life expectancy.



Old Battery

Capacity

Cycles



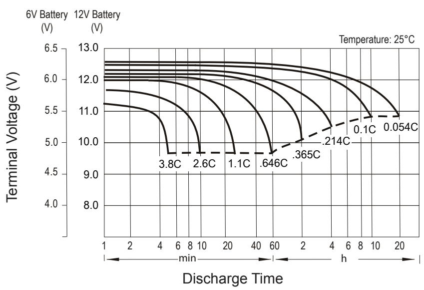
New Battery

PDC Series - AGM Deep Cycle Batteries

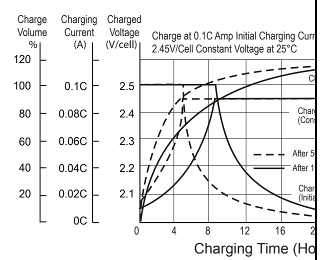
Model	Nominal Voltage	Rated Capacity AH		Length		Width		Height		Total Height		Weight		Terminal Type
		20-hr	10-hr	in.	mm.	in.	mm.	in.	mm.	in.	mm.	lbs.	kgs.	
PDC-1275	12	7.5	7.2	5.94	151	2.56	65	3.72	94.5	3.94	100	5.5	2.5	F2
PDC-1285	12	8.5	8.0	5.94	151	2.56	65	3.72	94.5	3.94	100	6.0	2.7	F[illegible]
PDC-12140	12	14.0	13.0	5.96	151.5	3.92	100	3.82	97	3.98	101	9.5	4.3	F2
PDC-12200	12	21.0	20.0	7.15	181.5	3.01	77	6.73	171	6.73	171	15	6.9	B (T12)
PDC-12260	12	28.0	26.0	6.56	166.5	6.89	175	4.92	125	4.92	125	21	9.4	NB
PDC-12260H	12	26.0	24.0	6.50	165	4.92	125	6.89	175	6.89	175	21	9.5	B (T12)
PDC-12350	12	35.0	33.0	7.68	195	5.12	130	6.46	164	7.09	180	25	11.2	NB
PDC-12400	12	40.0	38.0	7.76	197	6.50	165	6.69	170	6.69	170	32	14.5	B (T6)
PDC-12600	12	60.0	55.0	9.04	230	5.45	138	8.27	210	8.66	220	39	17.7	U (T9)
PDC-12800	12	80.0	75.0	10.24	260	6.61	168	8.27	210	9.06	230	50	22.7	U (T14)
PDC-121000	12	100	92.0	12.05	306	6.61	168	8.27	210	8.50	216	61	27.5	[illegible]
PDC-121100	12	107	100.0	12.99	330	6.81	173	8.46	215	8.66	220	67	30.4	[illegible]
PDC-122000	12	214	200.0	20.55	522	9.45	240	8.58	218	8.82	224	138	62.5	[illegible]

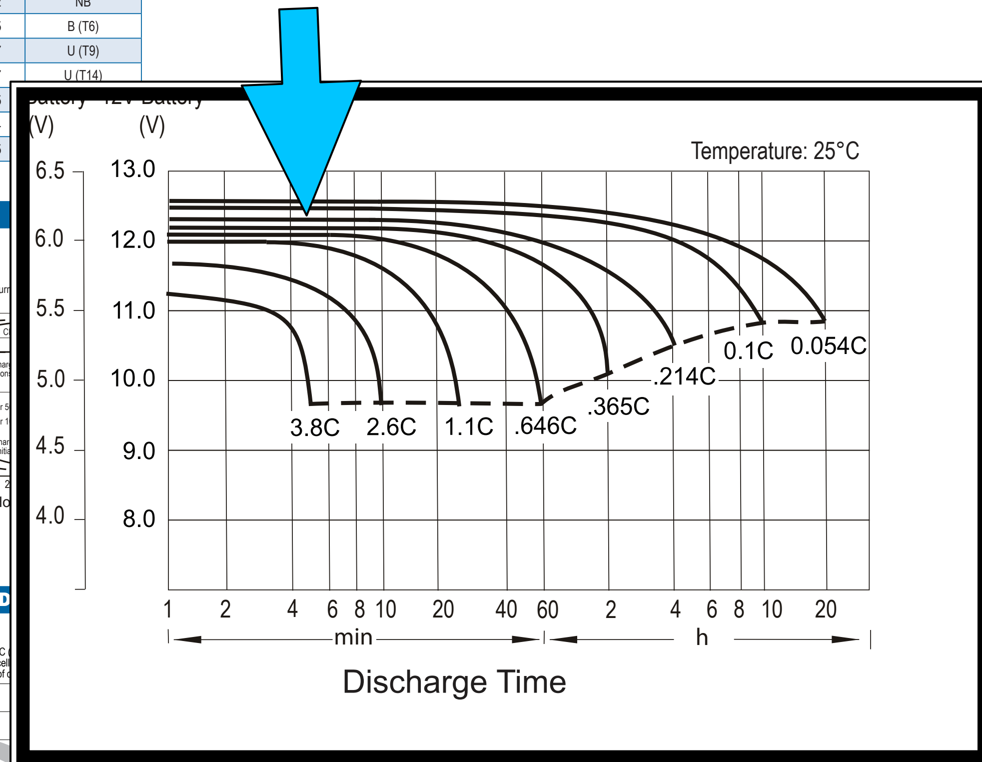
Hard to use Voltage alone to determine state of battery since these curves are so flat

Discharge Characteristics

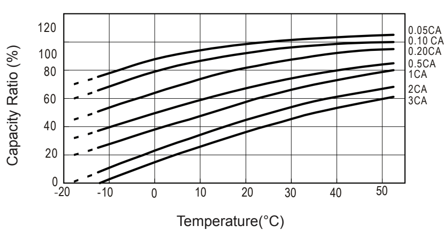


Float Charging Characteristics

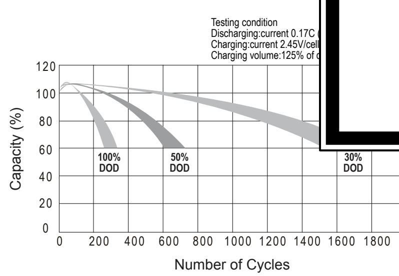




Temperature Effects in Relation to Capacity



Cycle Life in Relation to Depth of D



Contact Information

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DOMESTIC SALES
Tel: +1-619-661-2020
Fax: +1-619-661-3650
national-sales@power-sonic.com

CUSTOMER SERVICE
Tel: +1-619-661-2030
Fax: +1-619-661-3648
customer-service@power-sonic.com

TECHNICAL SUPPORT
Tel: +1-619-661-2020
Fax: +1-619-661-3648
support@power-sonic.com

INTERNATIONAL SALES
Tel: +1-650-364-5001
Fax: +1-650-366-3662
international-sales@power-sonic.com

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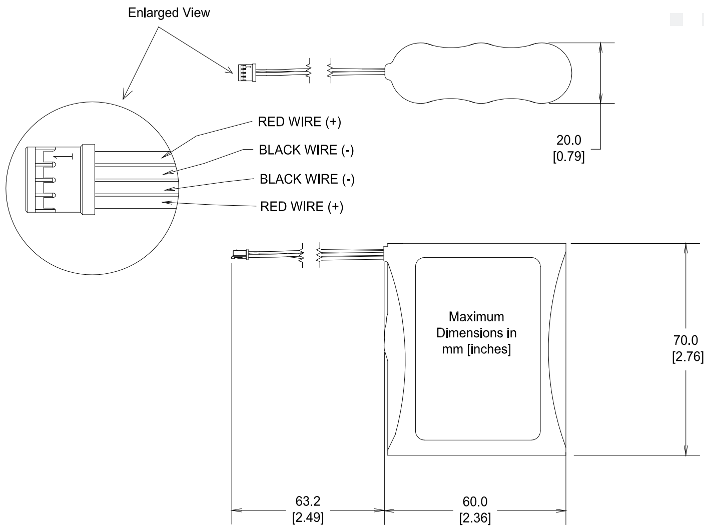
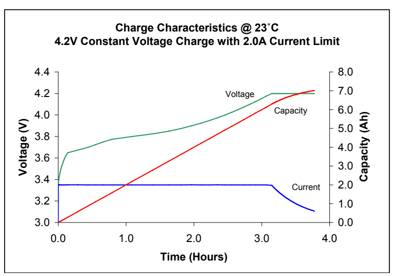
0912 1M

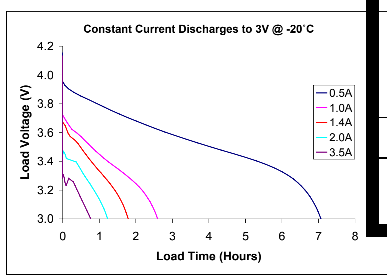
A little better… still need to know current in real time

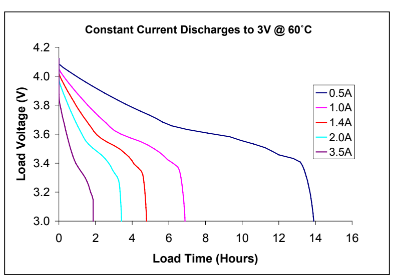
Dimensions

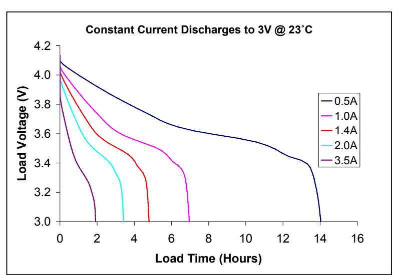


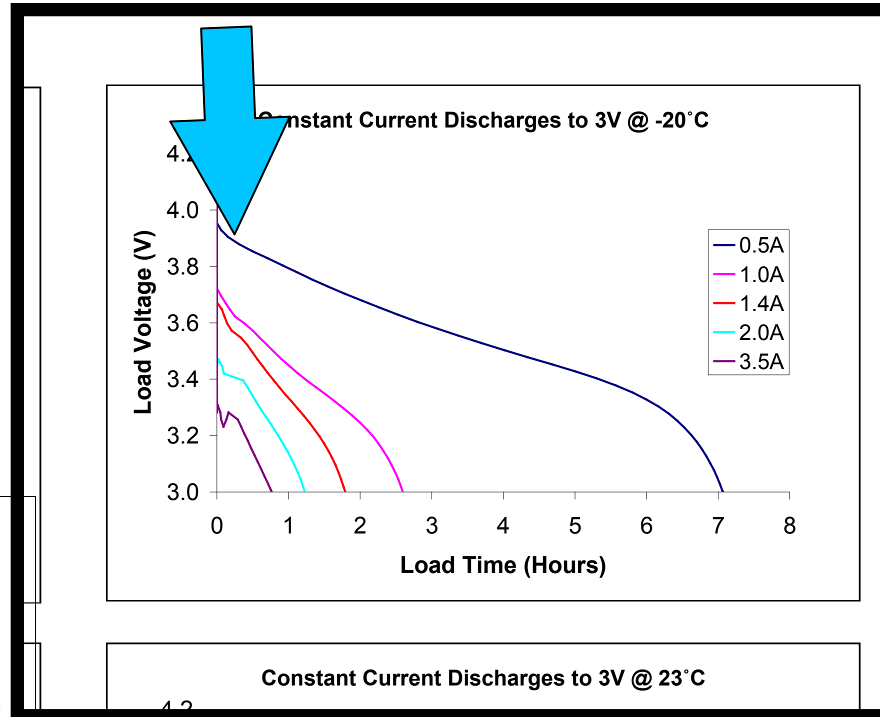
Performance Graphs











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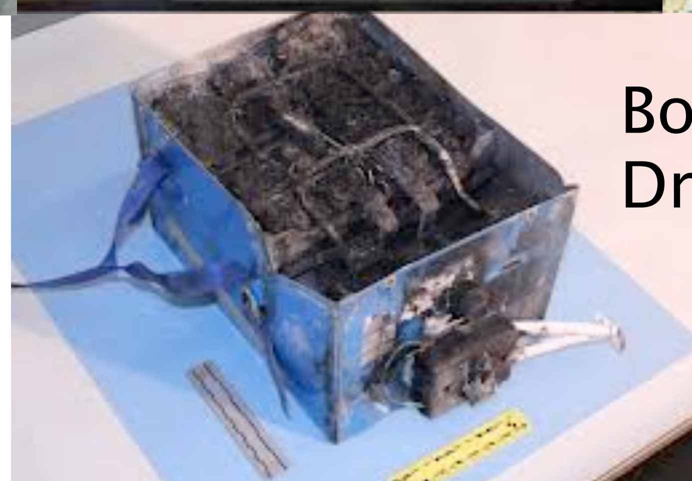
Charging

Charging batteries can be very complex.

Doing it wrong can be dangerous!



Boeing Dreamliner

and the list goes on…
(Note 7, Hoverboards…)

Charging – the hard (high performance) way

In order to maximize battery performance (most energy over longest time in smallest, lightest package) complex battery monitoring and charging circuits and algorithms are used.

They take into account:

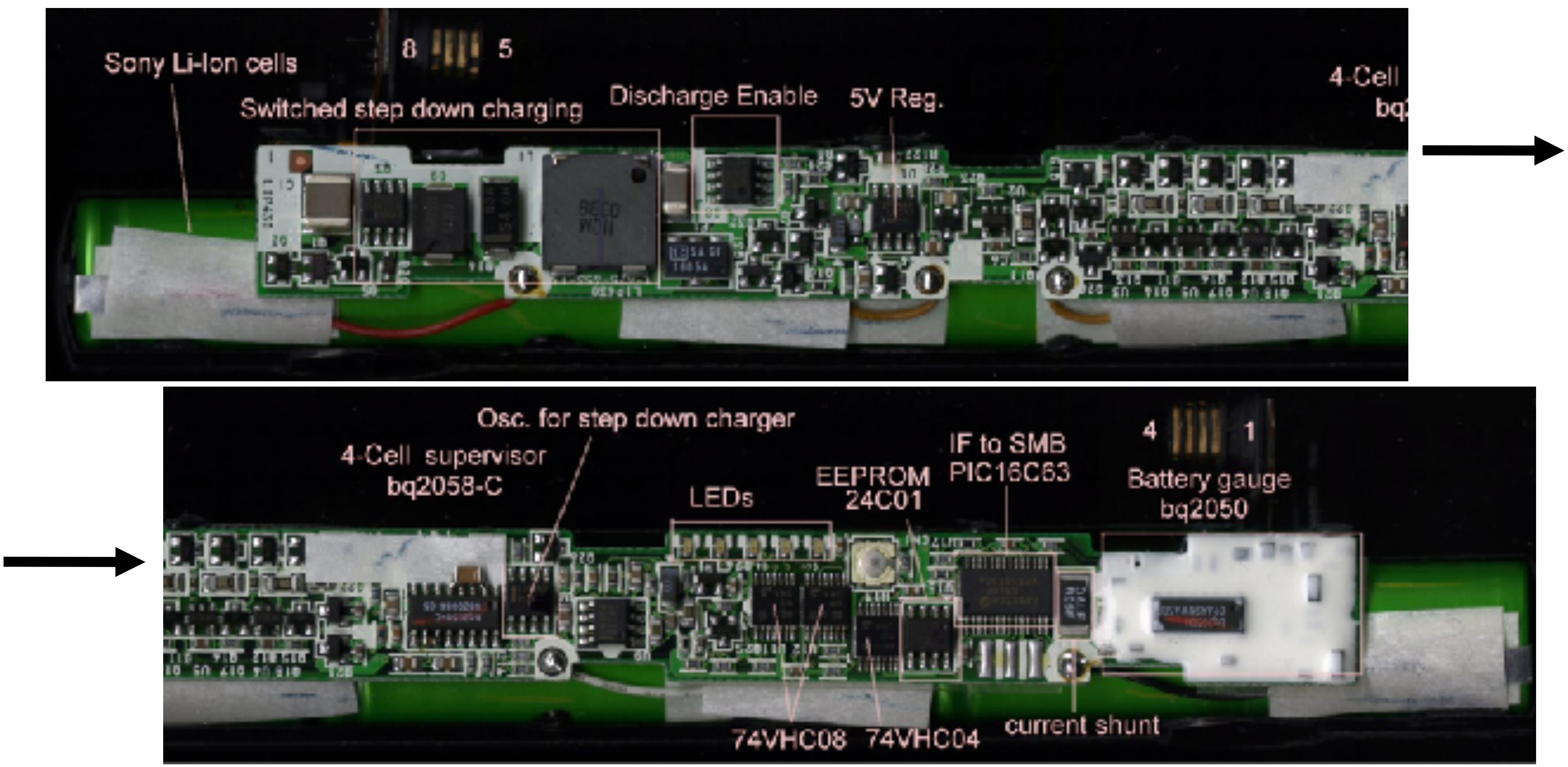
- Complete charge/discharge history of battery
- Temperature
- Battery age

An advanced system typically uses a combination of **constant current** and/or **constant voltage** charge stages coupled with **current, delta V, and/or delta T monitoring** (changes in the rate of change of voltage or temperature). These will be tailored to the battery chemistry, number of cells, and other considerations. Term of art is “**coulomb counting**”

Charging – the hard (high performance) way

Many manufacturers (Maxim, Analog Devices, etc) make dedicated battery ICs. (And publish whitepapers covering charging specifics)

The “Smart Battery” standard includes microcontrollers in the pack to communicate battery state to host device.



Panasonic

Lithium Ion

NCR18650PF

Features & Benefits

- High energy and power density
- Long, stable, high power density
- High safety performance
- Ideal for power assisted bicycles, 2-way radios, medical devices and robotics.

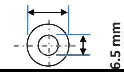
* At temperatures below 10℃, charge at a 0.25C rate.

Specifications

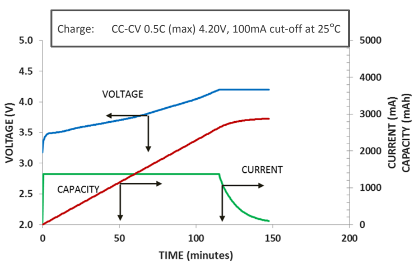
Rated capacity[1]	Min. 2700mAh
Capacity[2]	Min. 2750mAh Typ. 2900mAh
Nominal voltage	3.6V
Charging	CC-CV, Std. 1375mA, 4.20V, 4.0 hrs
Weight (max.)	48.0 g
Temperature	Charge*: 0 to +45°C Discharge: -20 to +60°C Storage: -20 to +50°C
Energy density[3]	Volumetric: 577 Wh/l Gravimetric: 207 Wh/kg

[1] At 20°C [2] At 25° C [3] Energy density based on bare cell dimensions

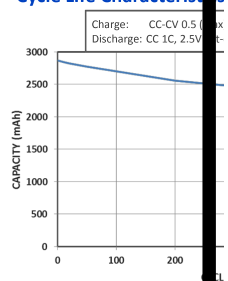
Dimensions



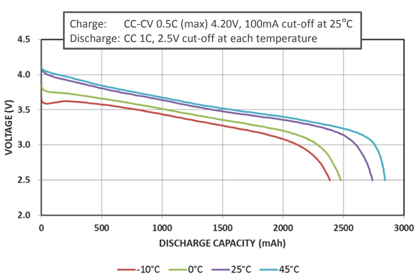
Charge Characteristics



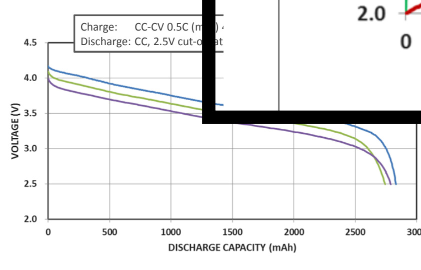
Cycle Life Characteristics

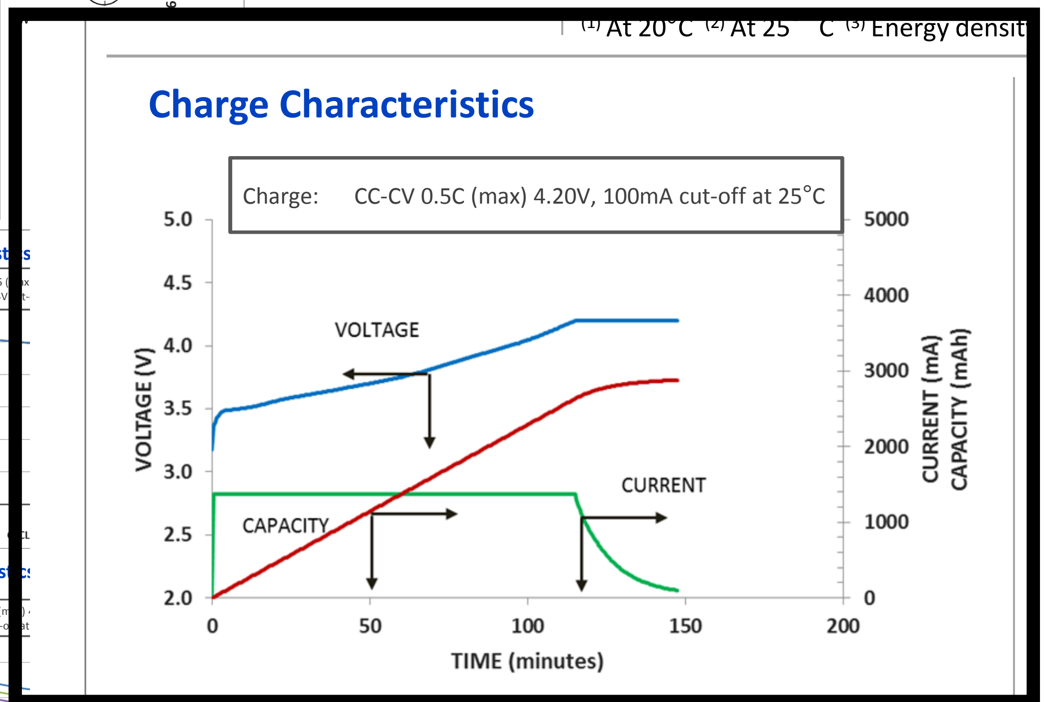


Discharge Characteristics (by temperature)



Discharge Characteristics





The data in this document is for descriptive purposes only and is not intended to make or imply any guarantee or warranty.

Charging – the easy (low performance) way

NiCad and NiMH batteries can be safely charged at C/10 (1/10C) at long periods of time (up to 15 hours). See for example Forrest Mims' Solar Charger circuit

SOLAR CELL BATTERY CHARGERS

SERIES ARRAYS OF SOLAR CELLS ARE USED TO CHARGE STORAGE CELLS AND BATTERIES. THE ARRAY MUST GENERATE A SLIGHTLY HIGHER VOLTAGE THAN THAT OF THE BATTERY BEING CHARGED. HERE ARE THE NUMBER OF SERIES-CONNECTED CELLS COMMONLY USED TO CHARGE SOME POPULAR BATTERY CONFIGURATIONS:

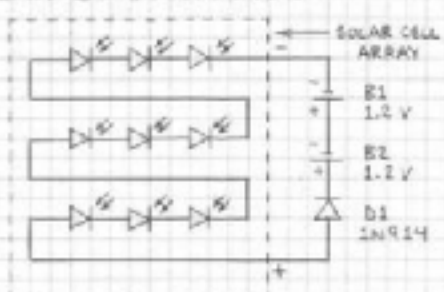
1 1.2-VOLT NICd CELL – 4 SOLAR CELLS

2 1.2-VOLT NICd CELLS IN SERIES – 9 SOLAR CELLS

4 1.2-VOLT NICd CELLS IN SERIES – 18 SOLAR CELLS

1 12-VOLT LEAD-ACID BATTERY – 36 SOLAR CELLS

SOLAR 2×AA CHARGER



THIS CIRCUIT WILL CHARGE 2 AA NICd CELLS. IF THE CELLS ARE FULLY DISCHARGED, SOLAR CELLS THAT GENERATE 50 TO 100 mA WILL CHARGE THE CELLS IN ABOUT 5 TO 8 HOURS.

D1 PREVENTS THE NICd CELLS FROM DISCHARGING THROUGH THE SOLAR CELLS.

SOLAR BATTERY CHARGER TIPS

1. NEVER EXCEED THE RECOMMENDED CHARGE RATE FOR A STORAGE CELL.

2. INCREASED CURRENT REDUCES CHARGING TIME. CHECK THE BATTERY'S SPECIFICATIONS TO FIND THE MAXIMUM ALLOWABLE CURRENT.

3. DO NOT USE A SOLAR ARRAY THAT DELIVERS TOO MUCH CURRENT TO THE CELLS BEING CHARGED.

4. SEVERAL TIMES A DAY REORIENT A SOLAR PANEL SO IT FACES THE SUN.

5. SOLAR CELLS WORK BEST WHEN COOL. AVOID PLACING A SOLAR PANEL ON SURFACES THAT BECOME HOT IN SUNLIGHT, SUCH AS PAVEMENT OR DARK PAINTED METAL.

6. STORAGE BATTERIES CAN BE MOUNTED ON THE BACK SIDE OF A SOLAR PANEL, BUT THEY WORK BEST WHEN KEPT IN A COOLER LOCATION WHILE BEING CHARGED.

MONITORING A SOLAR CHARGER

YOU CAN MEASURE THE CURRENT FROM A SOLAR PANEL WITH A MULTIMETER.

1. CONNECT A MULTIMETER SET TO MEASURE CURRENT BETWEEN THE BLOCKING DIODE AND THE BATTERY BEING CHARGED. BE SURE TO OBSERVE POLARITY, OR ...

2. CONNECT A 1-OHM POWER RESISTOR BETWEEN THE BLOCKING DIODE AND THE BATTERY BEING CHARGED. USE A MULTIMETER TO MEASURE THE VOLTAGE (V) ACROSS THE RESISTOR (R). FROM OHM'S LAW, CURRENT EQUALS V/R OR, IN THIS CASE, V.

Strategies for projects

Many off-the-shelf battery charging solutions are available that may be used in place of designing your own battery charger.

Small solar charge controllers are available for lead-acid and lithium batteries.

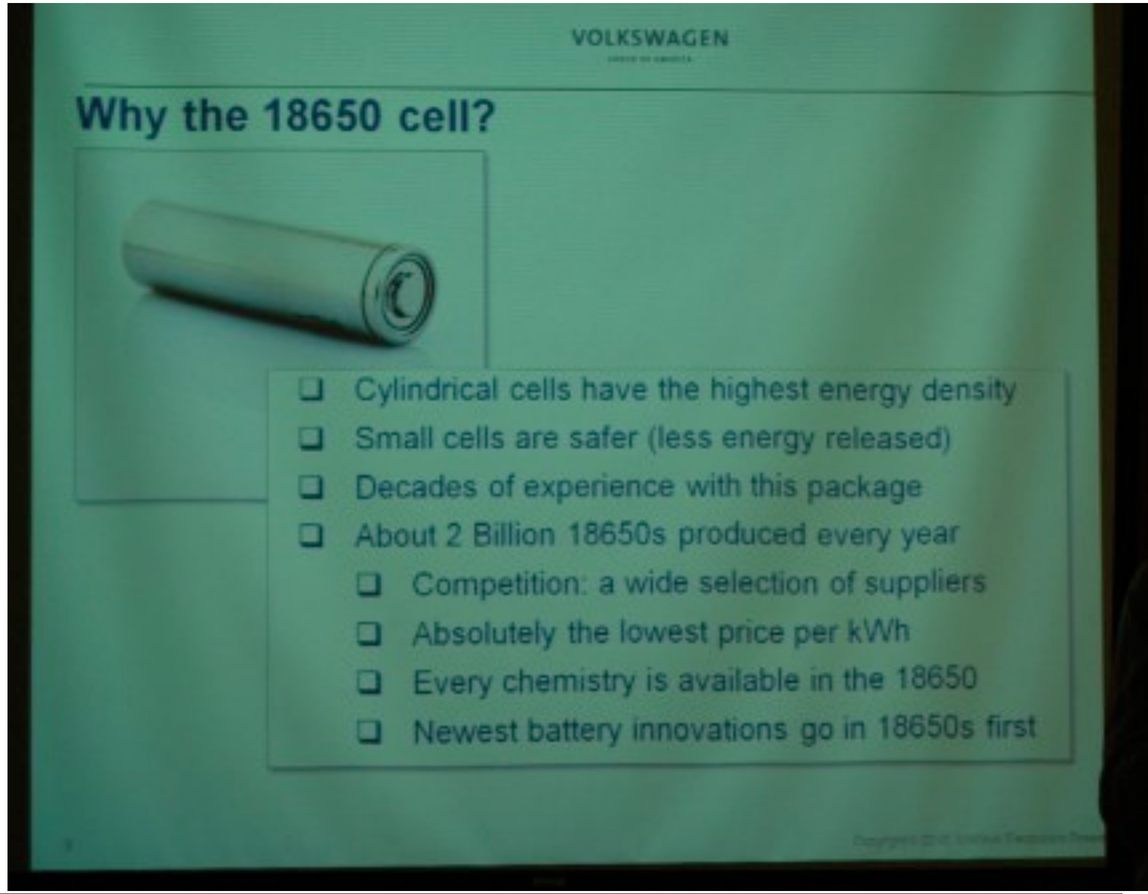
Ready-to-use lithium solar chargers are available (Solio, etc.)

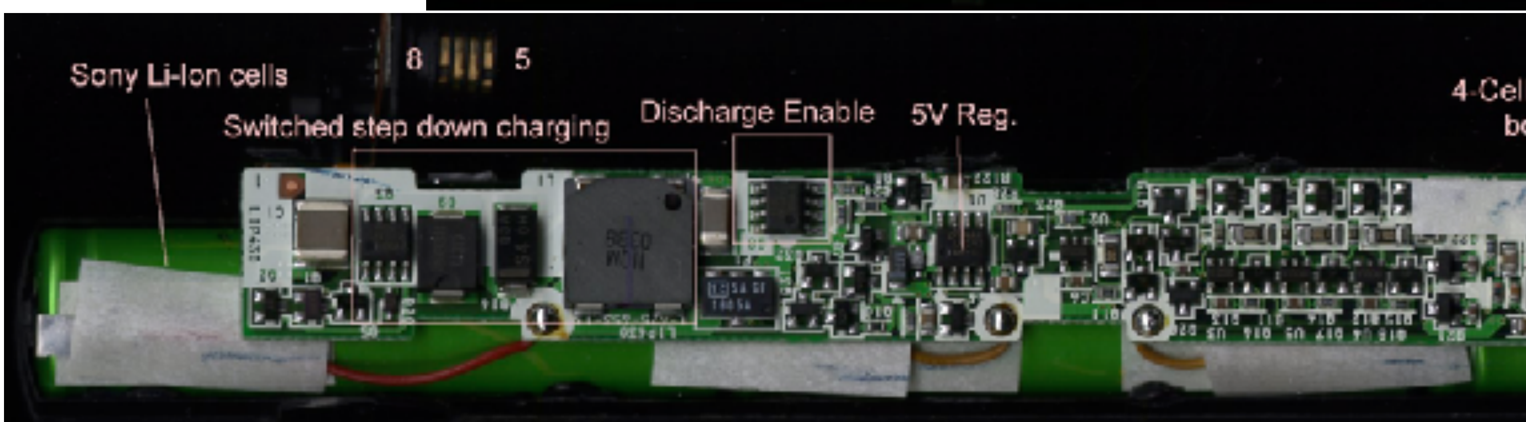
USB-powered chargers will work if you can provide up to 500 mA at 5 volts.

Etc…

18V Li-Ion battery, charger, and powerful variable speed motor ~$100

Tesla S


VOLKSWAGEN
Why the 18650 cell?
Cylindrical cells have the highest energy density
Small cells are safer (less energy released)
Decades of experience with this package
About 2 Billion 18650s produced every year
Competition: a wide selection of suppliers
Absolutely the lowest price per kWh
Every chemistry is available in the 18650
Newest battery innovations go in 18650s first


Sony Li-Ion cells
8
5
Switched step down charging
Discharge Enable
5V Reg.
4-Cell

Trend: Vehicle-to-Grid storage

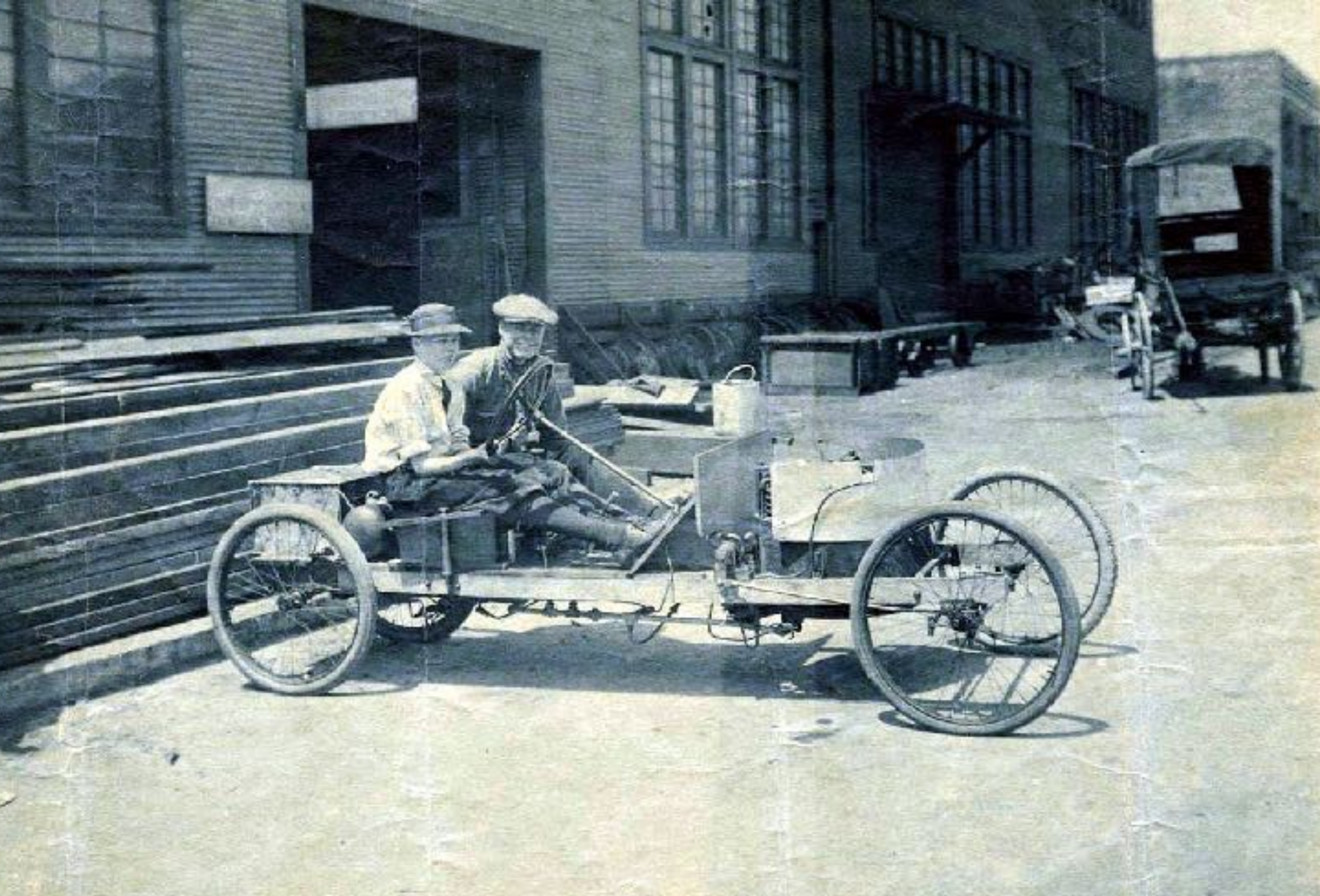
Wide-spread adoption of electric vehicles would be the first time the grid would have significant storage capacity, first big new electricity demand since AC.

Tesla S

Chevy Volt

Nissan Leaf

https://www.youtube.com/watch?v=OhnjMdzGusc

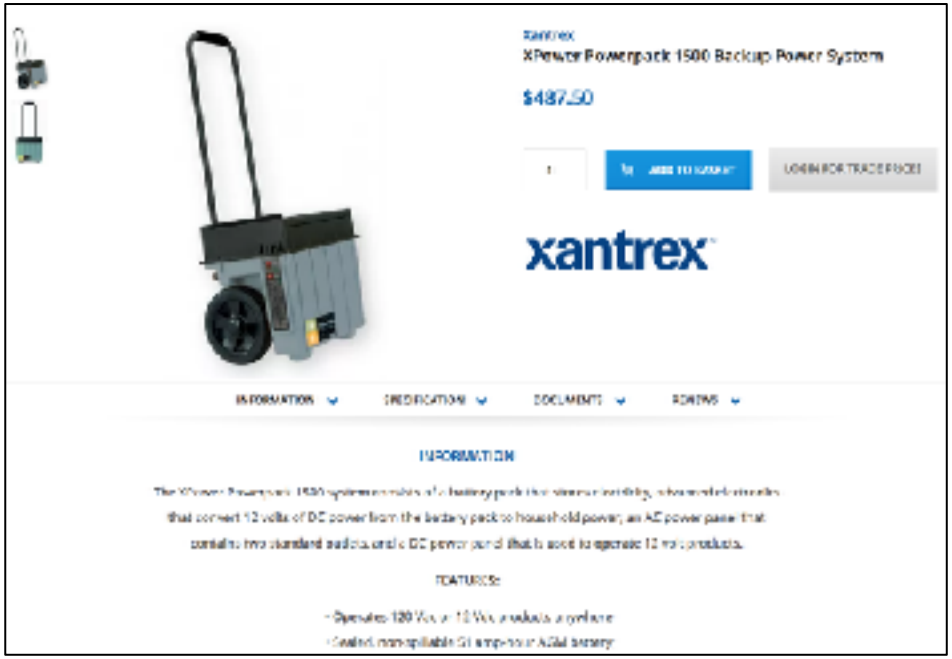


Warren (at the wheel and Bill Doble
in their Steam Car in 1912

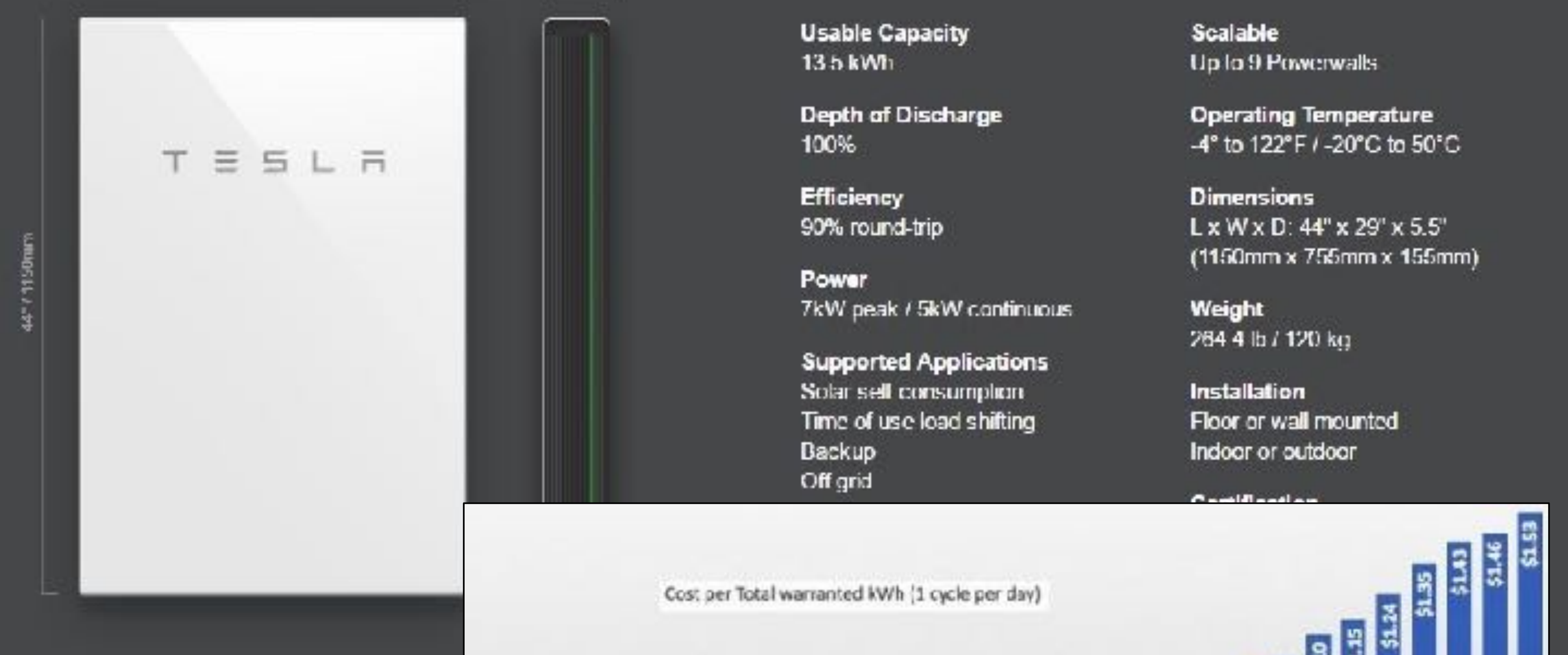
~1Wh AAA alkaline

~10Wh smart phone battery

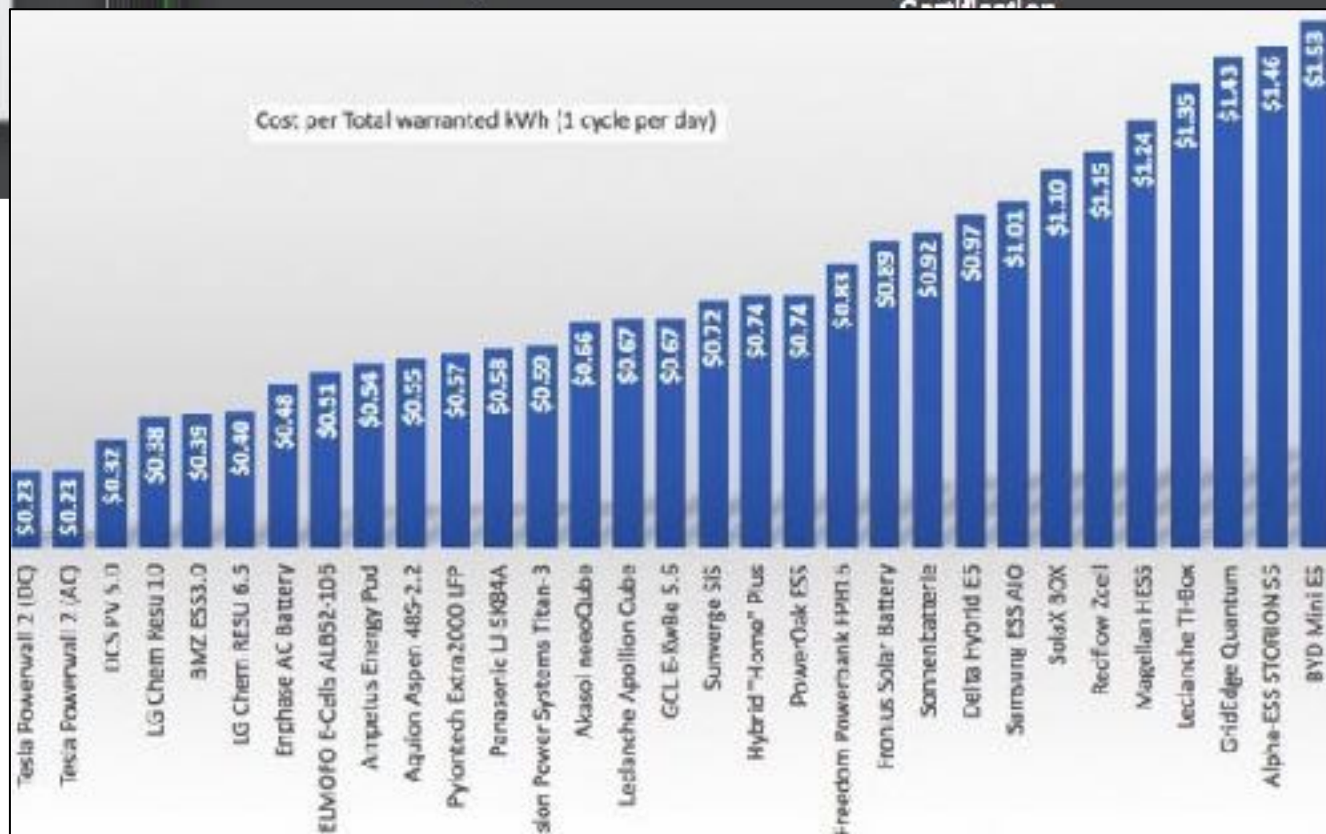
~100Wh laptop battery

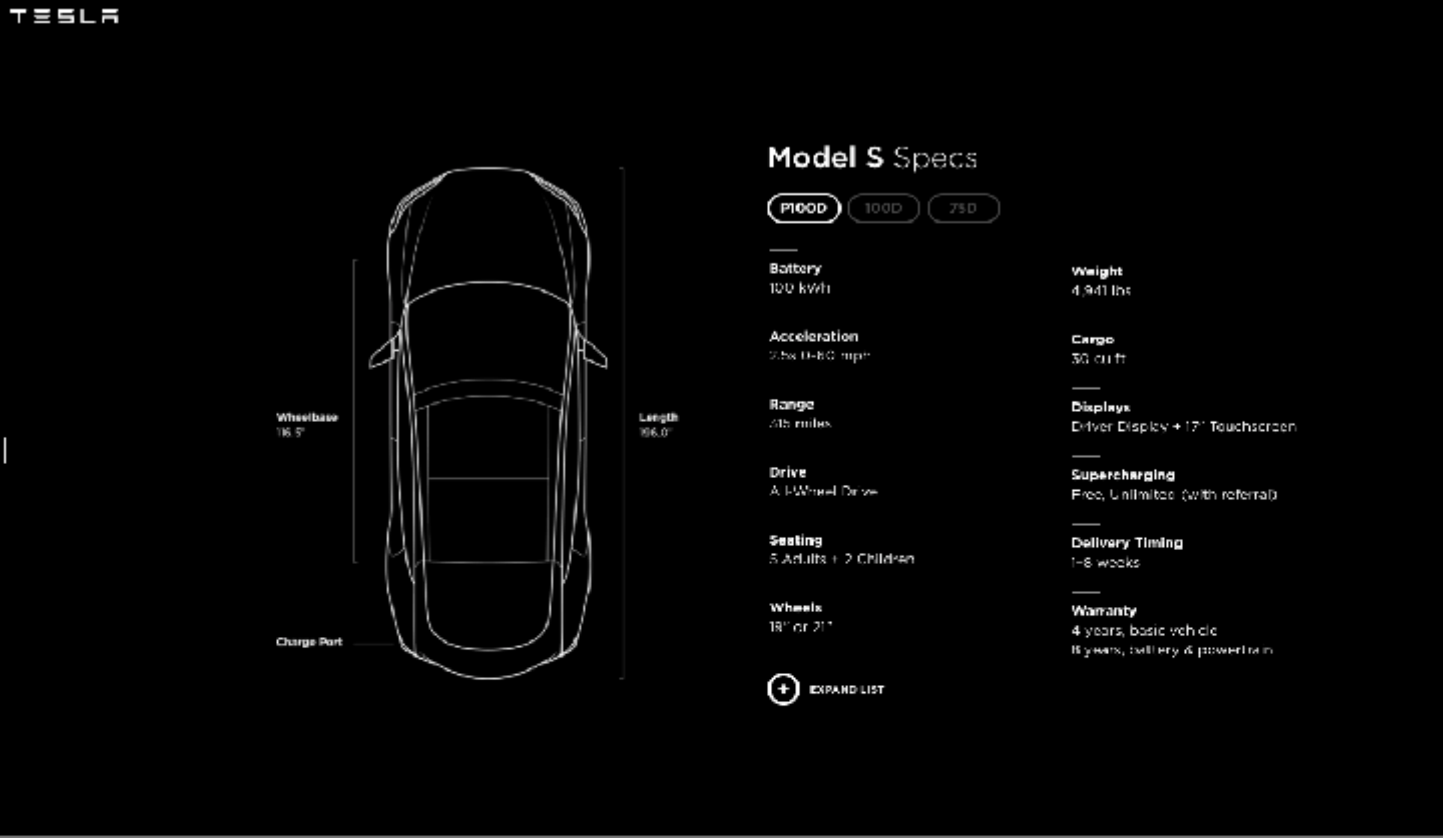


~1kWh portable battery
“generator”



~10kWh home battery




TESLA
Model S Specs
P100D
100D
75D
Wheelbase
Length
Charge Port
Battery
100 kWh
Acceleration
Range
Drive
Seating
5 Adults + 2 Children
Wheels
Weight
4,941 lbs
Cargo
Displays
Supercharging
Delivery Timing
Warranty
4 years, basic vehicle
EXPAND LIST

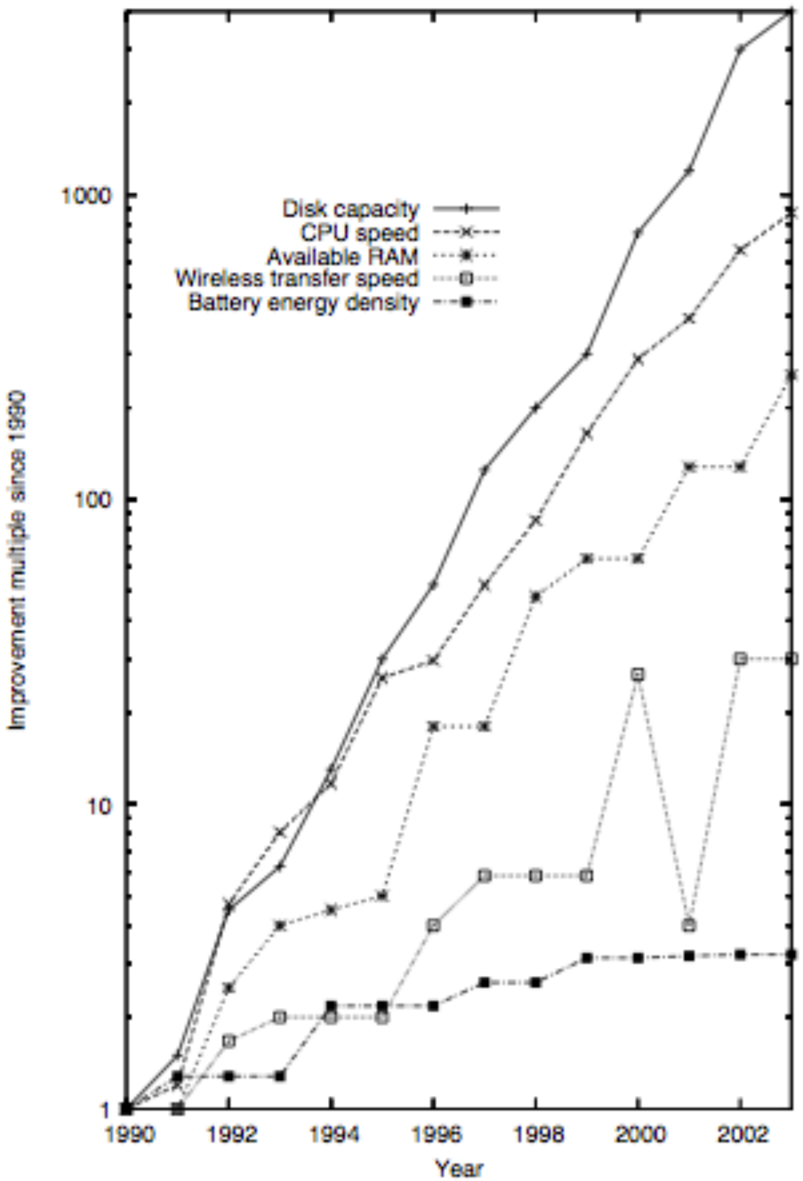
~100kWh EV

1-10MWh Grid-backup

GTM forecast: 1.6GW in US by 2020

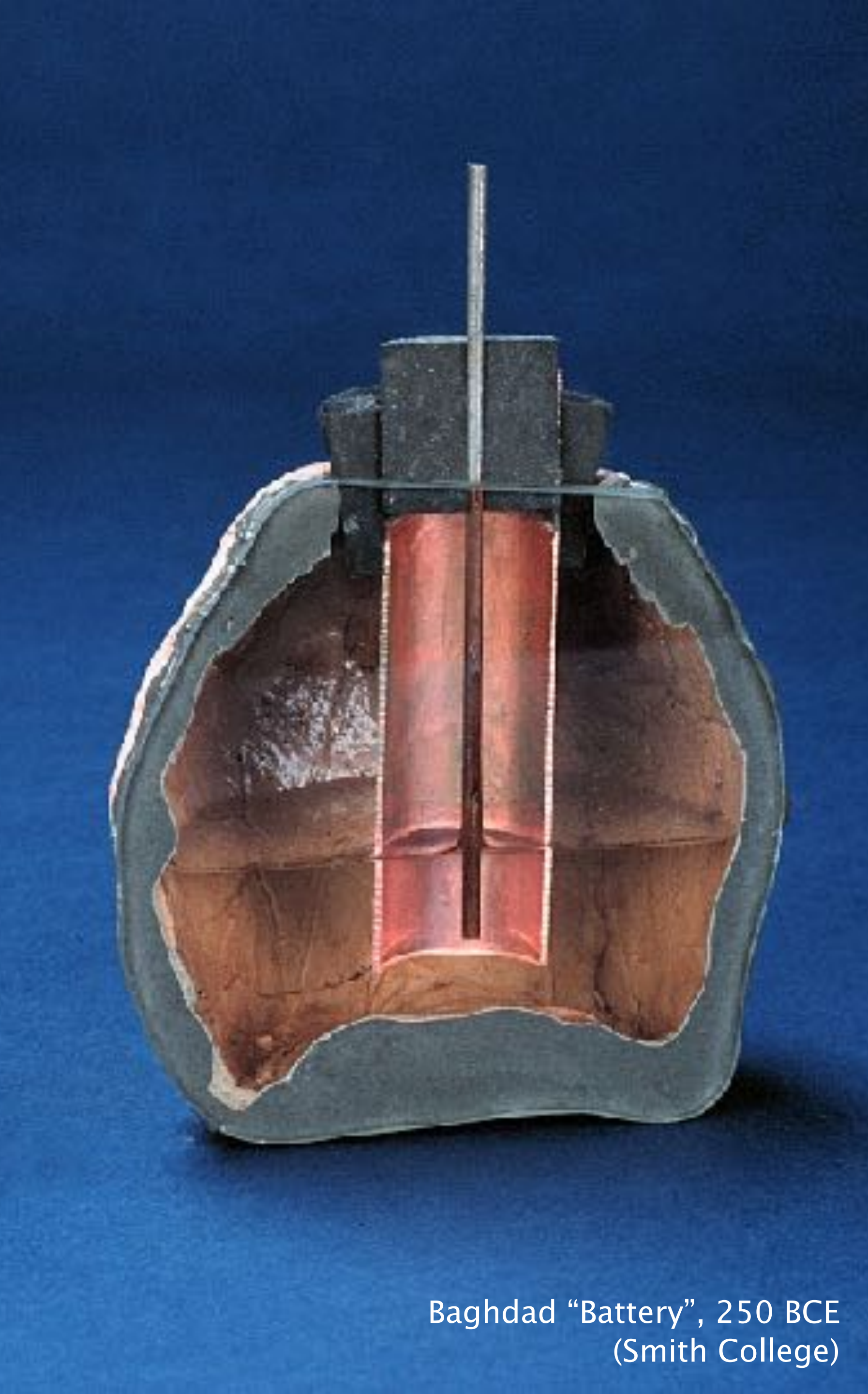
This was built in 2017 in West Caldwell, NJ

More data: http://css.umich.edu/sites/default/files/U.S._Grid_Energy_Storage_Factsheet_CSS15-17_e2017.pdf



“Don’t let anybody tell you batteries are going to get better. They can’t, it’s physically impossible.” Batteries are made of electrons on metal with oxygen in between; without a way to compress matter and make it more dense, battery store can’t improve, ever. What people can speak to is “power density” — but on the whole, batteries are “lousy, lousy, lousy, lousy.” We use fuels because they have lots of energy. We could use other energy sources, but when push comes to shove, we get a lot of energy out of fuels, because we can put electrons in tiny volumes of space.

Daniel Nocera interviewed in:
http://poptech.org/blog/daniel_nocera_on_personalized_energy



Baghdad "Battery", 250 BCE
(Smith College)

Junkyard Battery, 2016
Vanderbilt