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

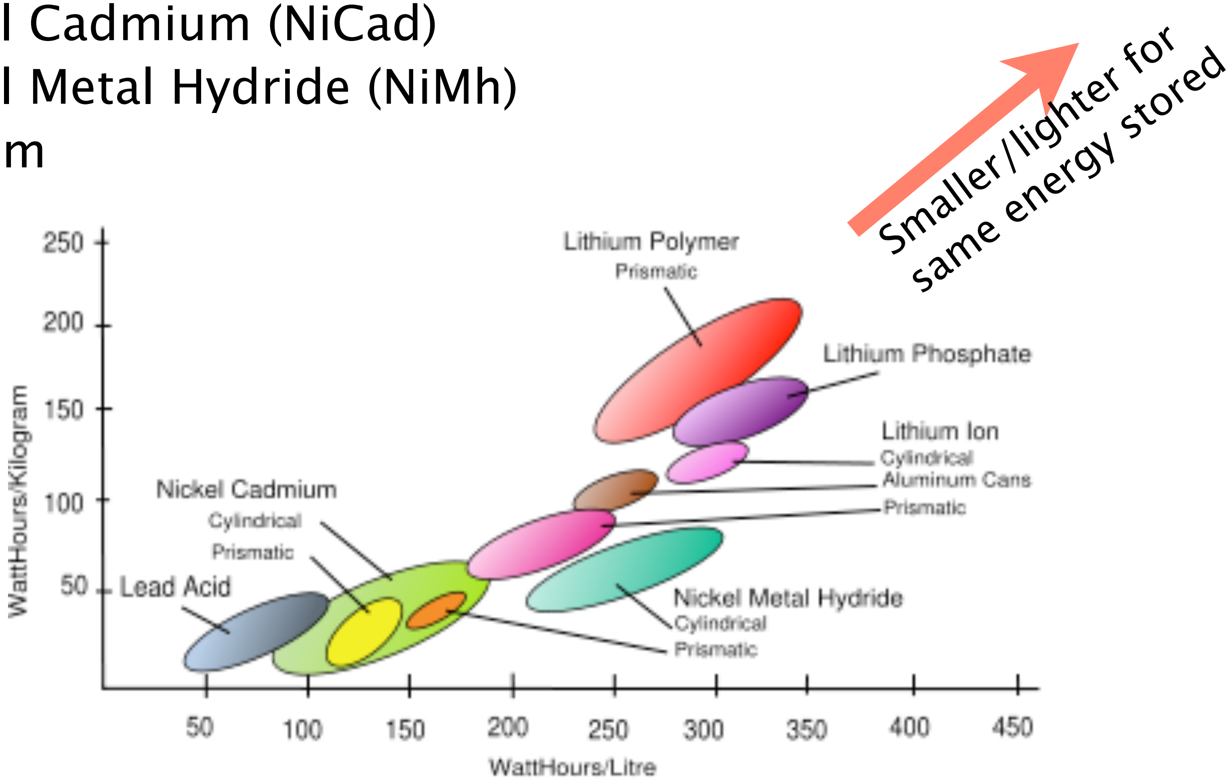
General battery concepts

- "**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

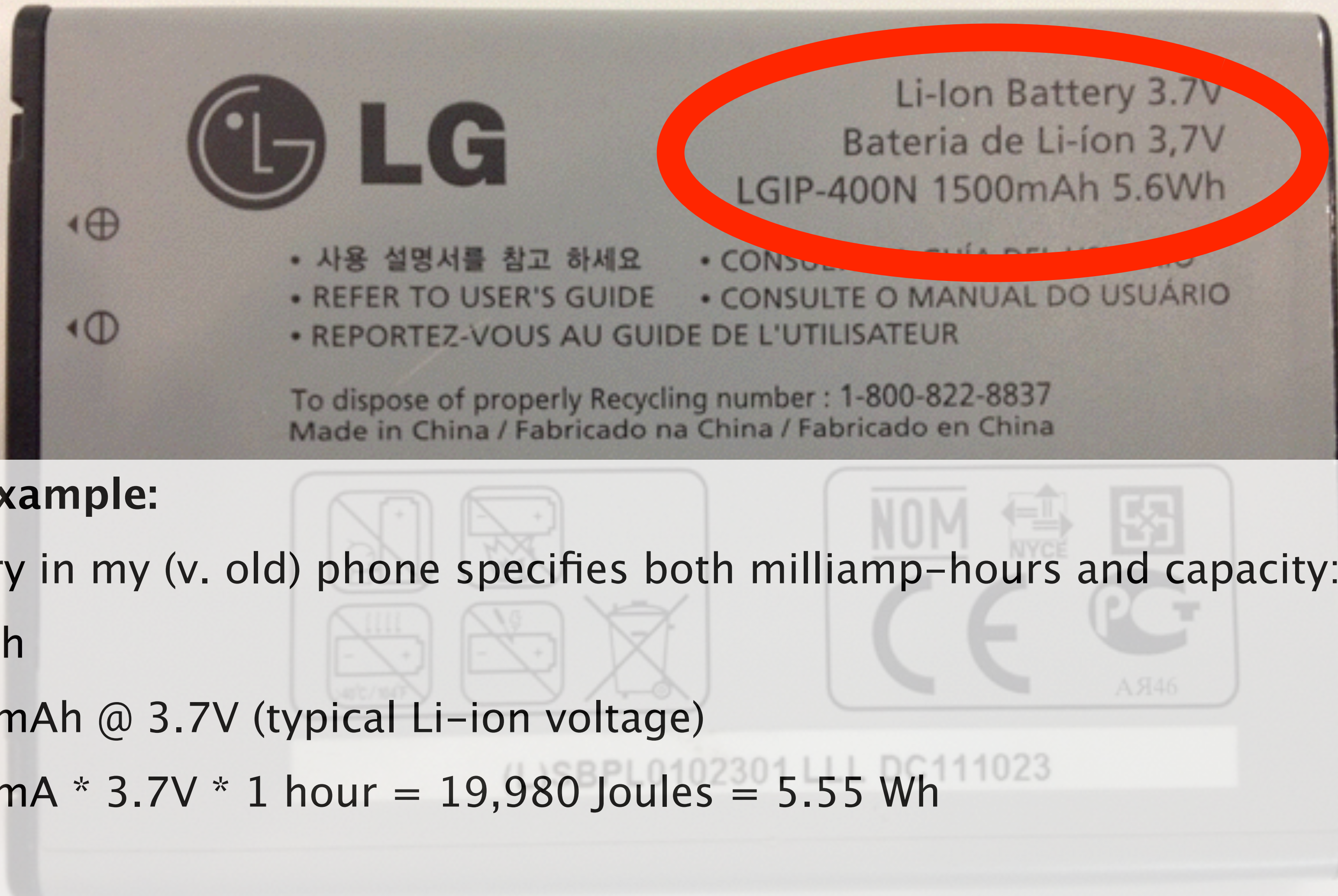


Capacity - how much can the battery hold?

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

Capacity – how much can the battery hold?

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 (see C Rate, next slide).

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.

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:

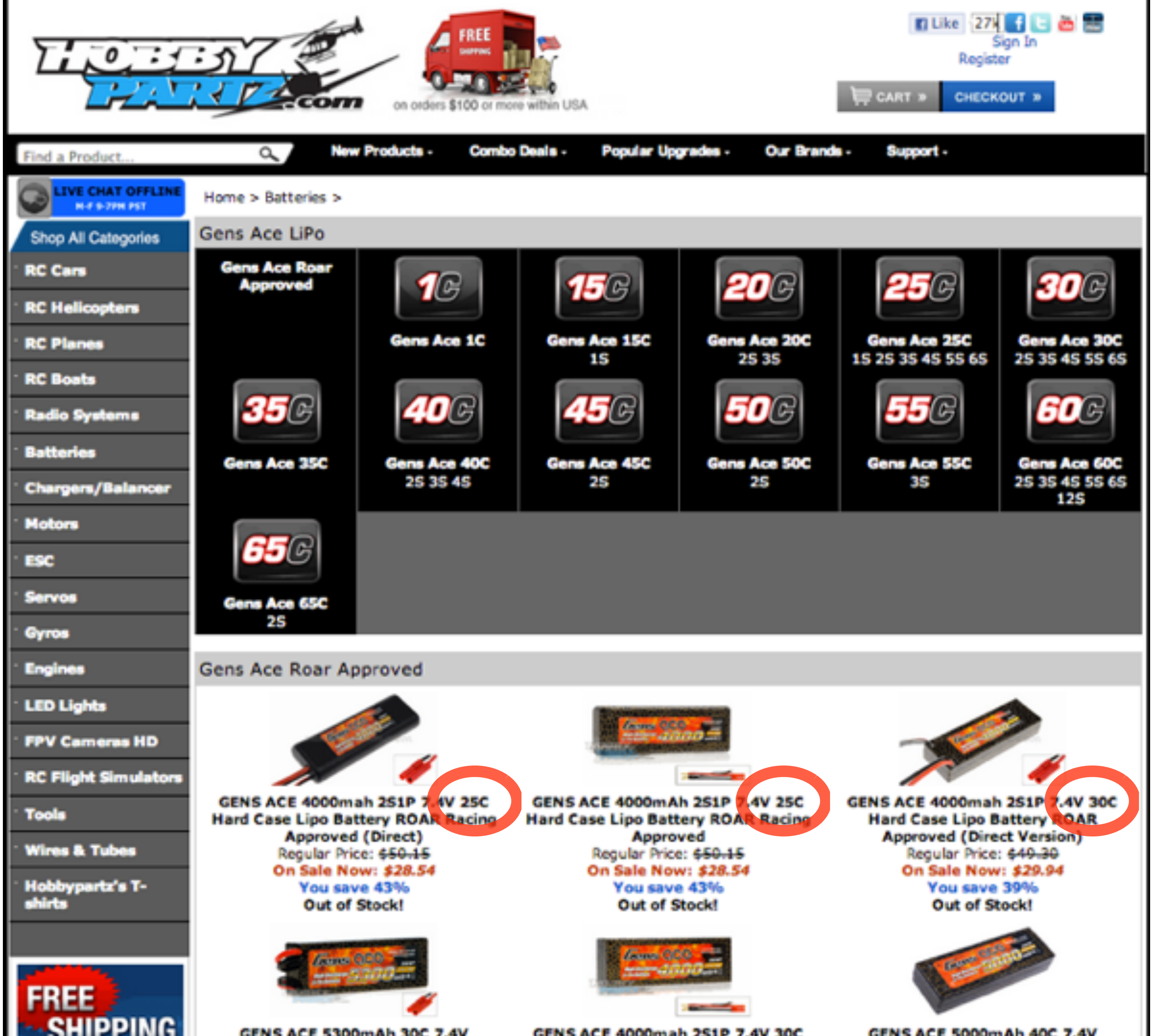
1C = 750mA

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.

As mentioned, the rated capacity of a battery is determined for its **C/20 (1/20 C) discharge rate**. Higher or lower rates of discharge may decrease realized capacity.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1S 2S 3S 4S 5S 6S
30C
Gens Ace 30C
2S 3S 4S 5S 6S
35C
Gens Ace 35C
40C
Gens Ace 40C
2S 3S 4S
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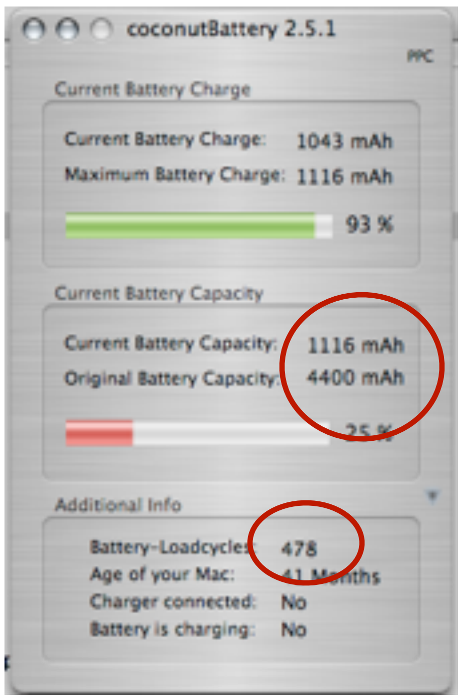
Other considerations:

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

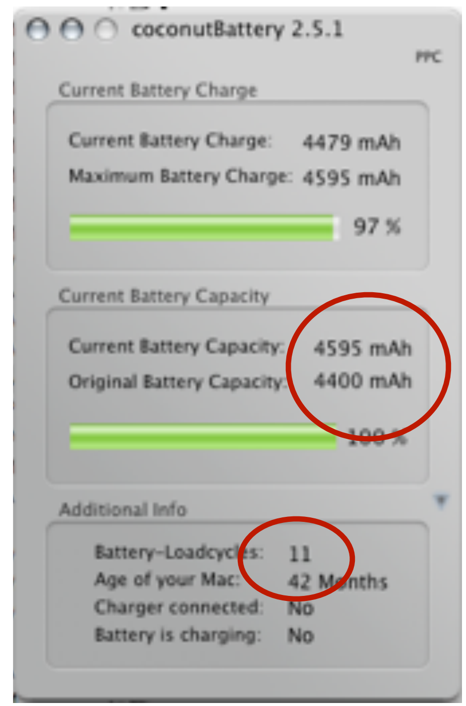
Depth of discharge – how deeply can it be discharged? Decreasing DOD increased life expectancy.



Old Battery

Capacity

Cycles

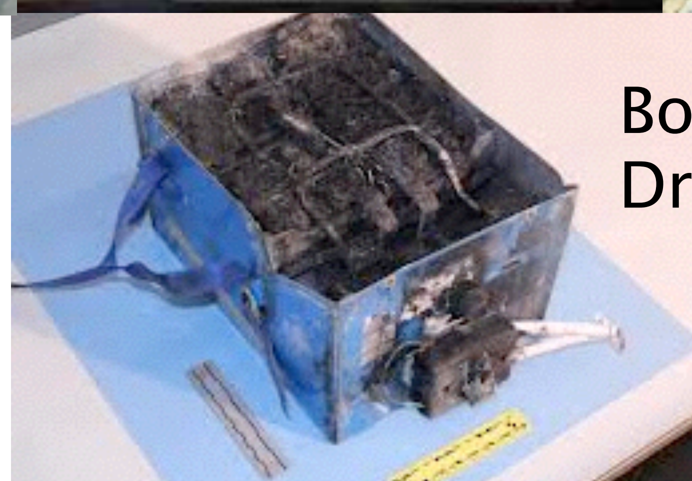


New Battery

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:

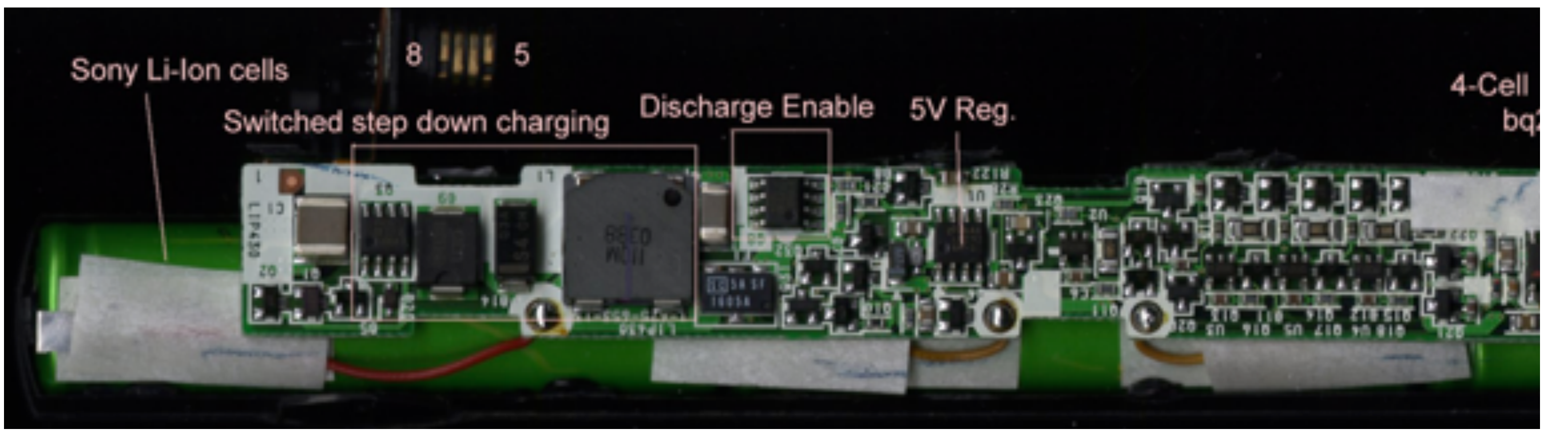
- Complete charge/discharge history of battery
- Temperature
- Battery age

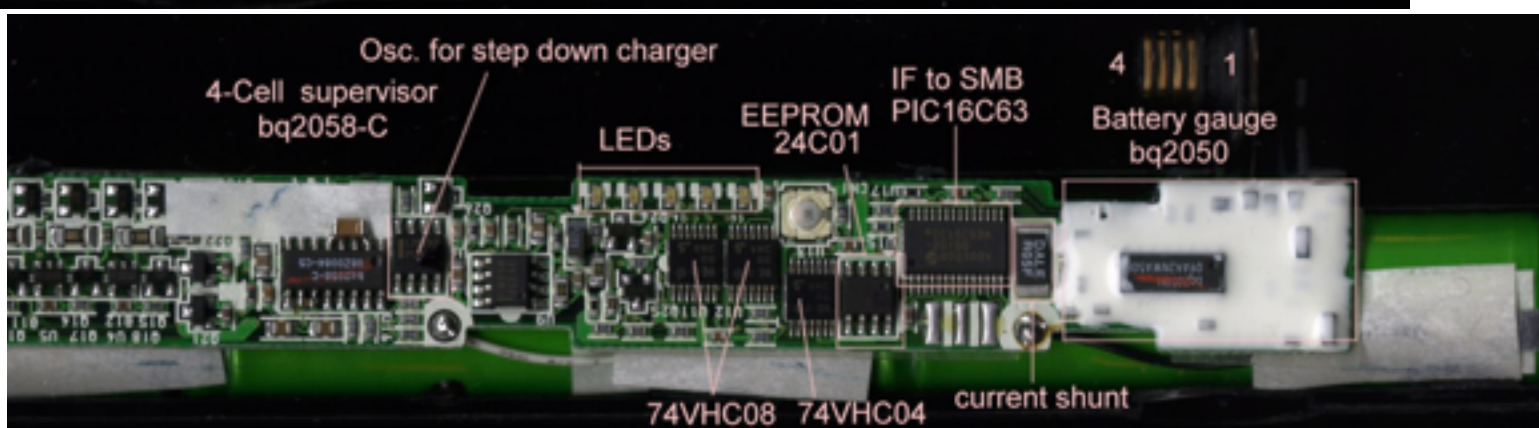
An advanced system typically uses a combination of constant current and/or constant voltage charge stages coupled with current, delta V, and/or delta T monitoring (changes in the rate of change of voltage or temperature). These will be tailored to the battery chemistry, number of cells, and other considerations.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

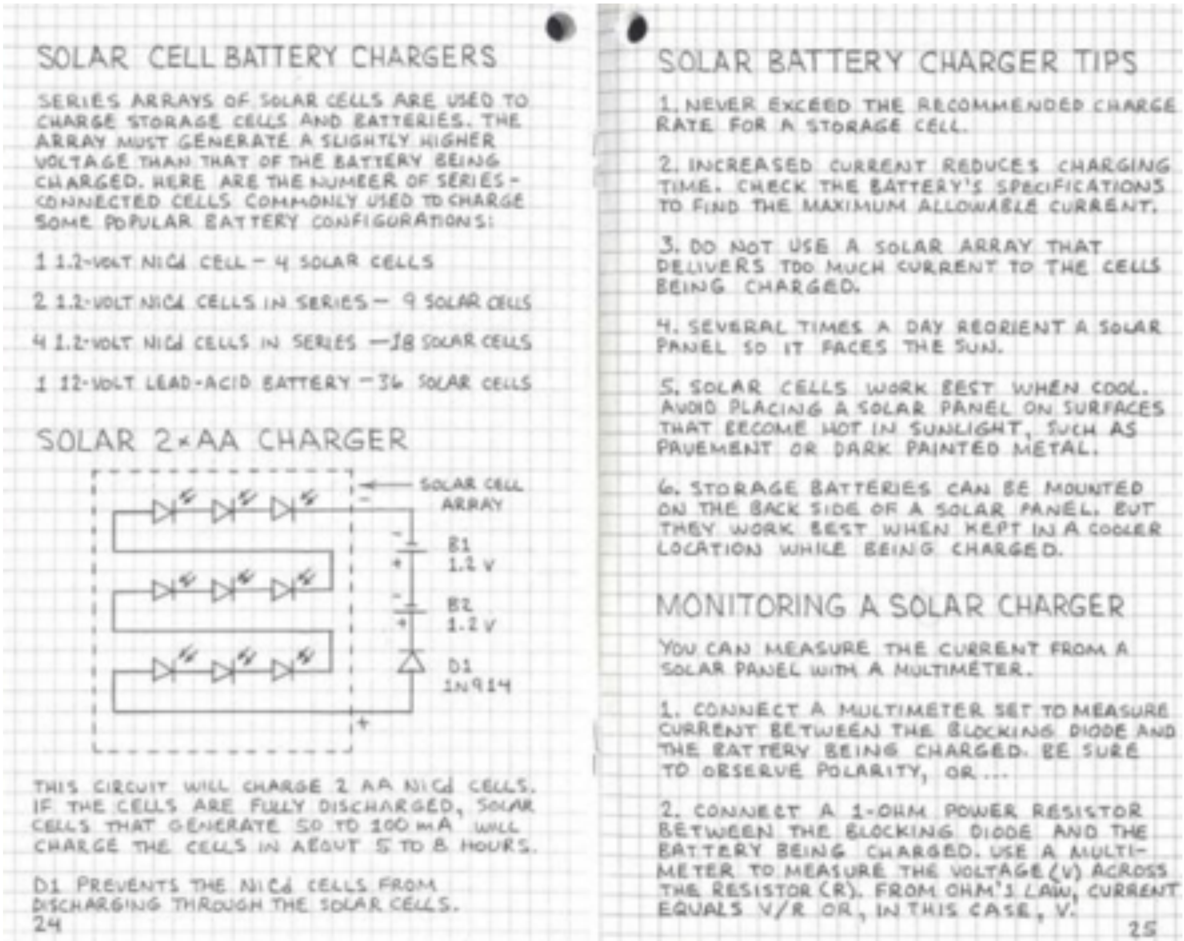
The “Smart Battery” standard includes microcontrollers in the pack to communicate battery state to host device.





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.

24

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.

25

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.

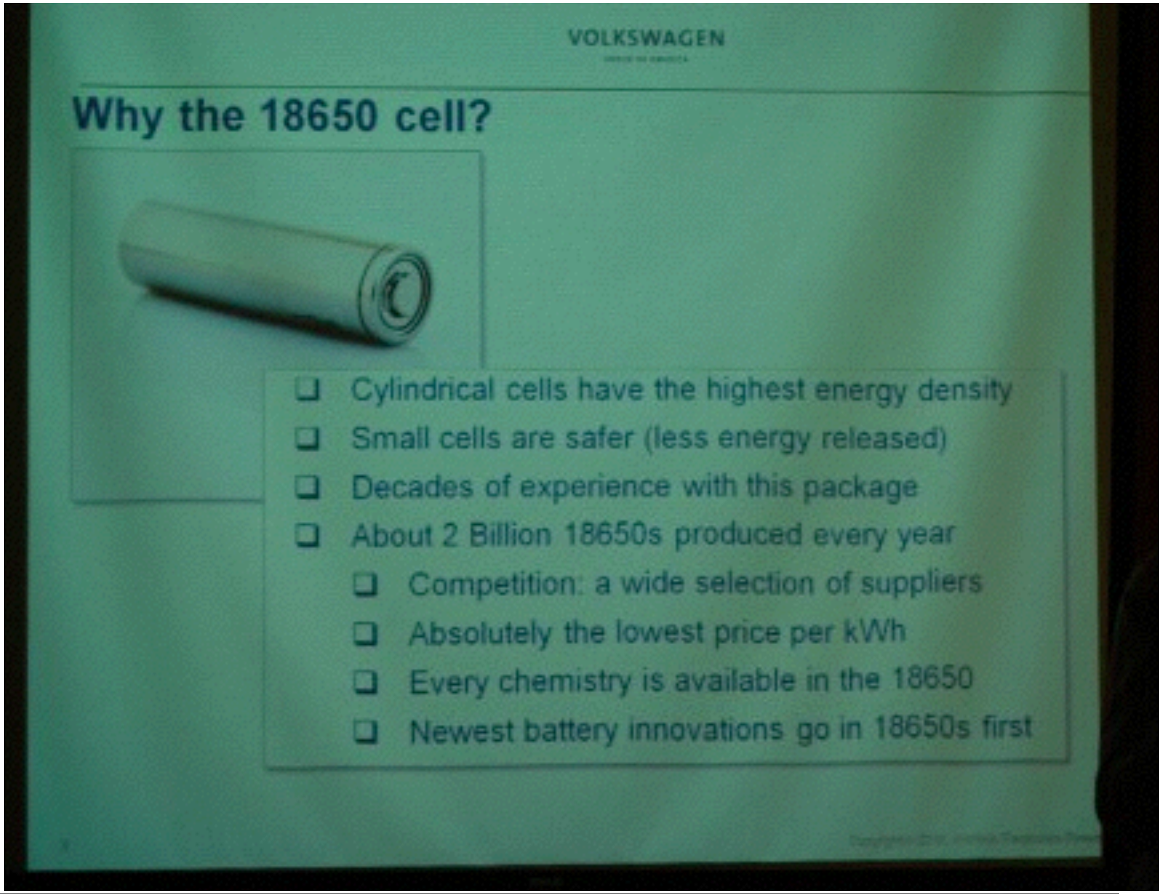
Ready-to-use lithium solar chargers are available (Solio, etc.)

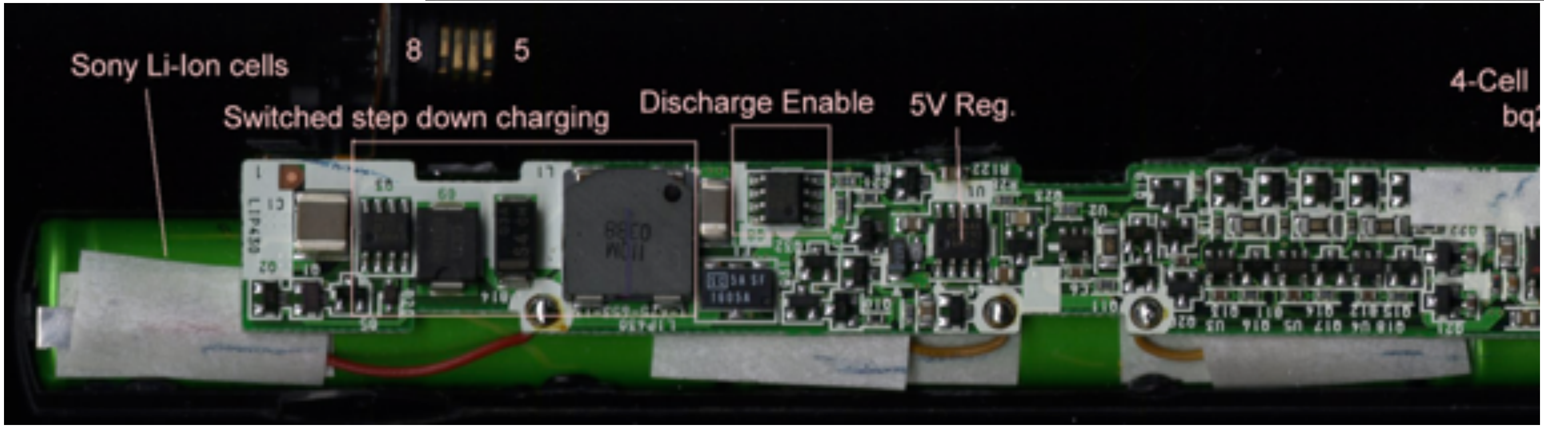
USB-powered chargers will work if you can provide up to 500 mA at 5 volts.

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

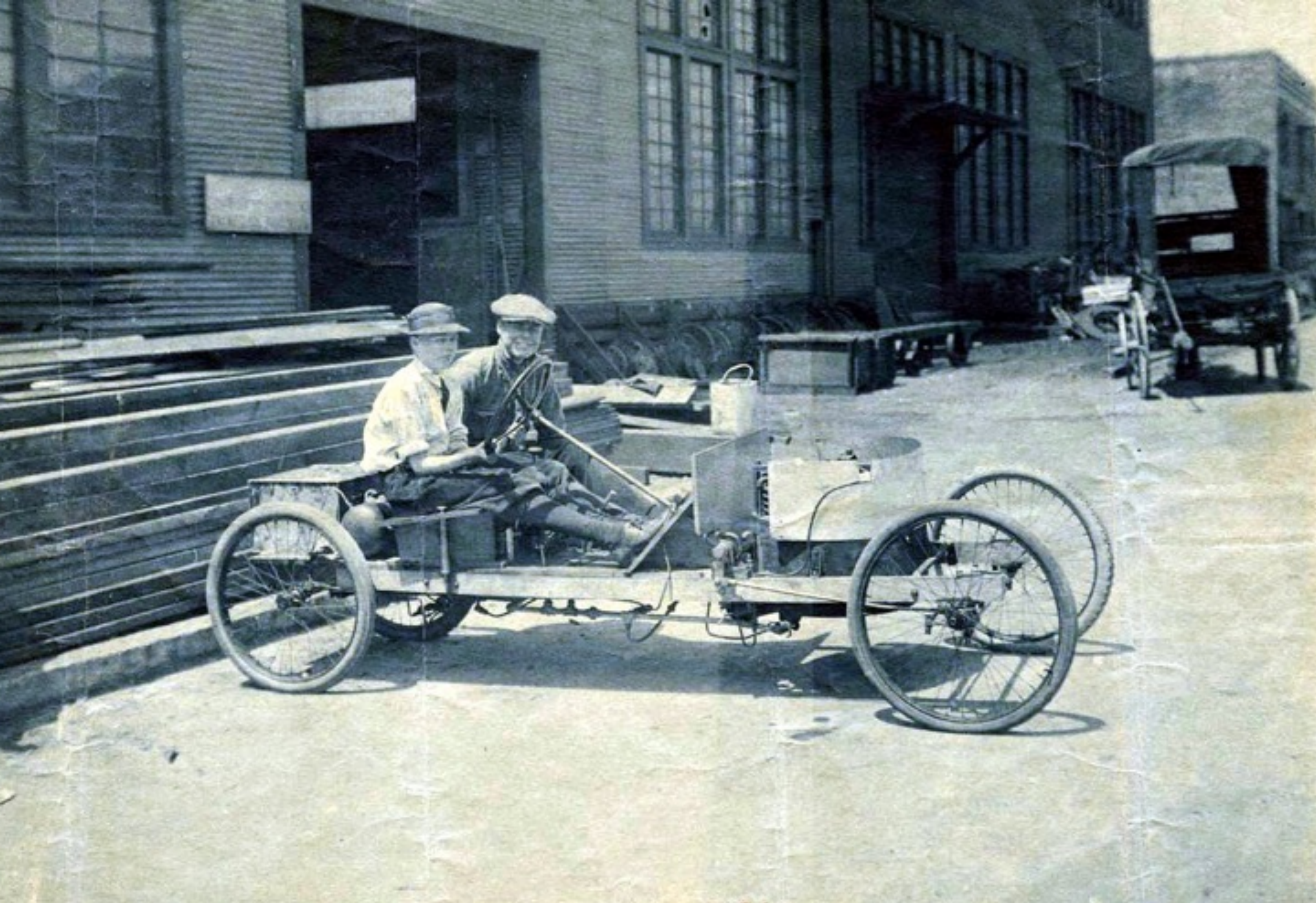
Wide-spread adoption of electric vehicles would be the first time the grid would have significant storage capacity, first big new electricity demand since AC.

Tesla S

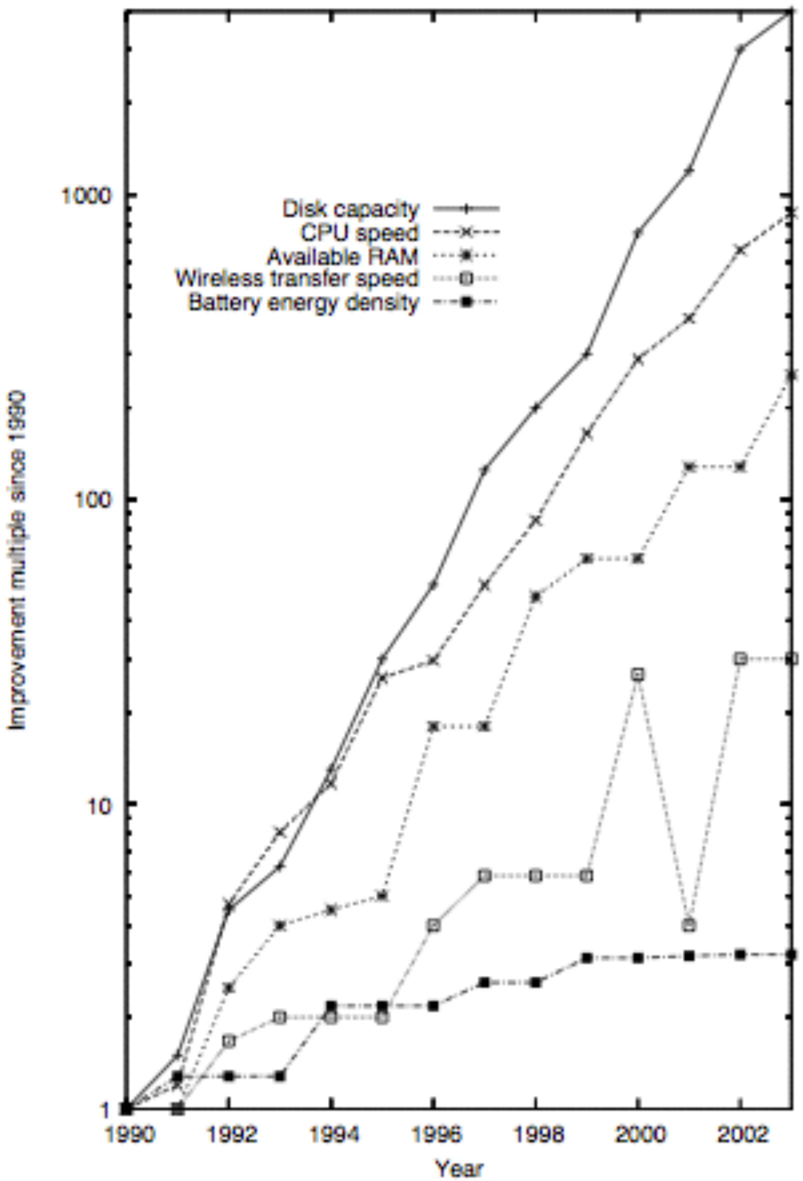
Chevy Volt

Nissan Leaf

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

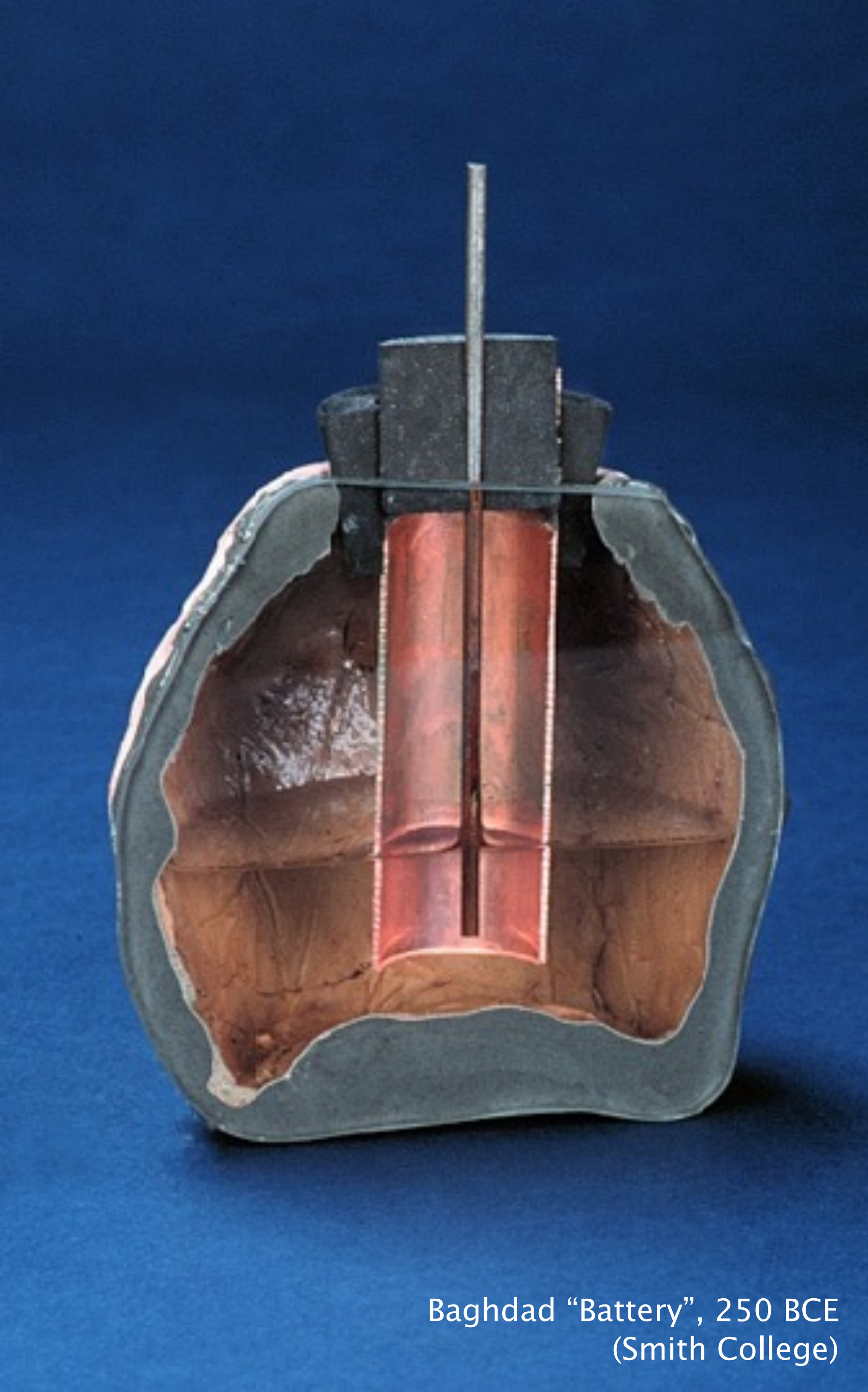


Warren (at the wheel and Bill Doble
in their Steam Car in 1912



“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