Batteries

Energy

ITP / NYU / Feddersen

Batteries

Electrochemical energy storage devices. Many materials, chemistries, forms.

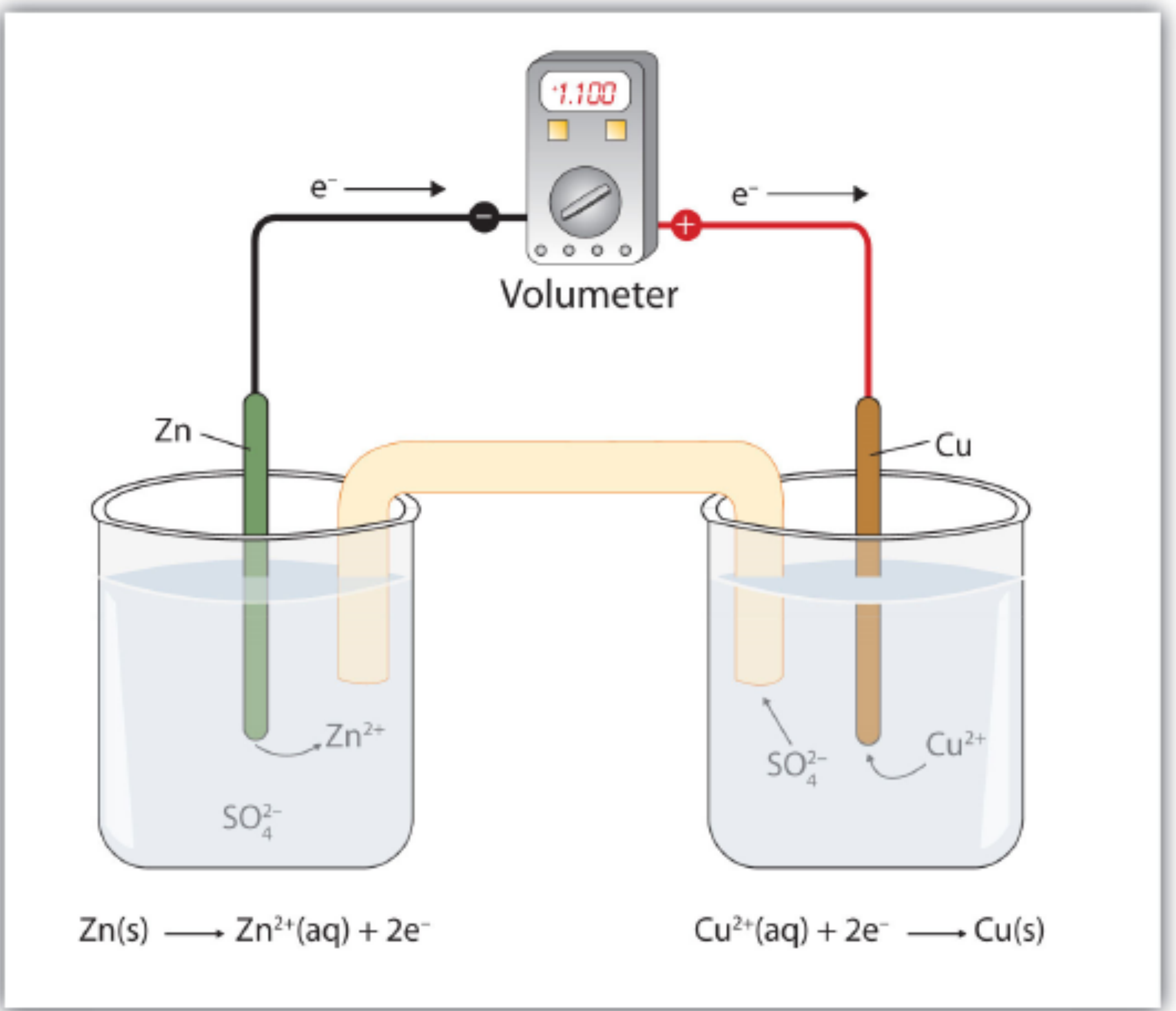
No matter how they work, the same considerations apply as for any energy storage:

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

"Goo makes it go"

Redox

"Oxidation is defined as the loss of one or more electrons by an atom. Reduction is defined as the gain of one or more electrons by an atom…**Chemical reactions that involve the transfer of electrons are called oxidation-reduction (or redox) reactions.**



A Redox Reaction in Which the Two Half Reactions Are Physically Separated.

If you were to mix zinc metal and copper ions in a container, this reaction would [spontaneously] proceed by itself.

Suppose, however, we set up this reaction in a way depicted [here]. Zinc and zinc ions are on one side of the system, while copper and copper ions are on the other side of the system. The two parts are connected with a wire [and a salt bridge].

Even though the two half reactions are physically separated, a spontaneous redox reaction still occurs. However, in this case, the electrons transfer through the wire connecting the two half reactions; that is, **this setup becomes a source of electricity. Useful work can be extracted** from the electrons as they transfer from one side to the other…

All batteries are based on redox reactions."

CHARACTERISTIC	LFP ($LiFePO_4$)	NMC ($LiNiMnCoO_2$)	LCO ($LiCoO2$)	LMO ($LiMn_2O_4$)	LTO ($Li_4Ti_5O_{12}$)
Voltage	3.2VPC (operating range 2.5-3.65VPC)	3.6VPC (operating range 3-4.2VPC)	3.6VPC (operating range 3-4.2VPC)	3.7VPC (operating range 3-4.2VPC)	2.4VPC (operating range 1.8-2.85VPC)
Specific Energy	90-120 Wh/kg	150-220 Wh/kg	150-200 Wh/kg	100-150 Wh/kg	50-80 Wh/kg
Energy Density	333 Wh/l	580 Wh/l	560 Wh/l	420 Wh/l	177 Wh/l
Charge Rate	1C	0.7-1C (>1C shortens life)	0.7-1C (>1C shortens life)	0.7-1C (3C Max)	1C (5C Max)
Charge Voltage	3.5-3.65VPC	4.2VPC	4.2VPC	4.2VPC	2.85VPC
Discharge Rate	1C (30C power cells); 2.0V cut-off	1C (2C on some cells); 2.5V cut-off	1C (>1C shortens life); 2.5V cut-off	1C (>1C shortens life); 2.5V cut-off	10C (30C 5 sec); 1.8V cut-off
Cycle Life (depending on depth of discharge)	2000-4000	1000-2000	500-1000	300-700	3000-7000
Thermal Runaway	270°C (518°F)	210°C (410°F)	150°C (302°F)	250°C (482°F)	NA
Prone to Thermal Runaway	No	Yes	Yes	Yes	No
Applications	Motive power and stationary needing needing high currents and endurance	E-bikes, medical devices, EVs, industrial	Mobile phones, laptops, tablets, cameras	Power Tools, medical devices, electric powertrains	UPS, electric powertrains, solar street lighting
Cost	$	$	$$	$$	$$$

https://relionbattery.com/resource-center/technology/why-choose-lithium

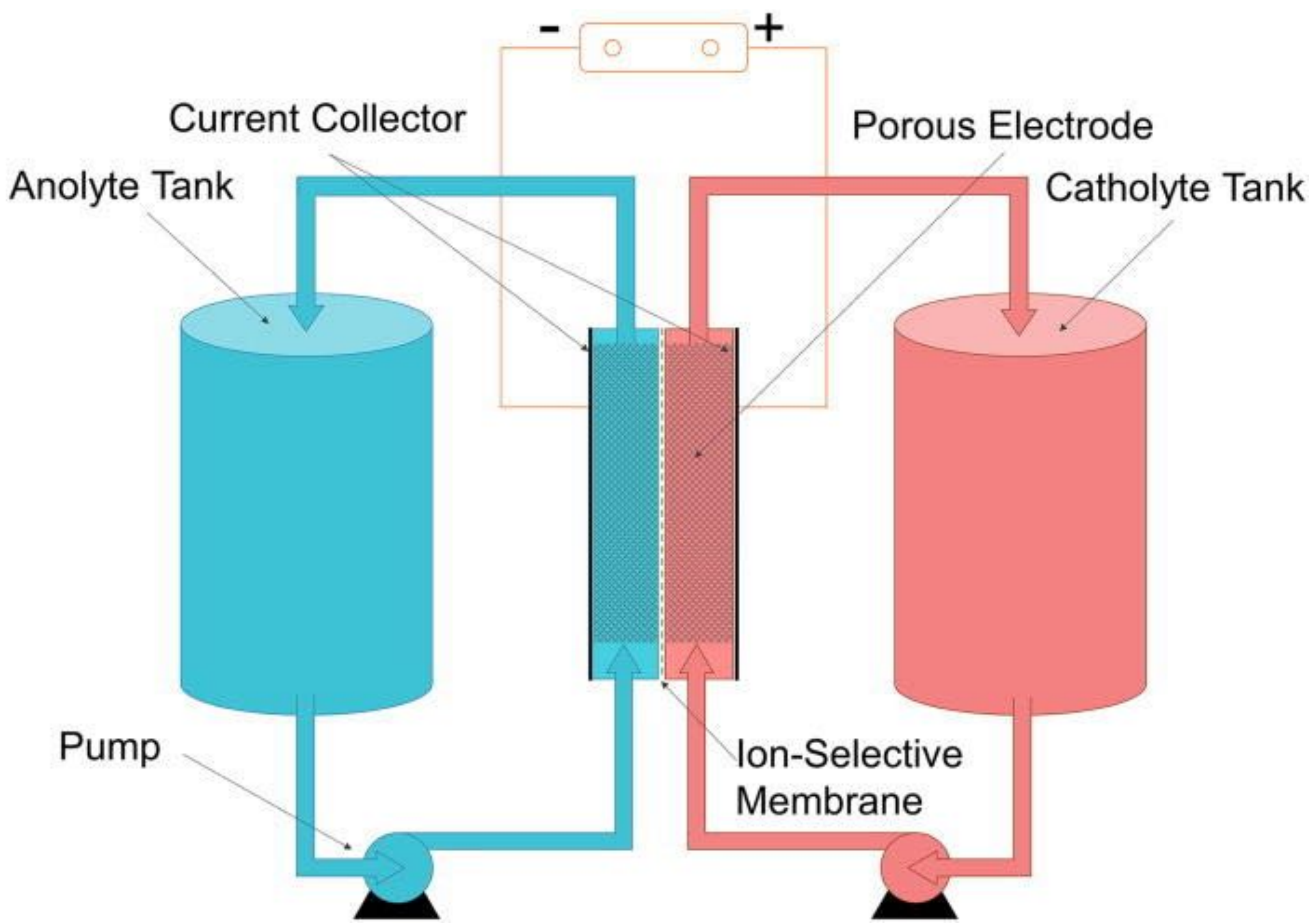
Specifications	Lead Acid	NiCd	NiMH	Li-ion[1] Cobalt	Manganese	Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to 122°F)	–20 to 65°C (–4 to 149°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

https://batteryuniversity.com/

We'll see these charts again later!

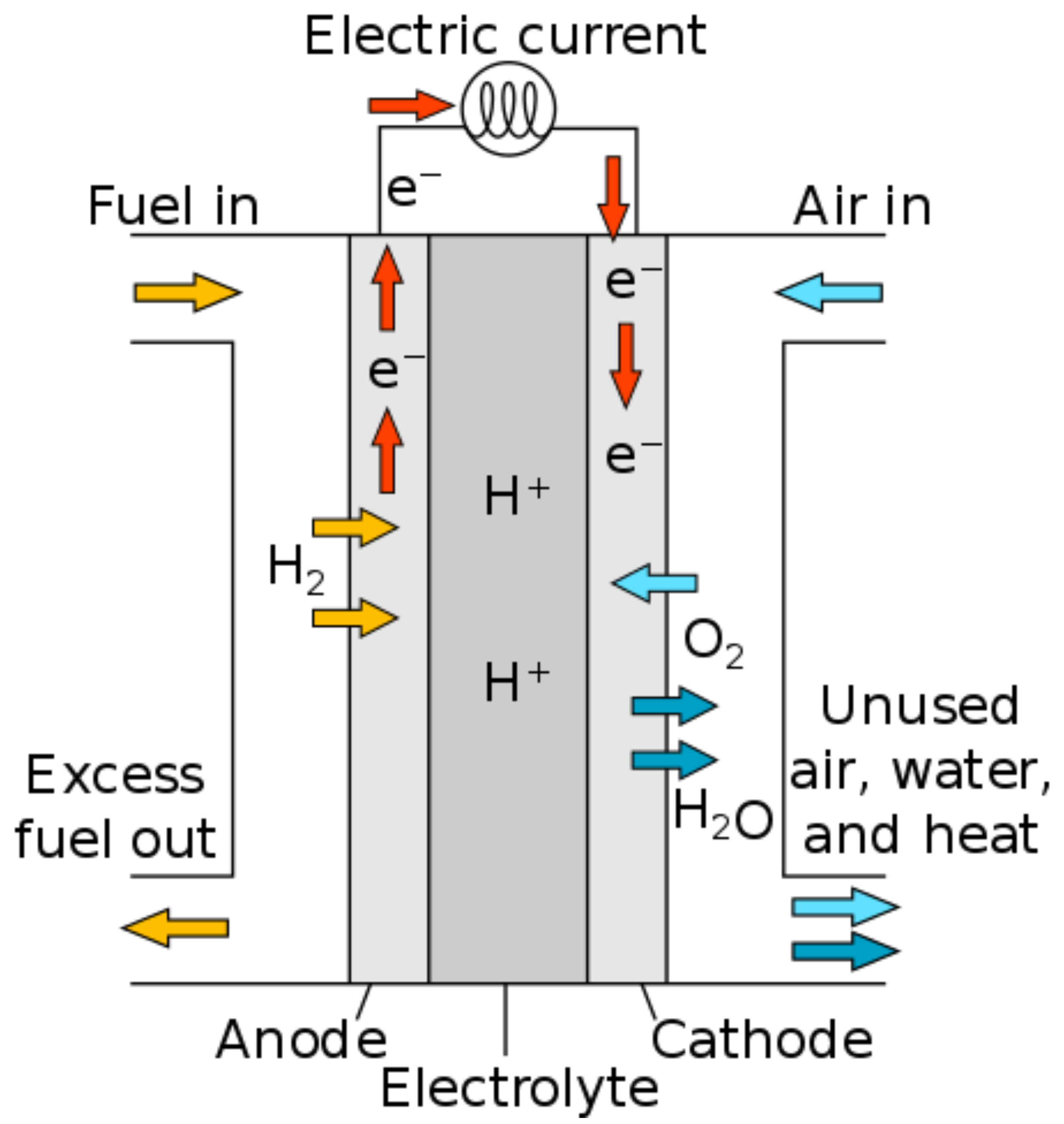
Related technologies

Flow battery



Closed Loop - stores and releases energy

Fuel cell



Open loop - consumes fuel energy carrier e.g. hydrogen

https://en.wikipedia.org/wiki/Flow_battery

https://en.wikipedia.org/wiki/Fuel_cell

Batteries

Electrochemical energy storage devices. Many materials, chemistries, forms.

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

"Goo makes it go"

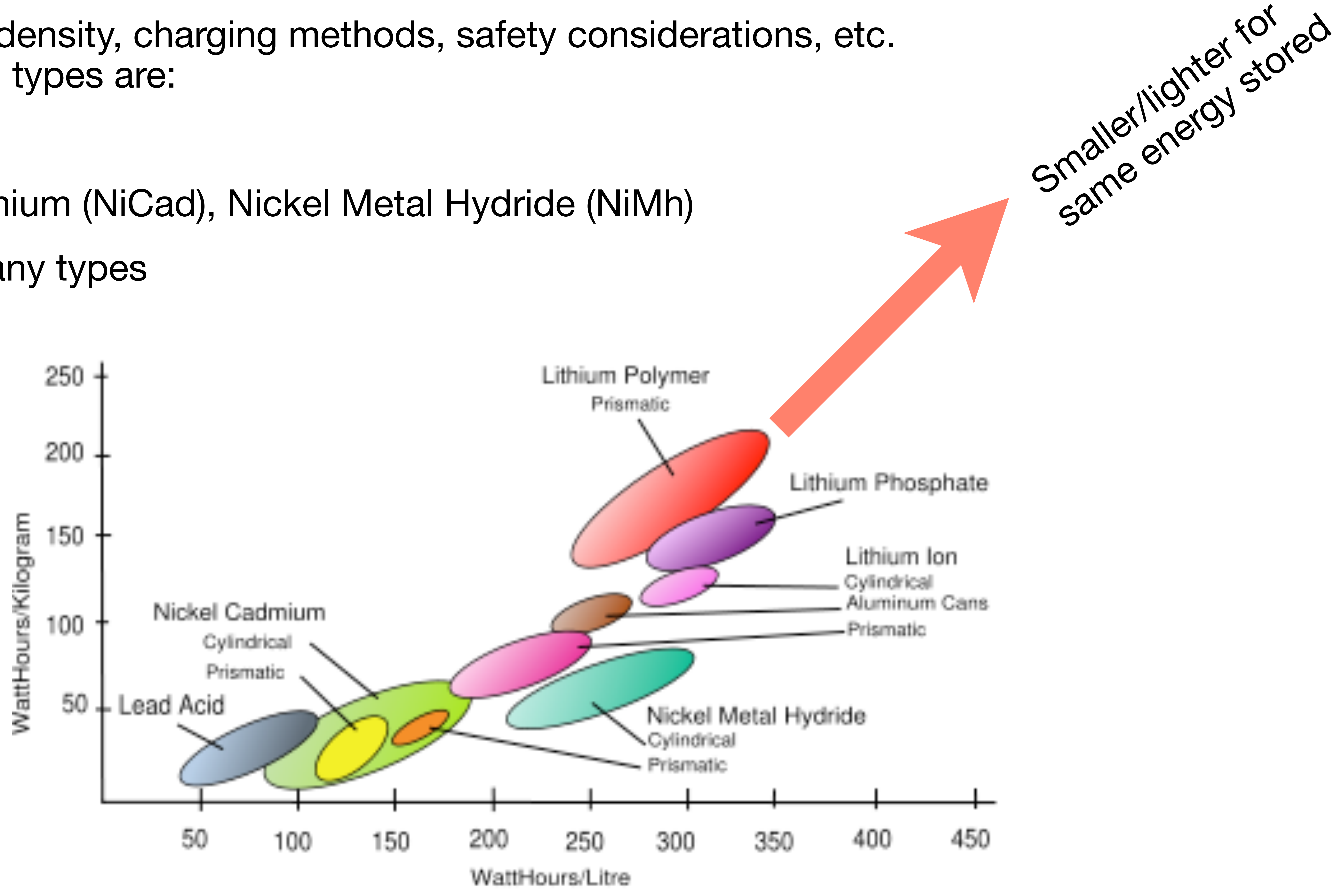
General battery concepts

- “**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 - many types

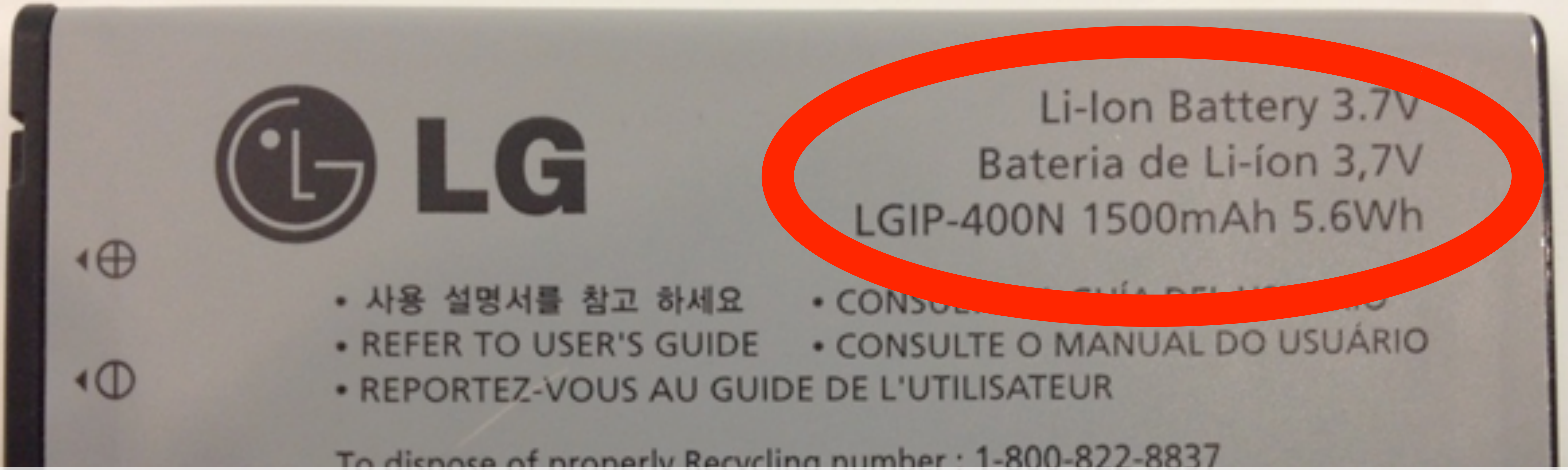


Capacity - how much can the battery hold?

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

Can be roughly converted to watt-hours (or 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:

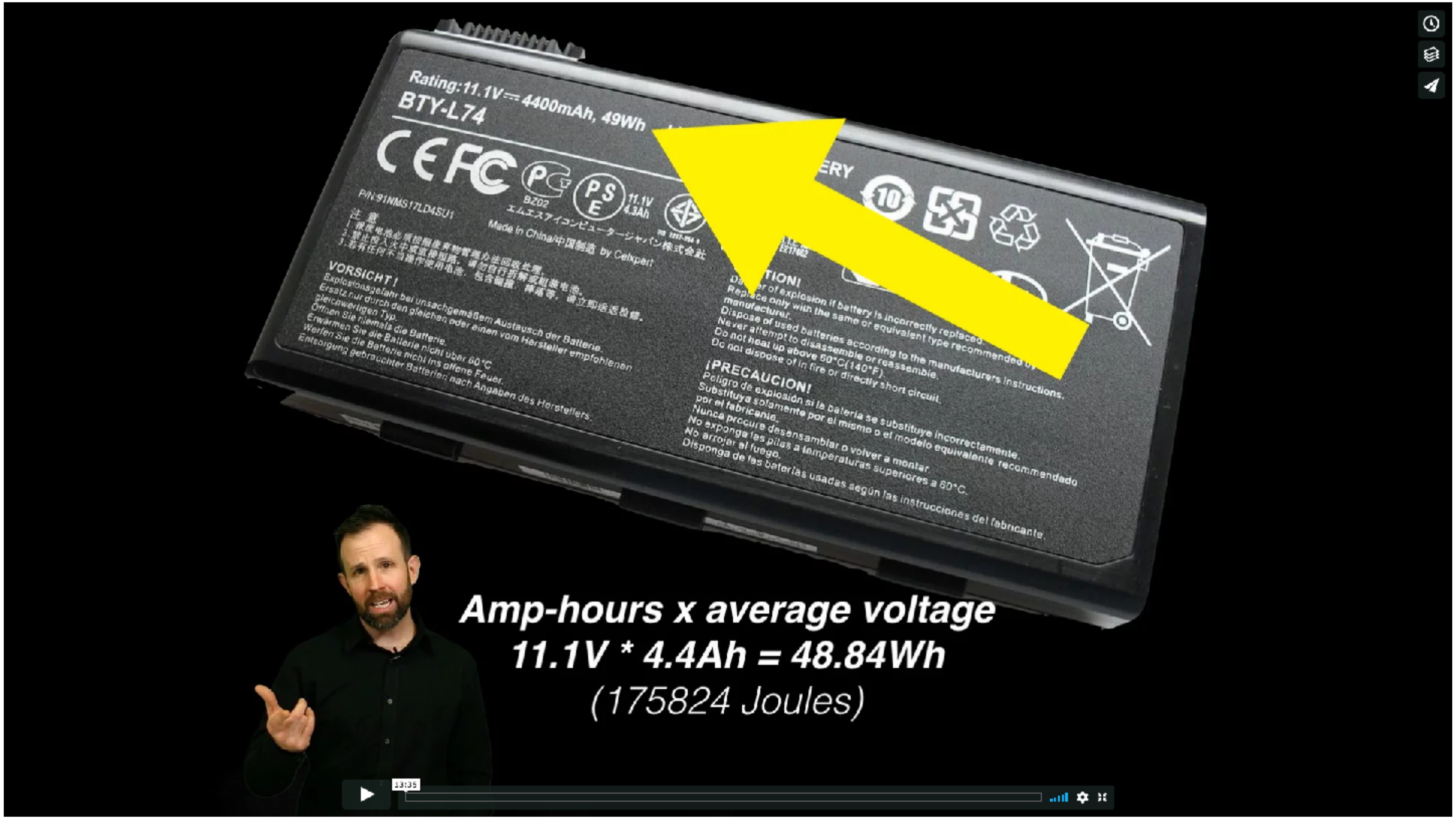
1C = 750mA

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.

Subtle note: The rated capacity of a battery is (usually) specified for its **C/20 (1/20 C) discharge rate**.



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 often 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

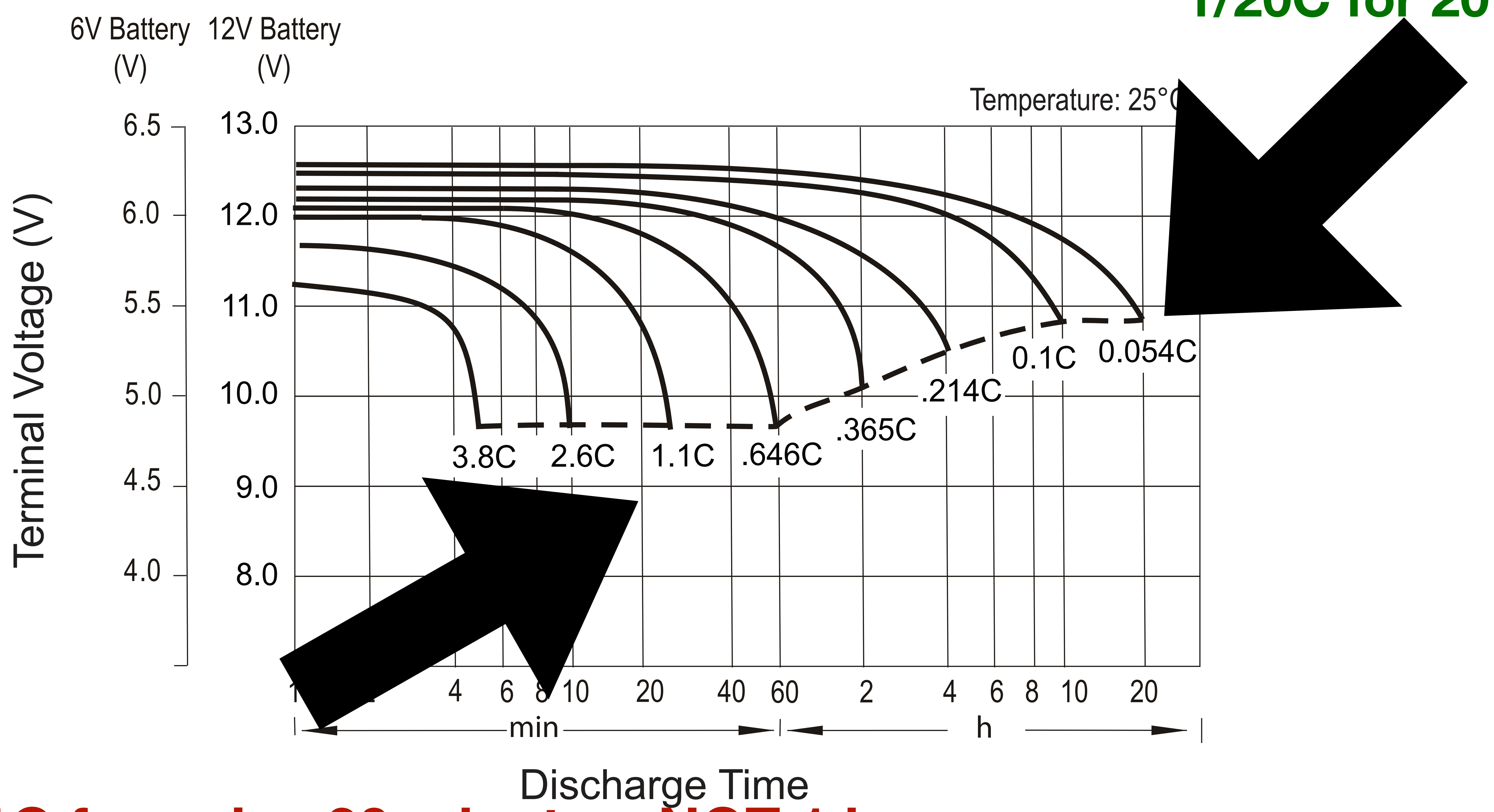
More about calculator.

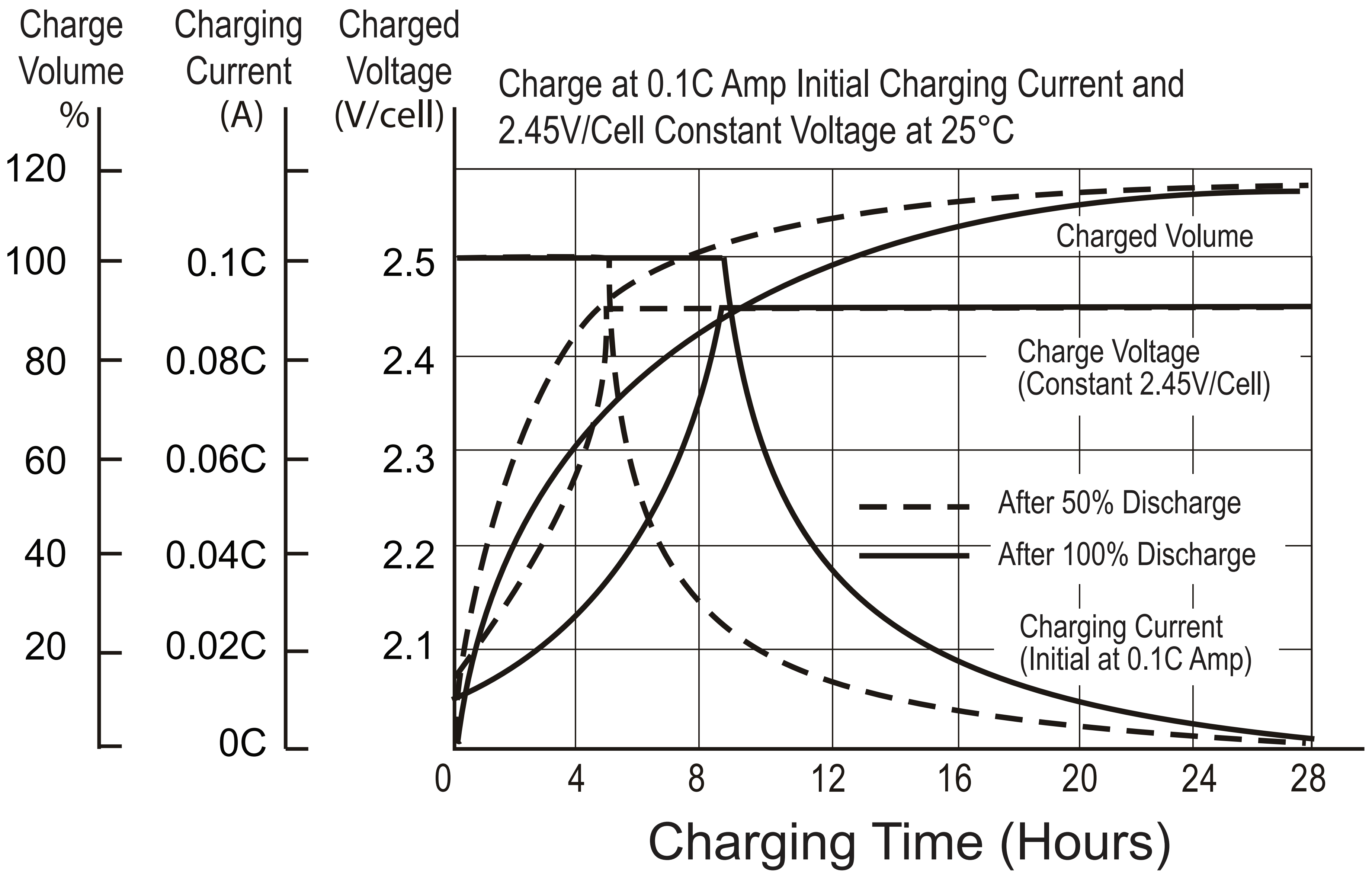
PDC-12800	12	80.0	75.0	10.24	260	6.61	168	8.27	210	9.00	230	50	22.7	U (T14)
PDC-121000	12	100	92.0	12.05	306	6.61	168	8.27	210	8.50	216	61	27.5	U (T14)
PDC-121100	12	107	100.0	12.99	330	6.81	173	8.46	215	8.66	220	67	30.4	B (T6)
PDC-122000	12	214	200.0	20.55	522	9.45	240	8.58	218	8.82	224	138	62.5	B (T11)

Discharge Characteristics

Float Charging Characteristics

1/20C for 20 hours OK!

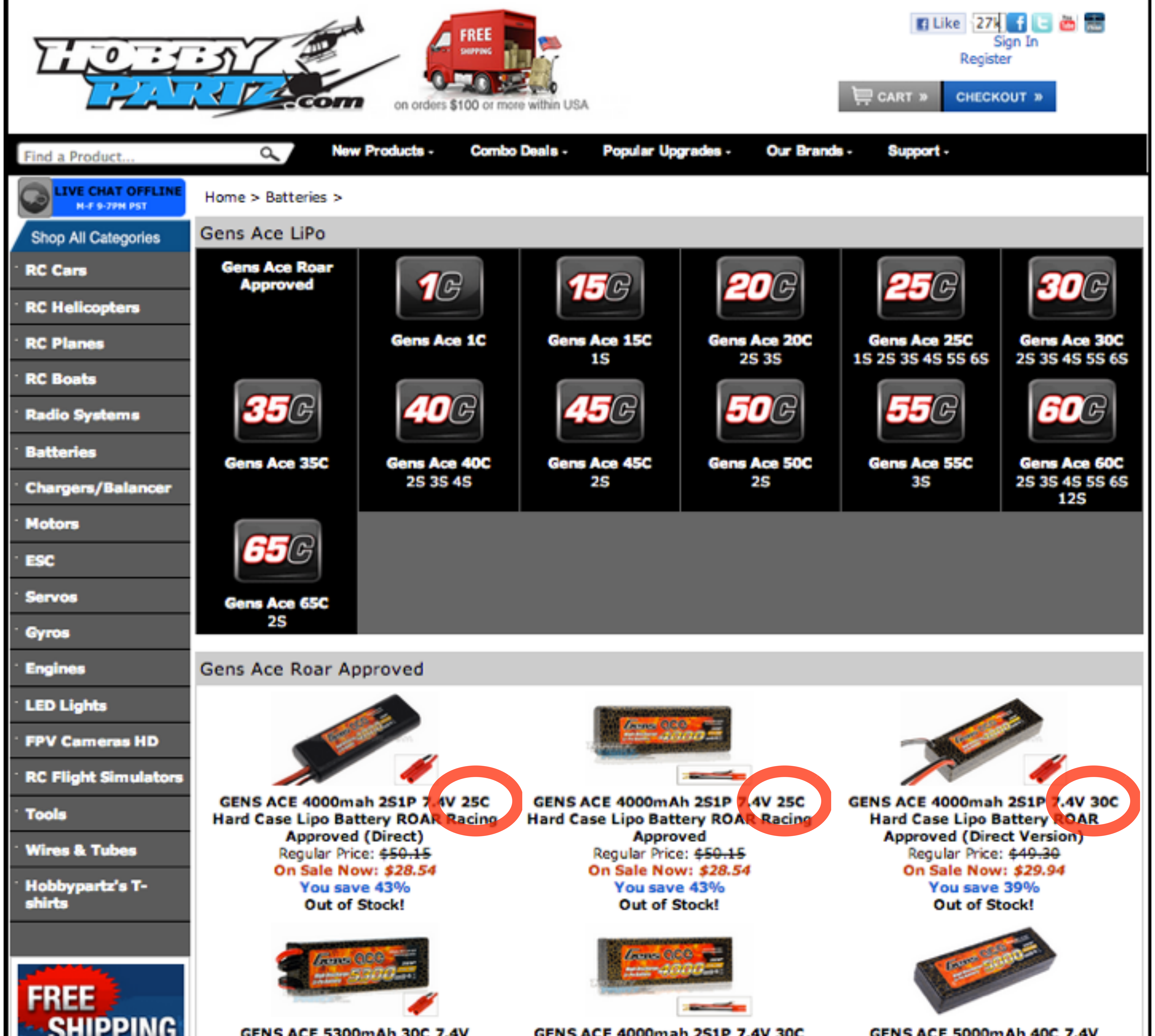




1C for only ~30 minutes, NOT 1 hour

Temperature Effects in Relation to Capacity

Cycle Life in Relation to Depth of Discharge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Gens Ace Roar Approved
1C Gens Ace 1C
15C Gens Ace 15C 1S
20C Gens Ace 20C 2S 3S
25C Gens Ace 25C 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
45C Gens Ace 45C 2S
50C Gens Ace 50C 2S
55C Gens Ace 55C 3S
60C Gens Ace 60C 2S 3S 4S 5S 6S 12S
65C Gens Ace 65C 2S
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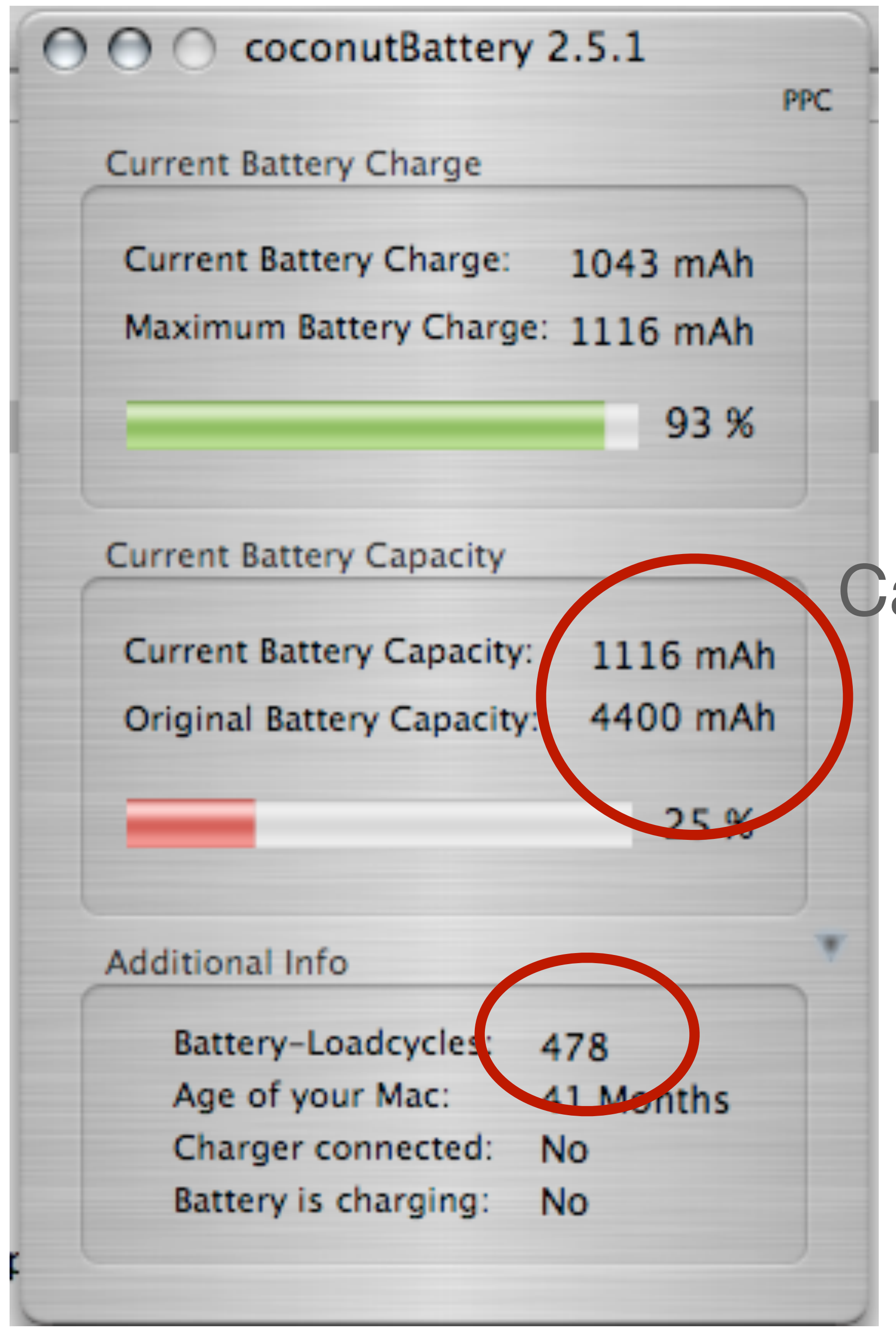
GENS ACE 5000mAh 40C 7.4V

Other considerations:

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

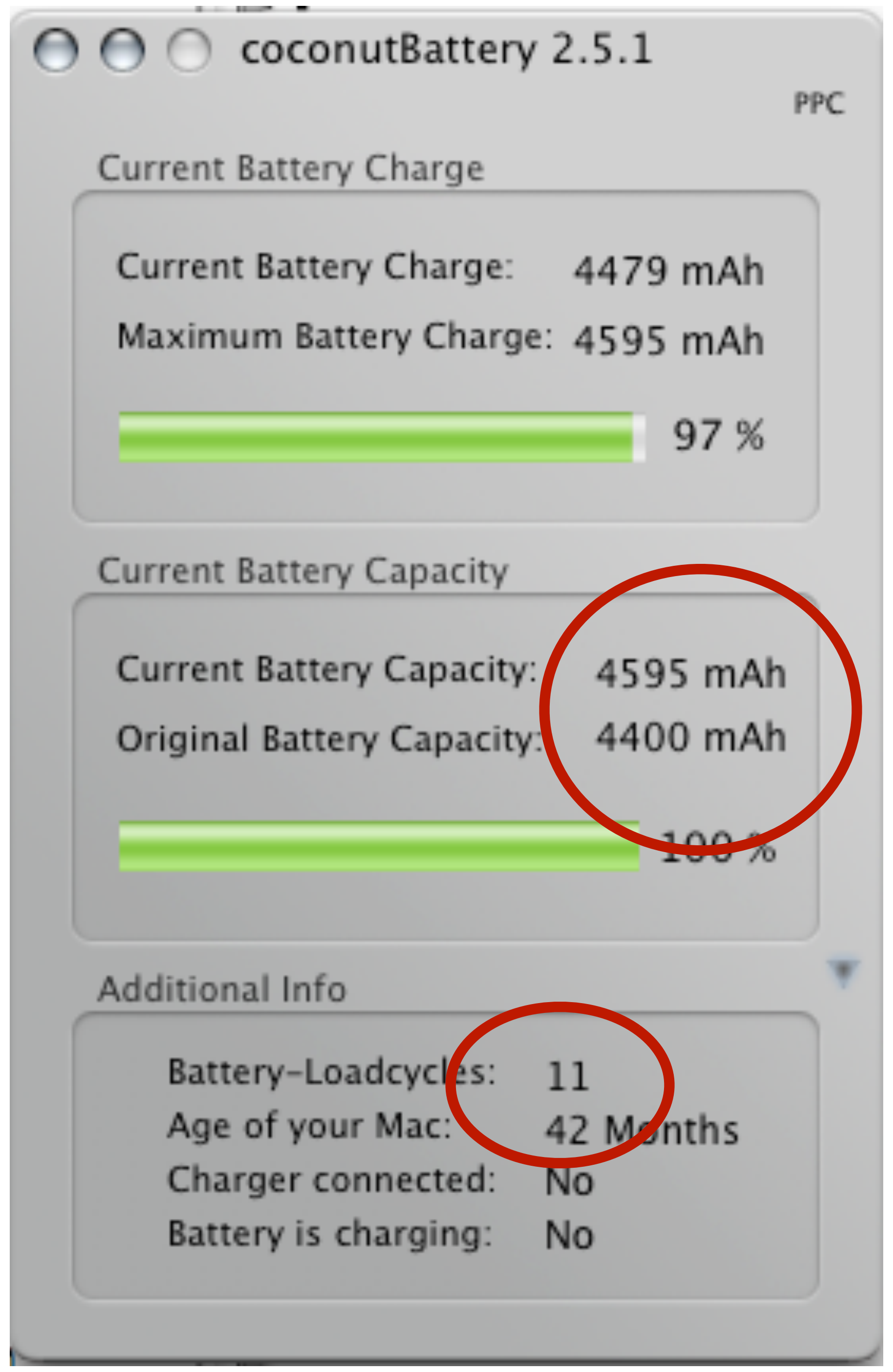
Depth of discharge - how deeply can it be discharged? Decreasing DOD increased life expectancy.



Capacity

Cycles

Old Battery



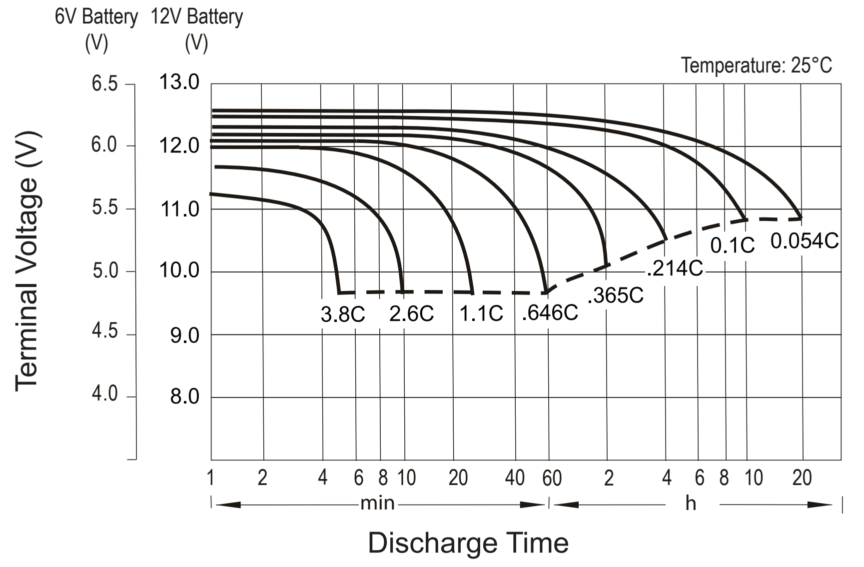
New Battery

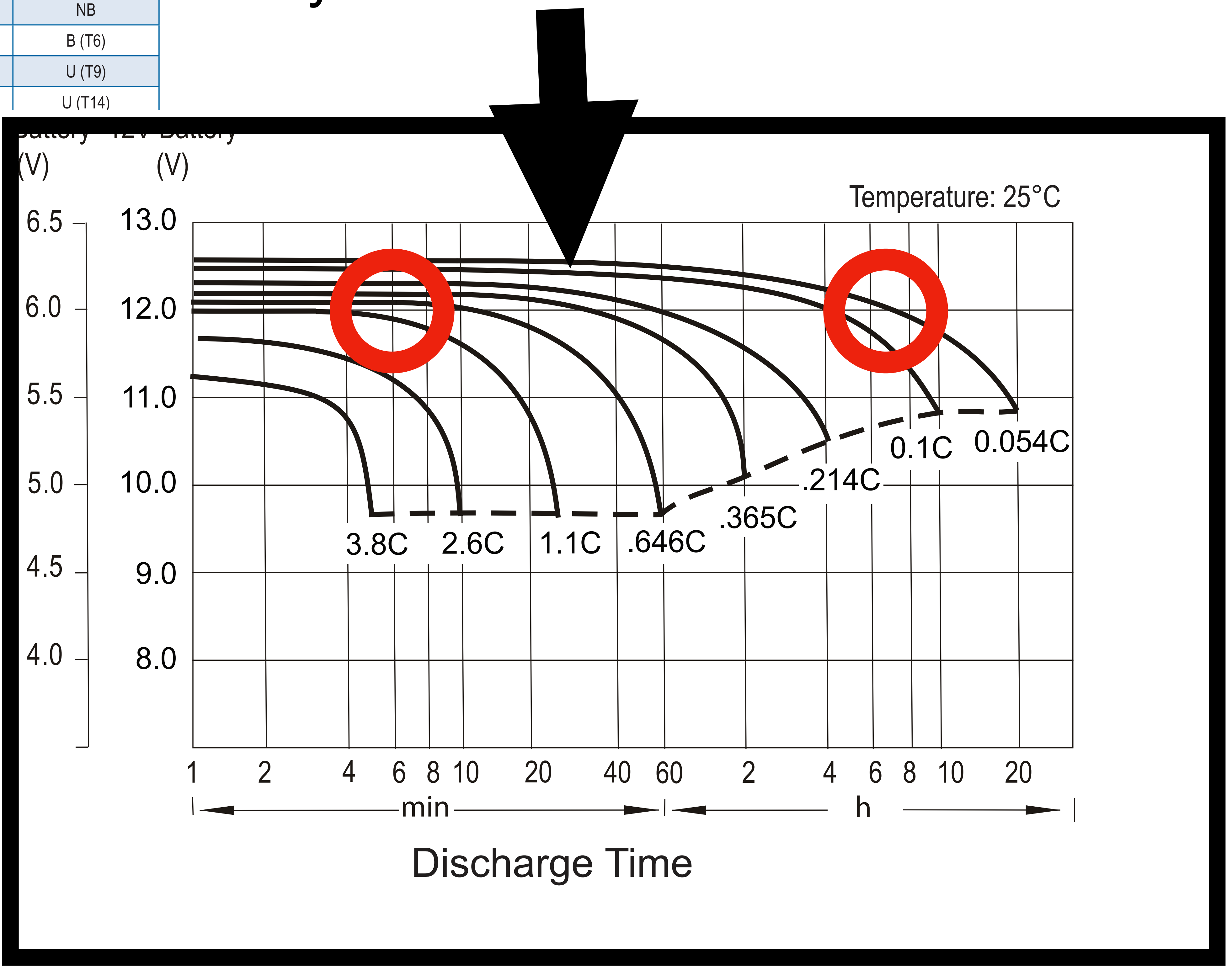
PDC Series - AGM Deep Cycle Batteries

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	F2
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]

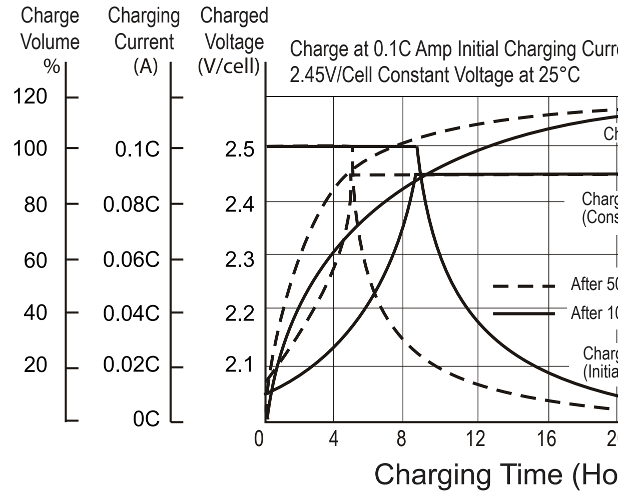
Hard to use **voltage alone** to determine state of battery since these curves are so flat.

Discharge Characteristics



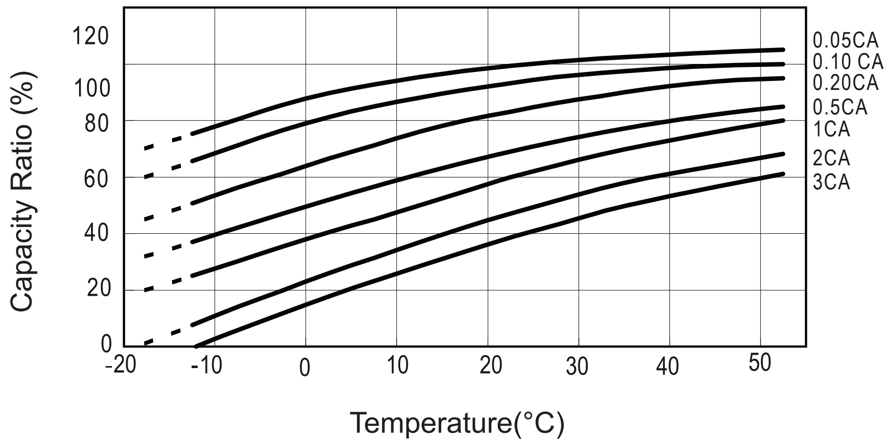


Float Charging Characteristics

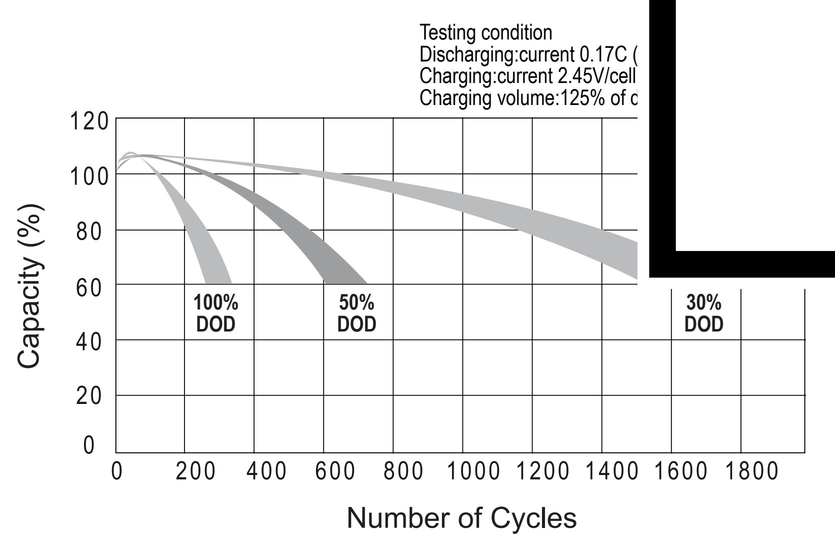


Which curve are you on if you read 12V?

Temperature Effects in Relation to Capacity



Cycle Life in Relation to Depth of D



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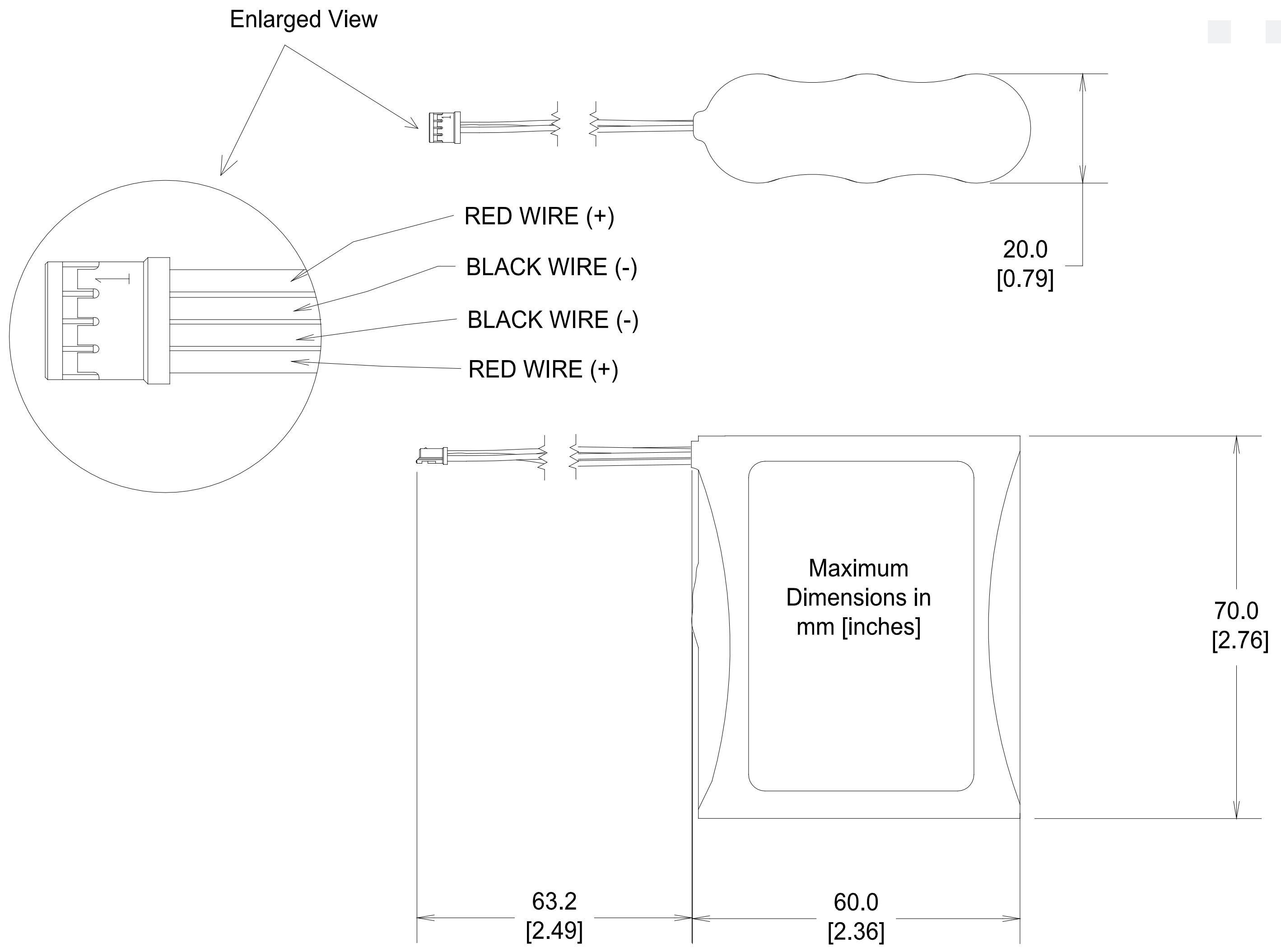
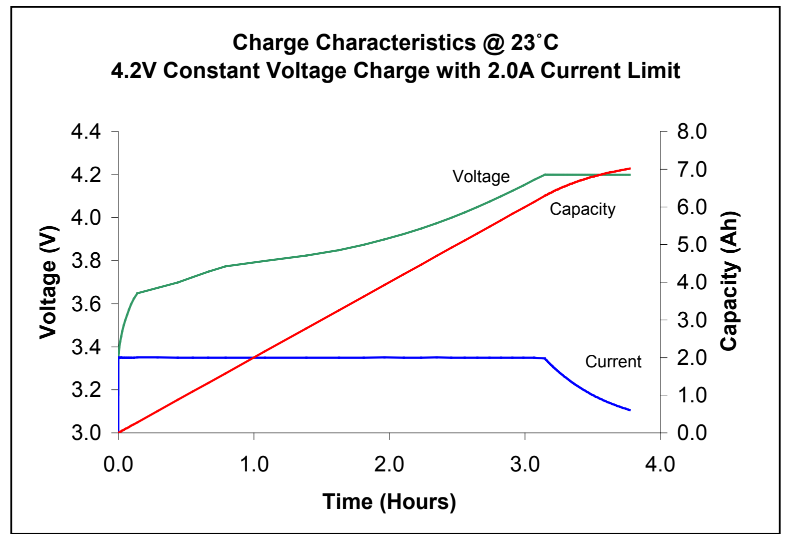
0912 1M

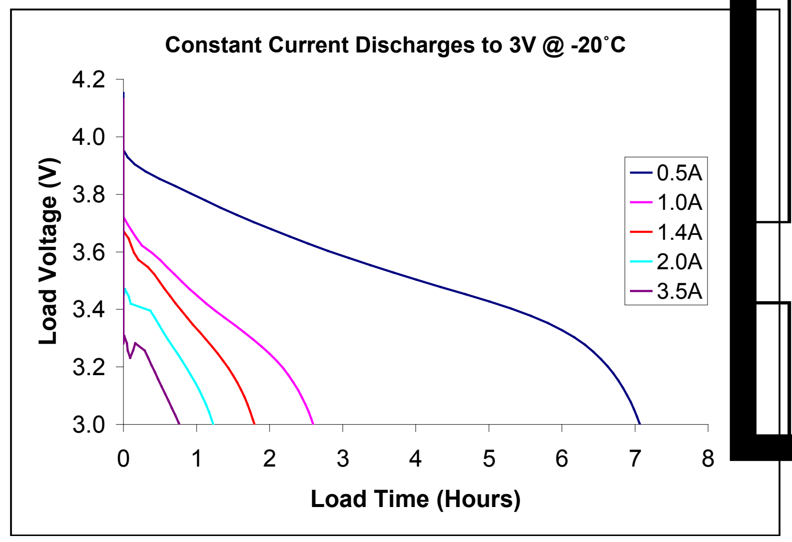
A little better… still need to know current in real time

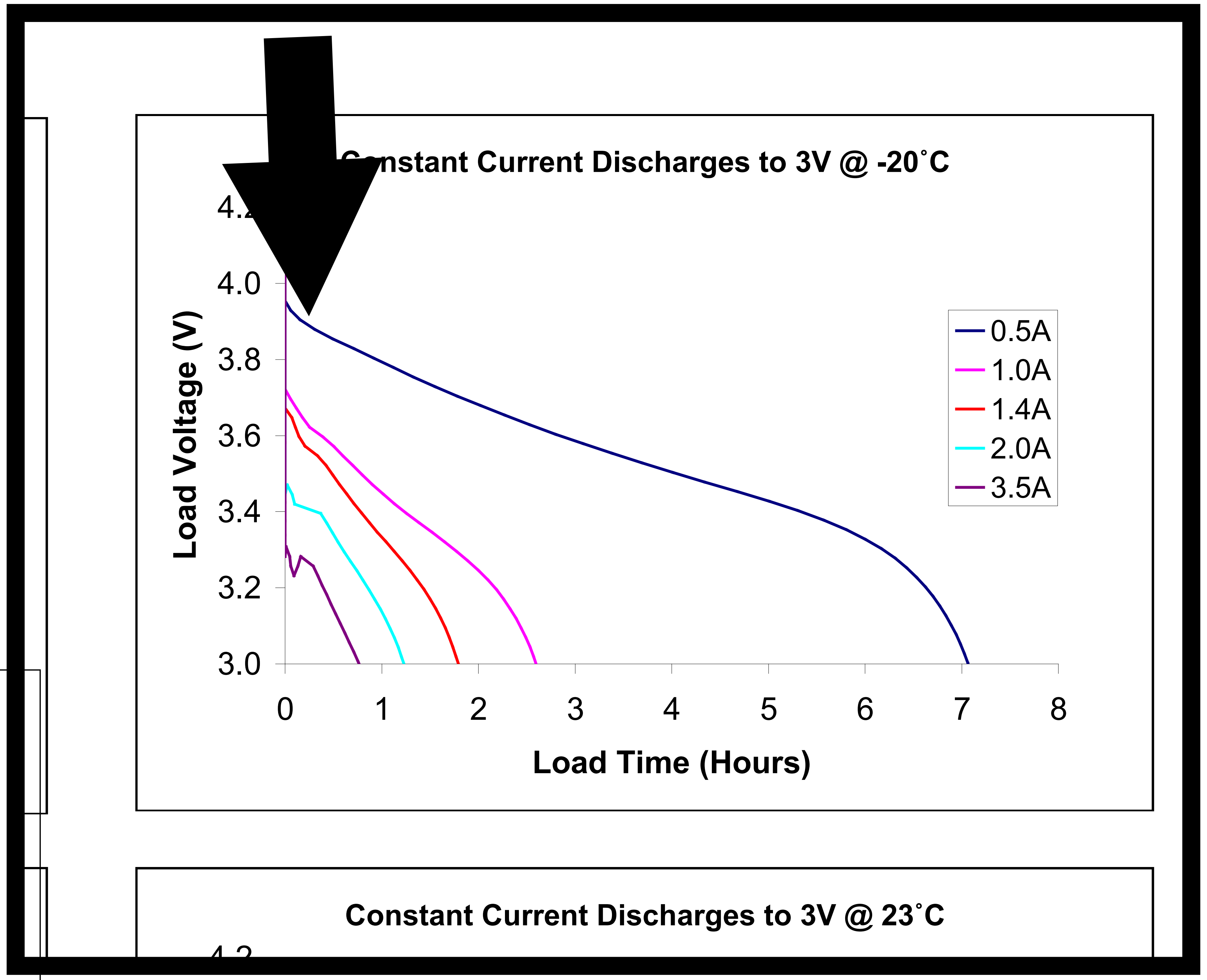
Dimensions

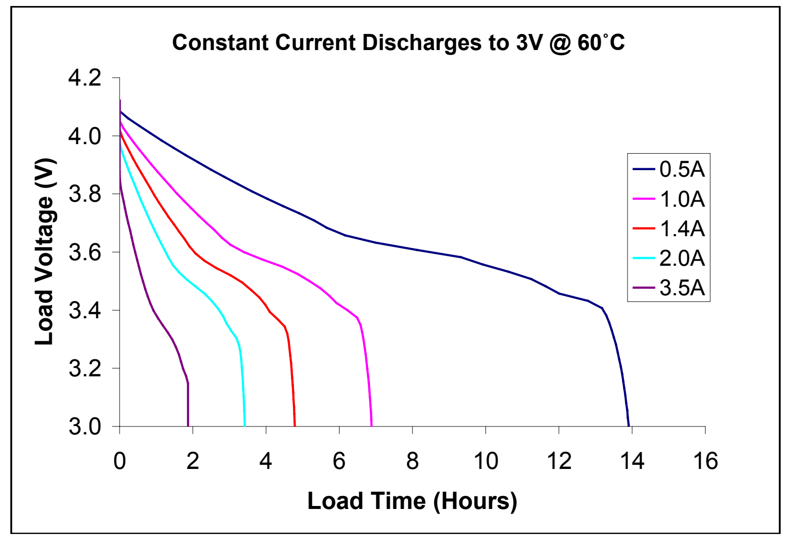


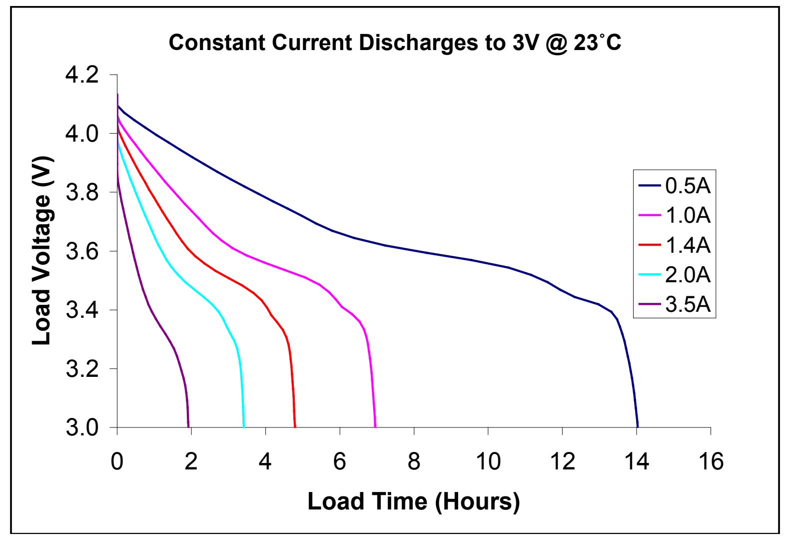
Performance Graphs











Newark, New York | 315-332-7100 | Fax: 315-331-7800

Charging

Charging batteries can be very complex. Doing it wrong can be dangerous!

Boeing Dreamliner

Lithium Fire 2022

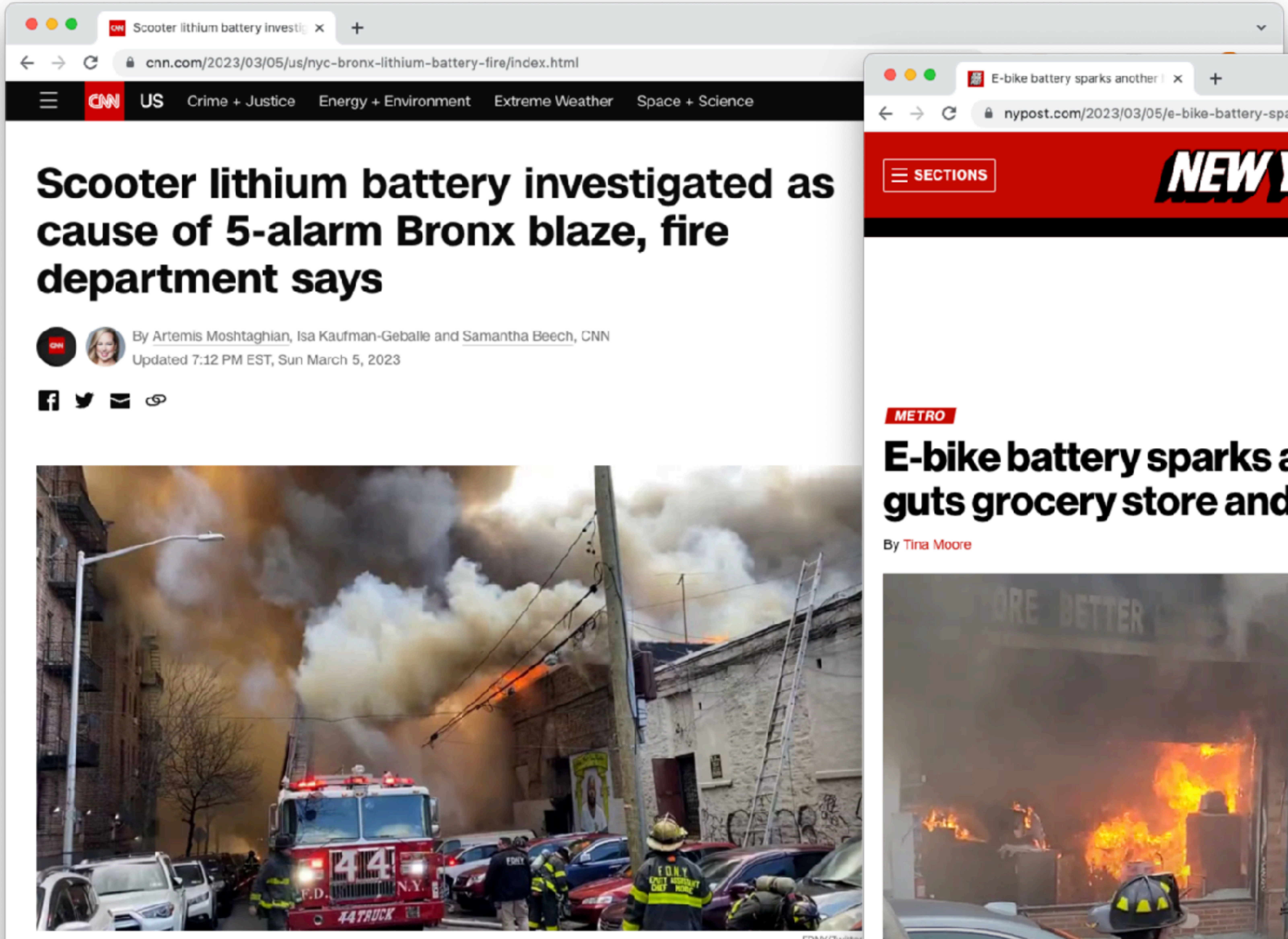
"The cargo ship Felicity Ace is aflame from bow to stern **with a lithium-ion battery fire that can't be put out with water** alone. The fire has been burning since Wednesday (Feb. 16), as the ship drifts in the Atlantic about 200 miles southwest of Portugal's Azores Islands. Its 22-person crew abandoned ship and was rescued on Thursday." - Quartz

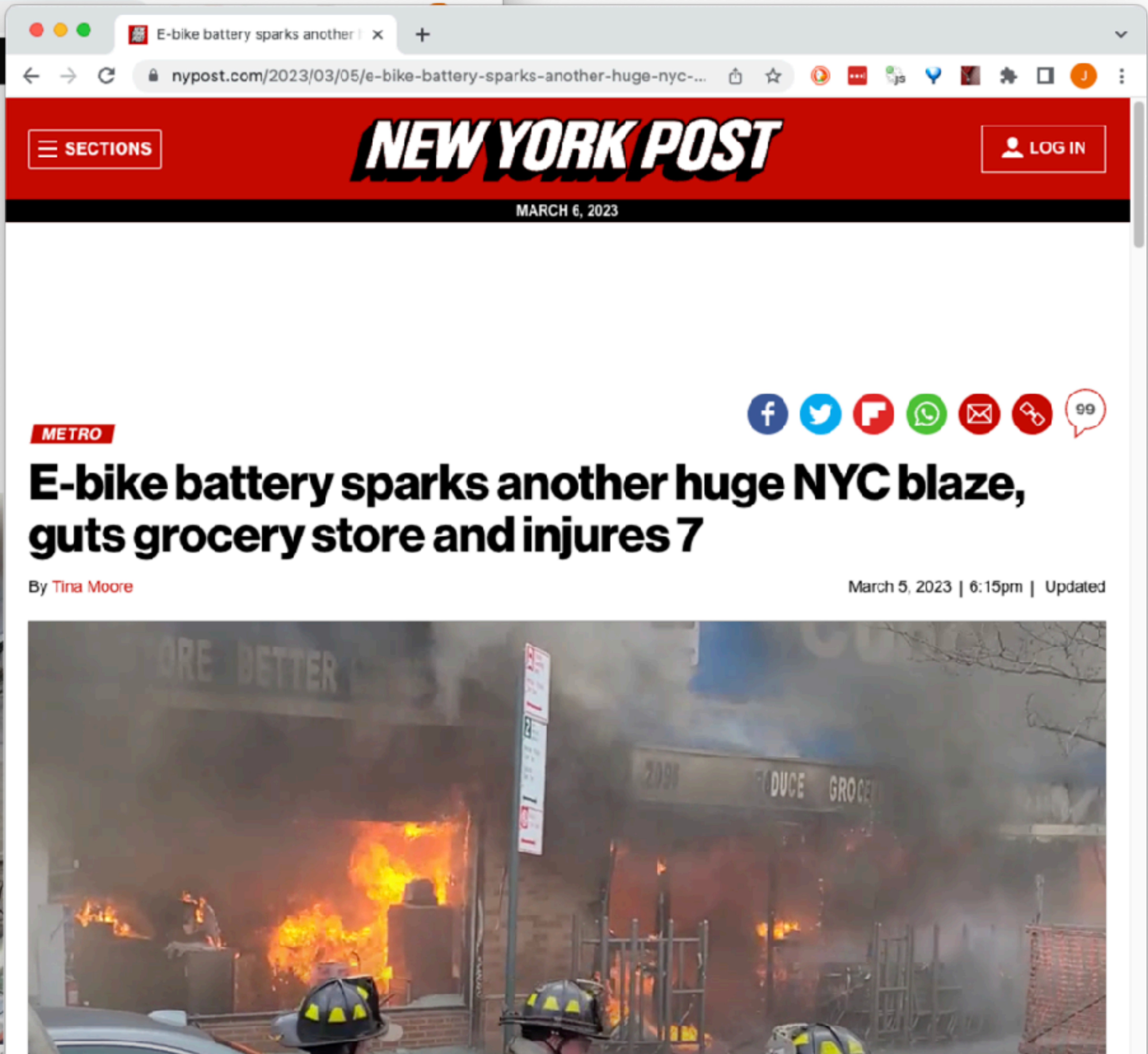
"The car carrier ship was hauling thousands of VW Group models… Volkswagen Golf R, GTI, Arteon, and ID.4 vehicles were on board, as well as unspecified **Porsche[, Lamborghini,] and Bentley** models." - Car & Driver

Lithium Fire 2022

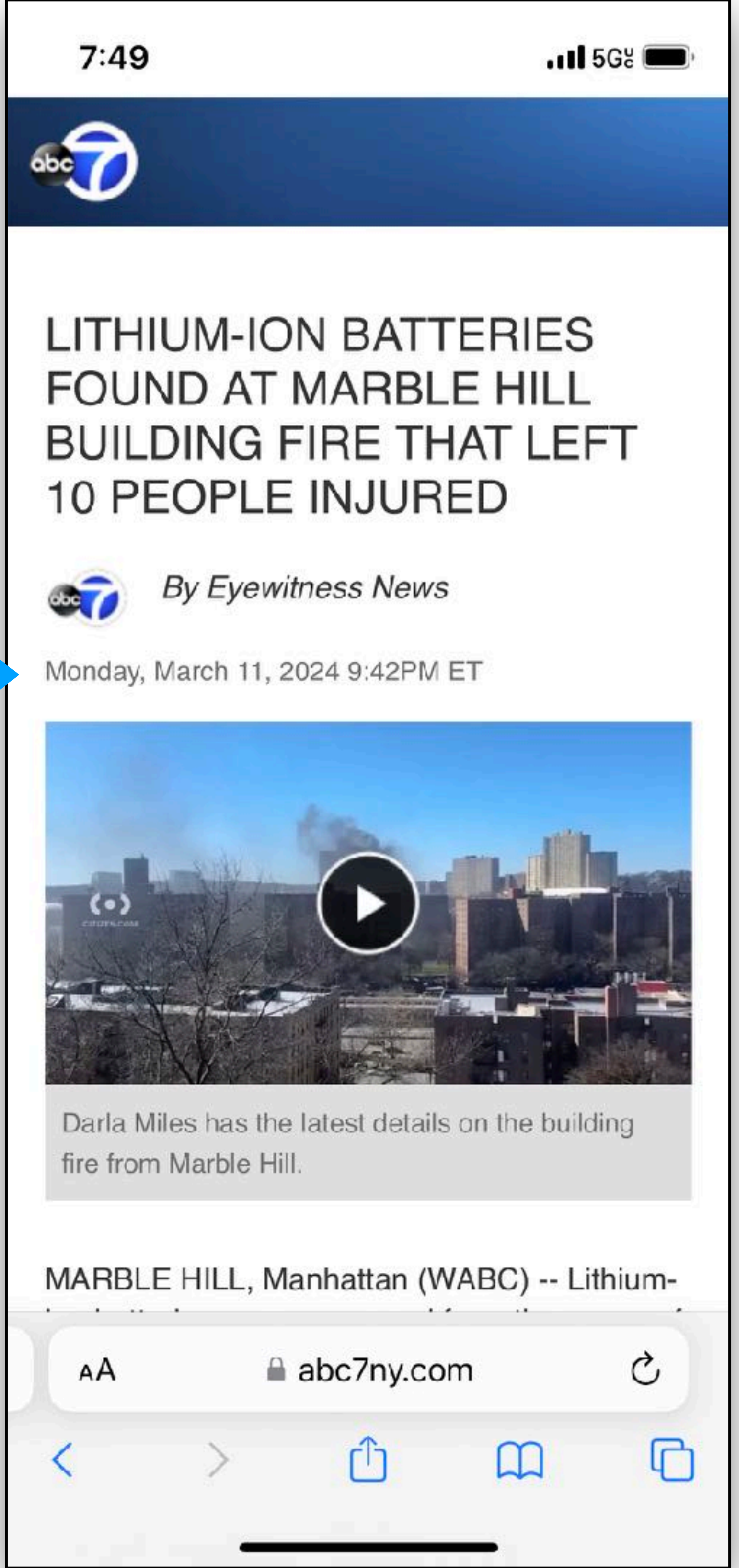
"A two-week transatlantic saga ended Tuesday with a massive ship — and thousands of luxury cars aboard — sinking about 250 miles off a Portuguese archipelago after catching fire." - Washington Post

Lithium Fire 2023





Lithium Fire 2024


7:49

LITHIUM-ION BATTERIES FOUND AT MARBLE HILL BUILDING FIRE THAT LEFT 10 PEOPLE INJURED

By Eyewitness News

Monday, March 11, 2024 9:42PM ET

Darla Miles has the latest details on the building fire from Marble Hill.

MARBLE HILL, Manhattan (WABC) -- Lithium-

abc7ny.com


Lithium Fire 2025
Moss Landing Fire

Don’t puncture, BITE, or otherwise f* with batteries!

Standard F1 Grenade has 60g TNT = 270,000 Joules*

Laptop battery 100Wh = 360,000 Joules

We want our batteries to be like bombs: to store a lot of energy and to charge/discharge as rapidly as we want. A grenade and a laptop contain similar energies. The difference is the grenade discharges its energy over milliseconds (ultra high power) while the laptop battery takes minutes to hours (moderate power).

*https://en.wikipedia.org/wiki/TNT_equivalent

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

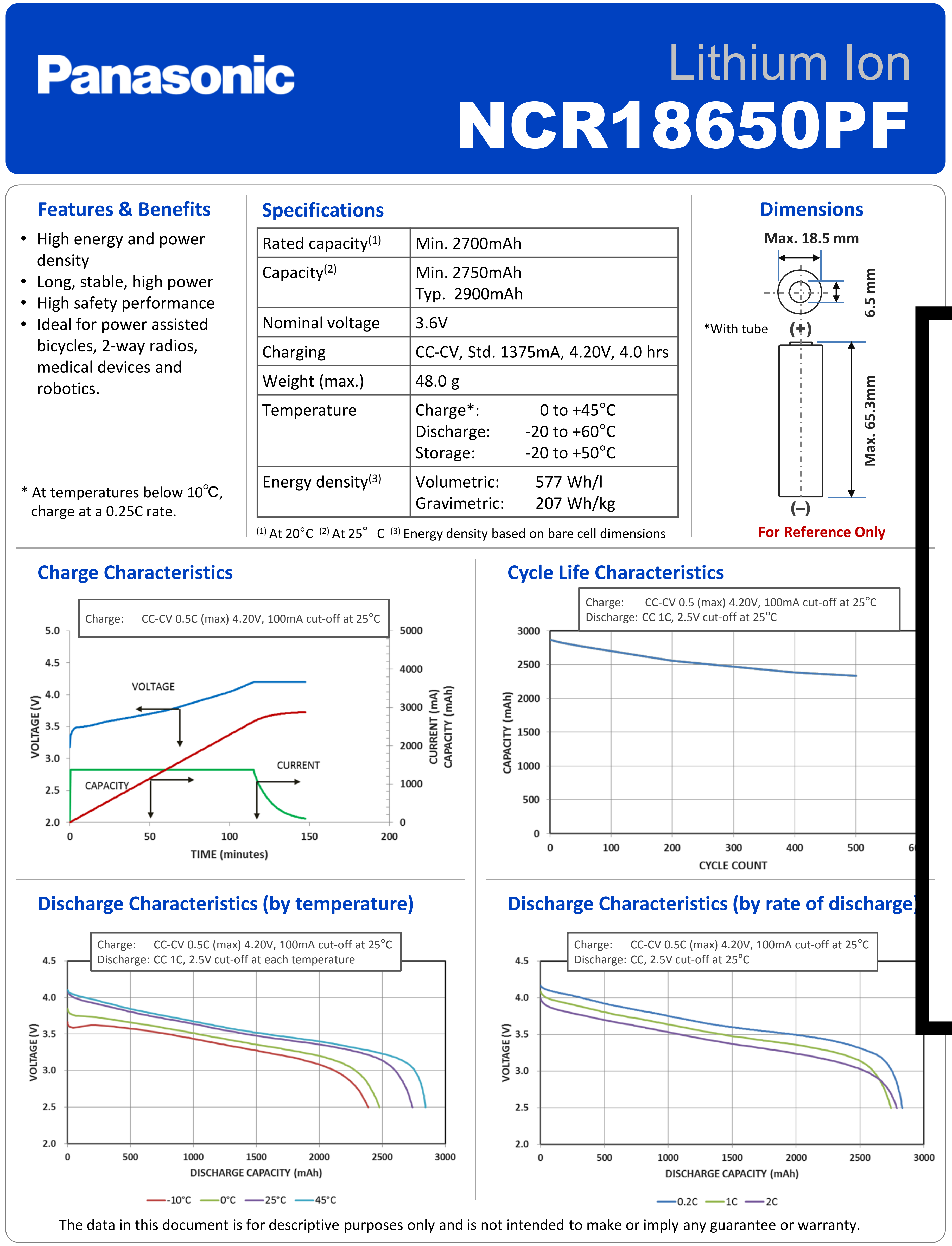
An advanced system typically uses a combination of **constant current** and/or **constant voltage** charge stages coupled with **current, delta V, and/or delta T monitoring** (changes in the rate of change of voltage or temperature). These will be tailored to the battery chemistry, number of cells, and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



Panasonic

Lithium Ion

NCR18650PF

Features & Benefits

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

* At temperatures below 10°C, 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

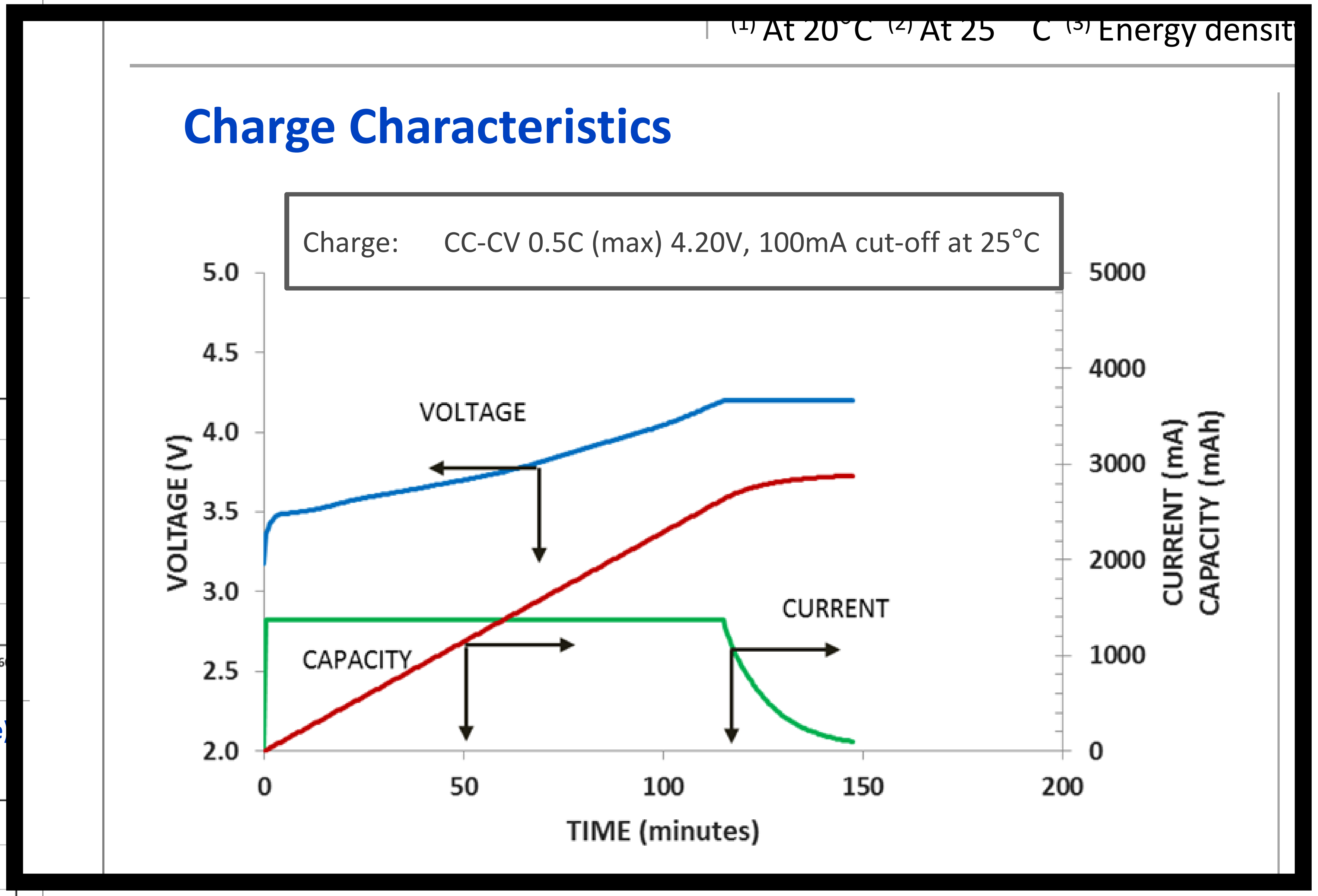
Charge Characteristics

Cycle Life Characteristics

Discharge Characteristics (by temperature)

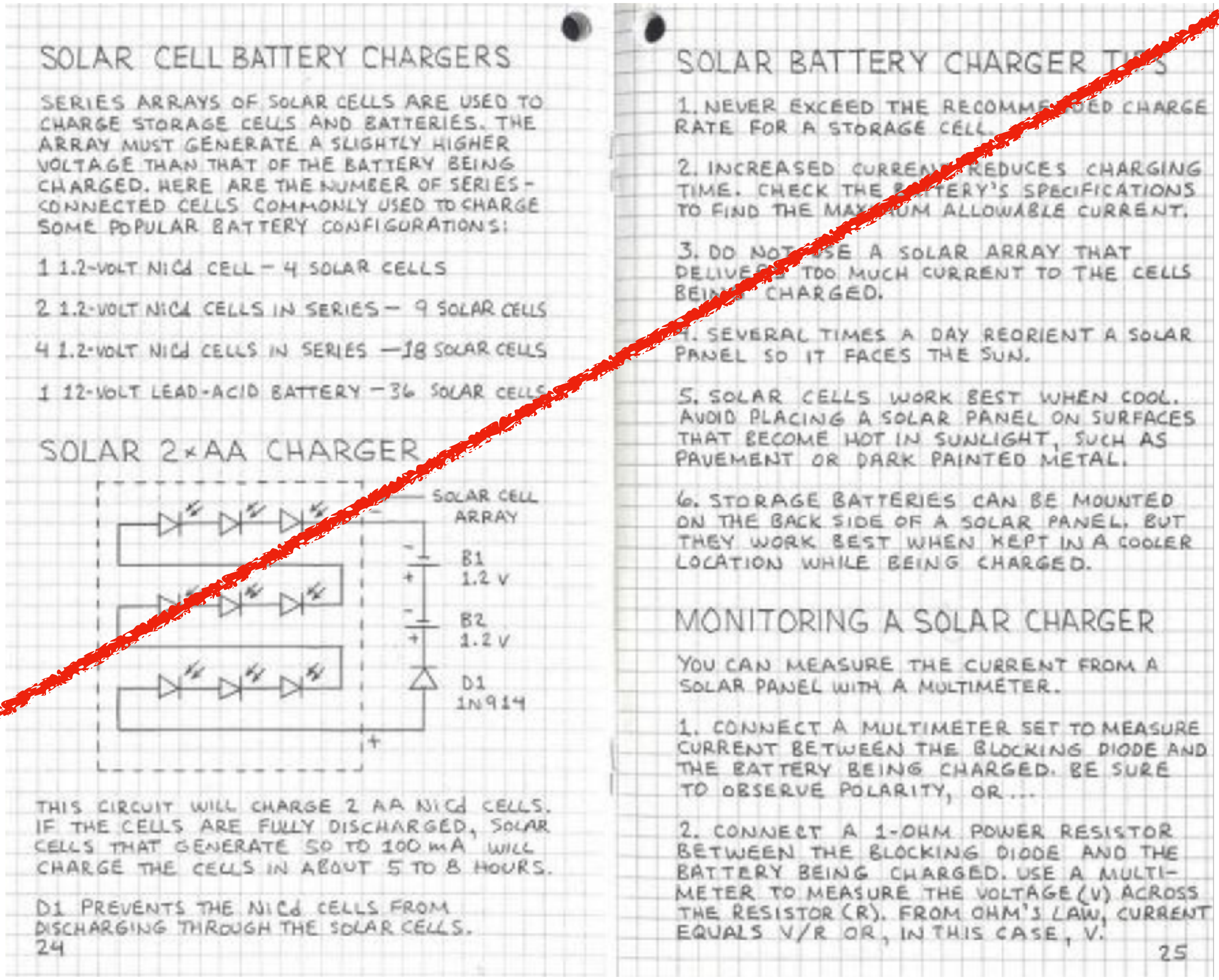
Discharge Characteristics (by rate of discharge)

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.

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

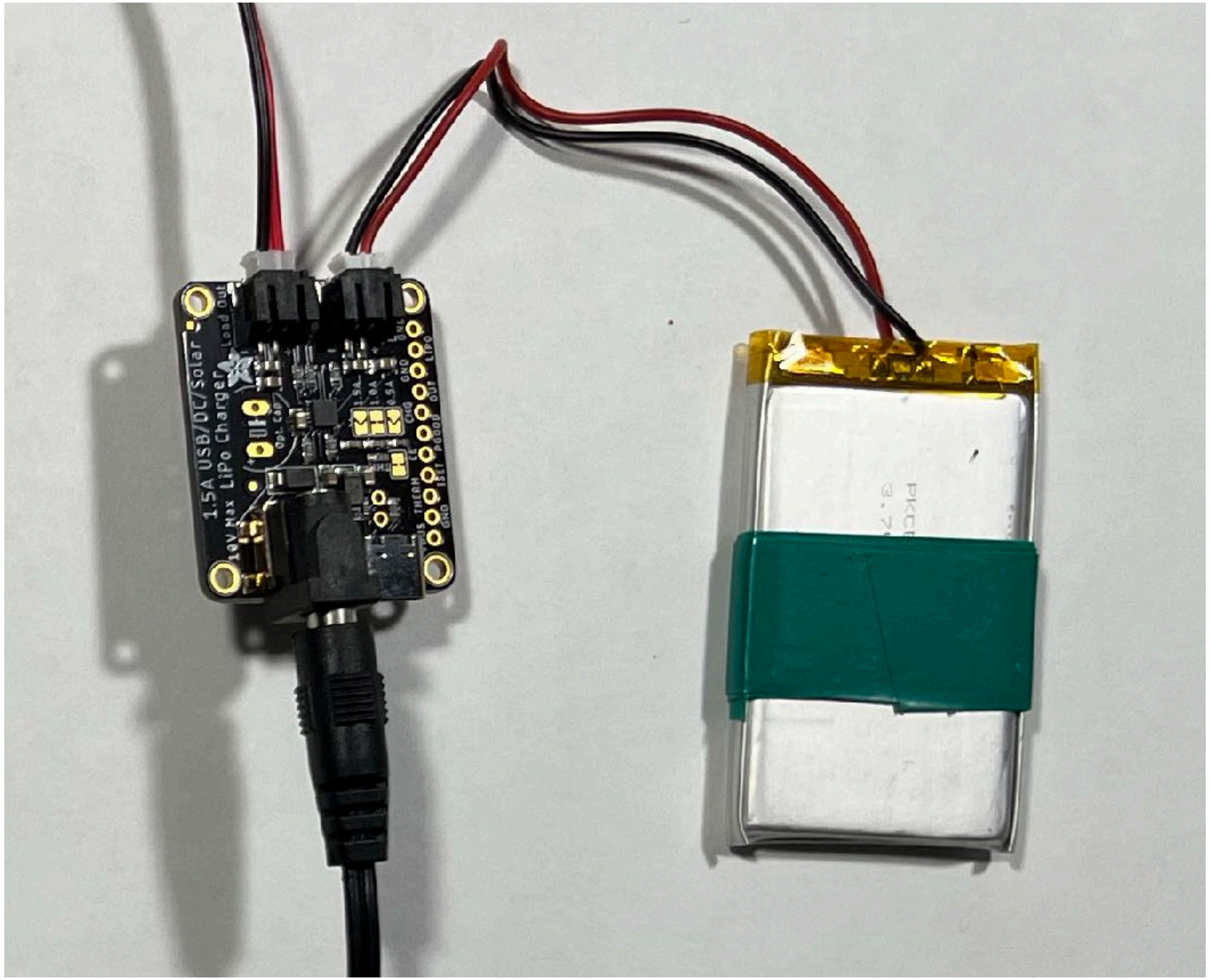
YOU CAN MEASURE THE CURRENT FROM A SOLAR PANEL WITH A MULTIMETER.

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

Batteries - TL;DR



Get a battery from Adafruit and only charge it with their charge controller. It will have the matching polarized connector and won't charge too fast. Use power requirements from your project to pick a size between ~500mAh and 2000mAh. Or guess and budget enough time/$ to revise your choice.

2024: Use the provided Voltaic packs. They've done all this work for us already!

3.7V 1000mAh 803040 Lipo battery Rechargeable Lithium Polymer ion Battery with JST Connector

4.3 (113)

50+ bought in past month

3.7V Lipo Battery 1000mAh Rechargeable Lithium ion Polymer Battery 503450 Lithium Polymer ion Battery with JST Connector

4.0 (25)

Some battery sizes

Orders of magnitude

1

~1Wh AAA alkaline

~10Wh smart phone battery

10

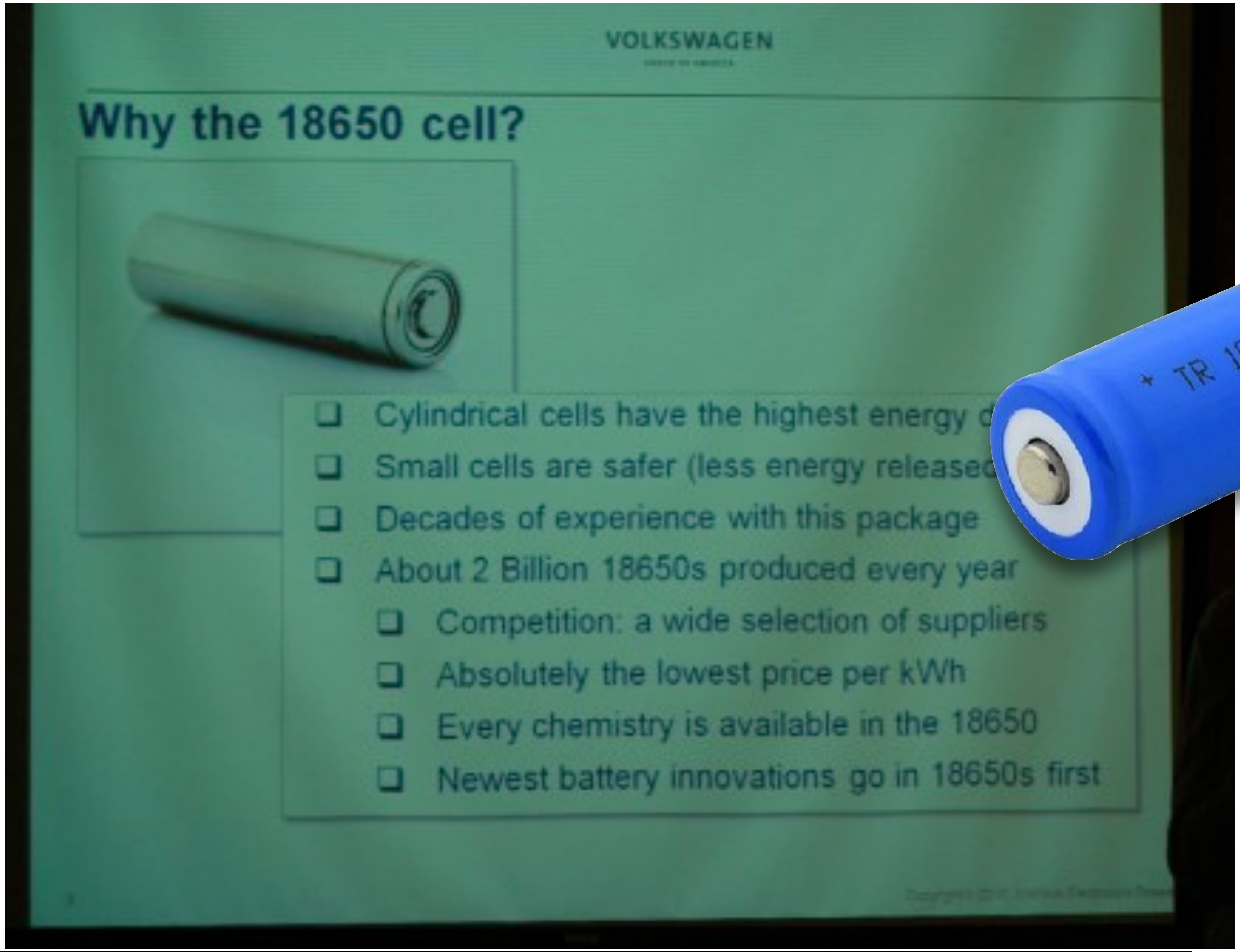
18650 cell ~ 10Wh

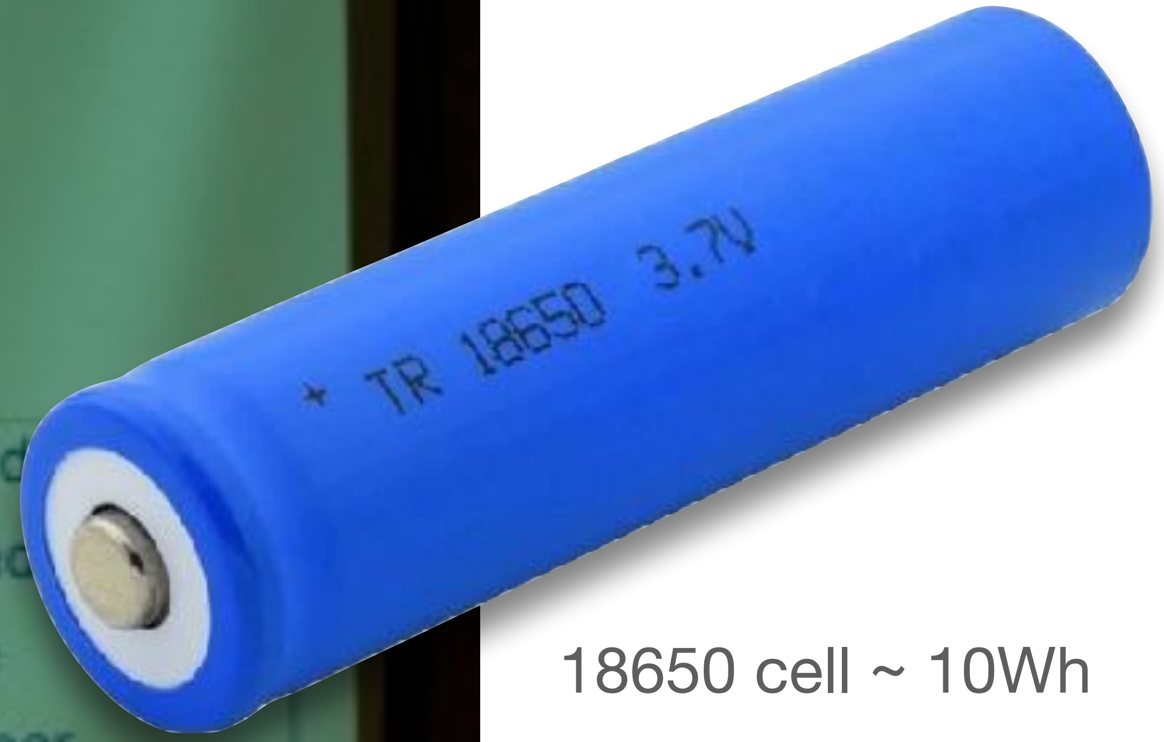
~100Wh laptop battery

100

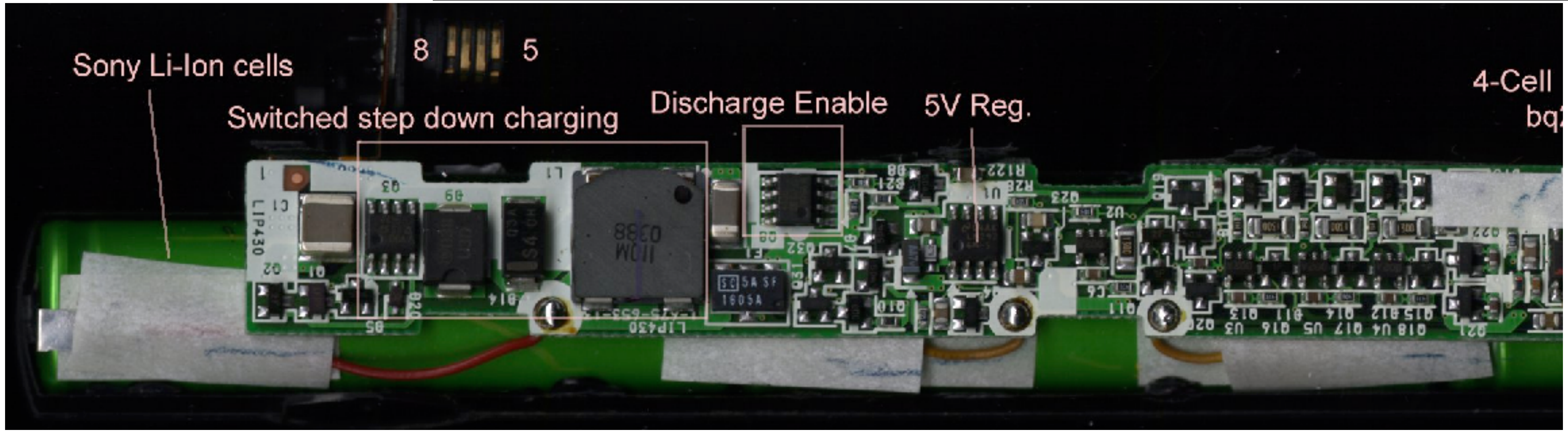
18650 cell was the lithium standard, used from laptops to EVs. Massive production numbers and learning curve.

Tesla S





18650 cell ~ 10Wh



18650 cell ~ 10Wh

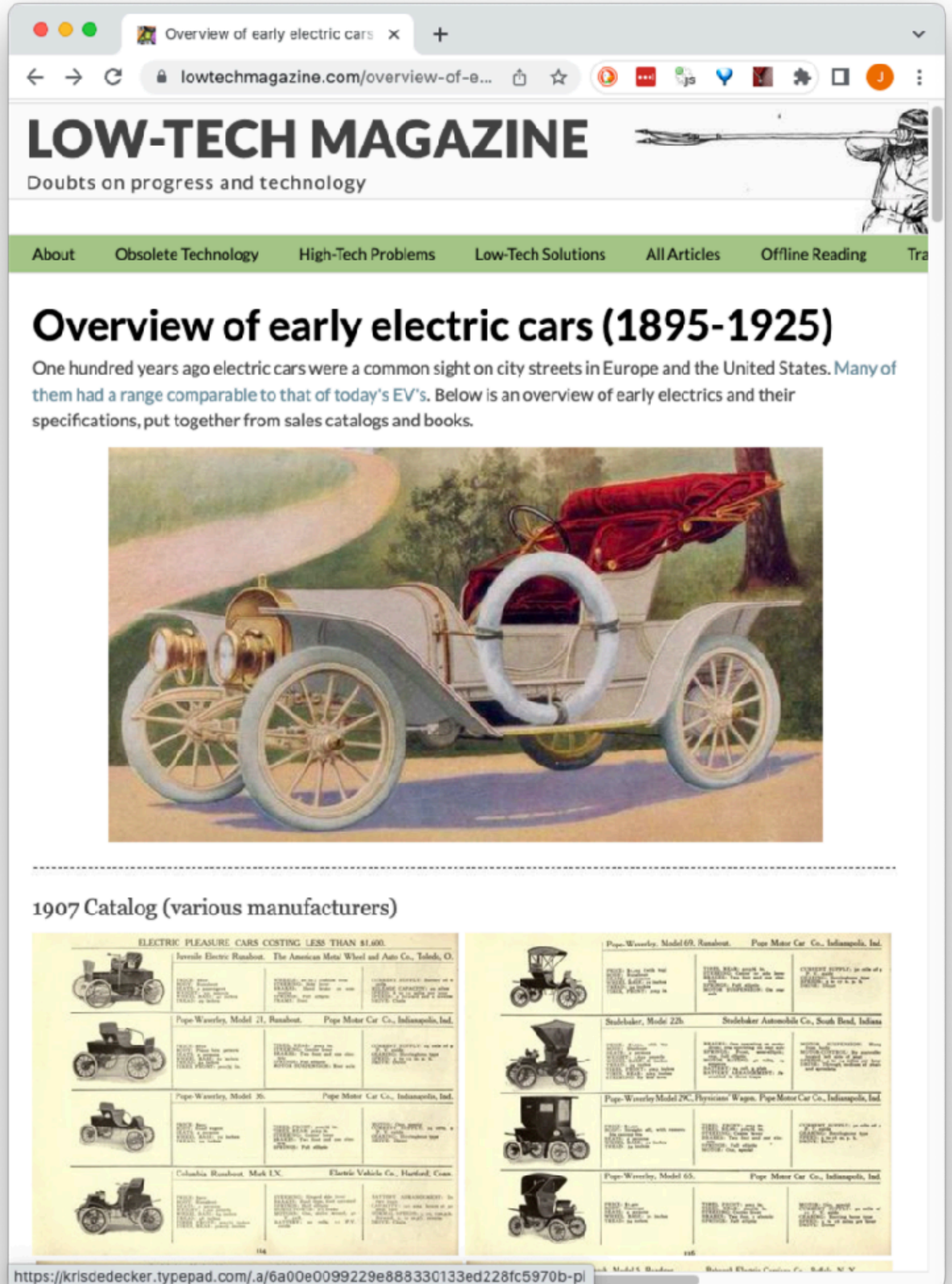
New emerging standard cell sizes.

Diameter

Length (with or w/out extra zero)

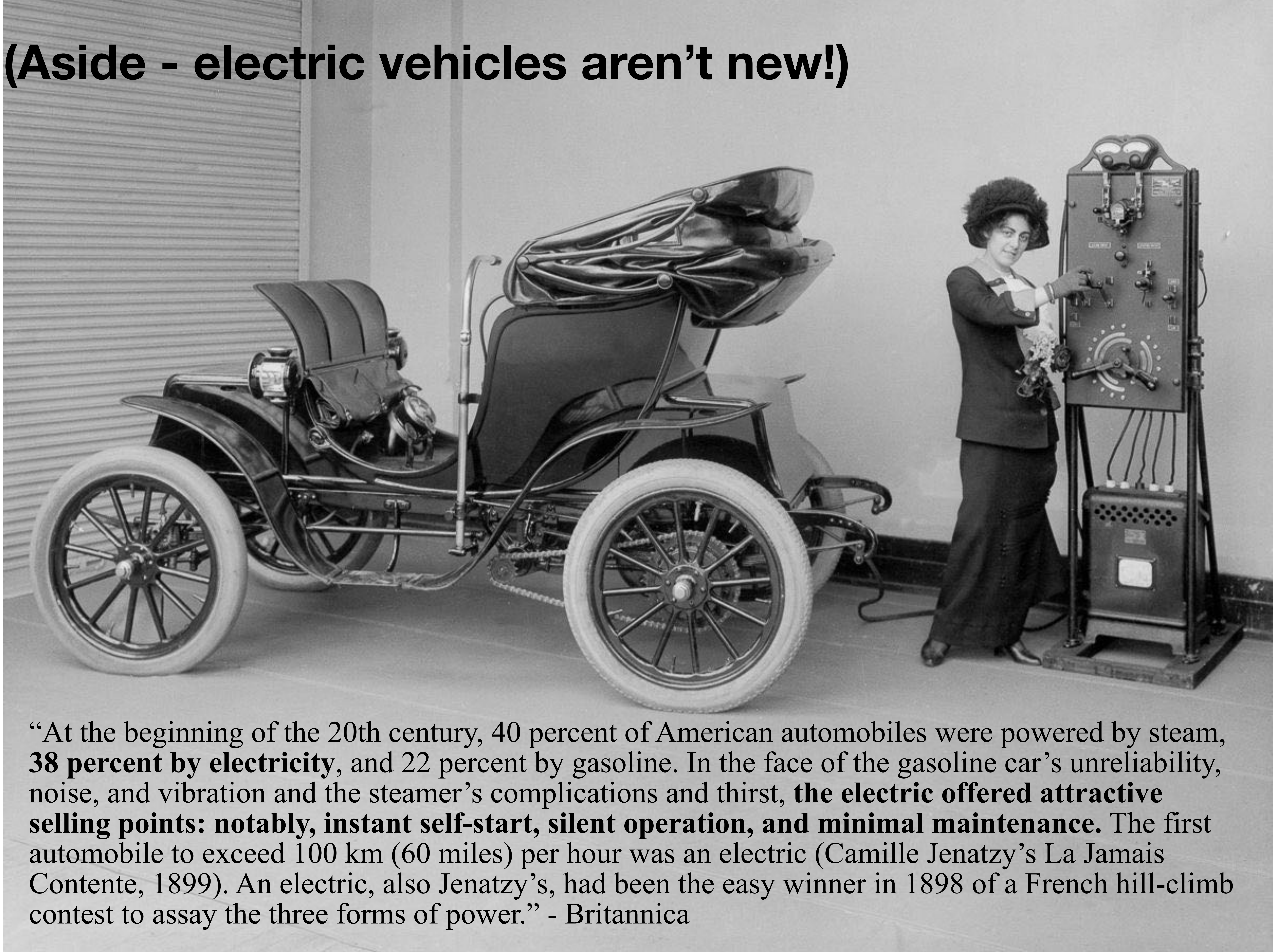
Rivian announced 4695 cells for R2 and R3 2/24.

(Aside - electric vehicles aren't new!)



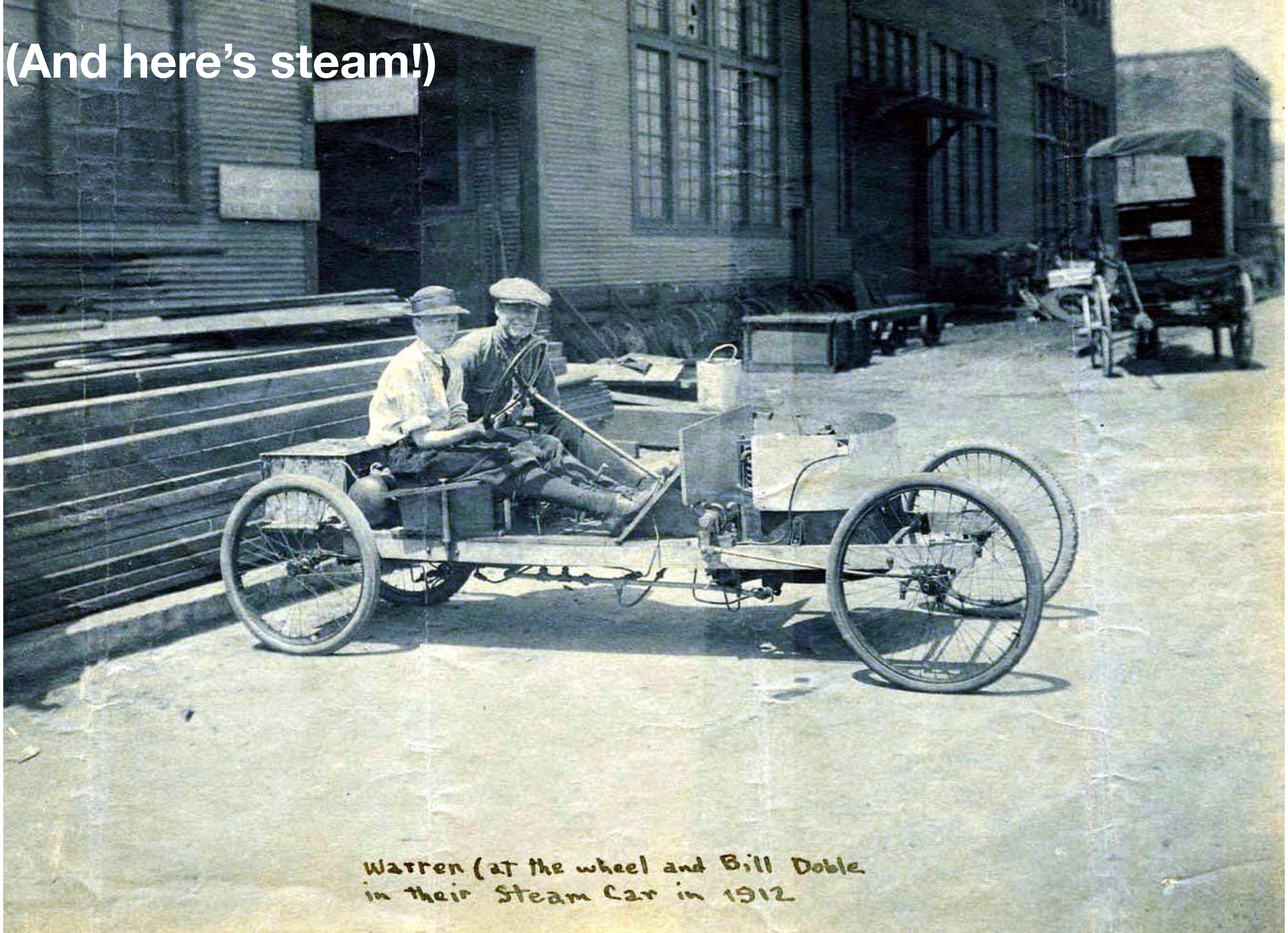
https://www.lowtechmagazine.com/overview-of-early-electric-cars.html

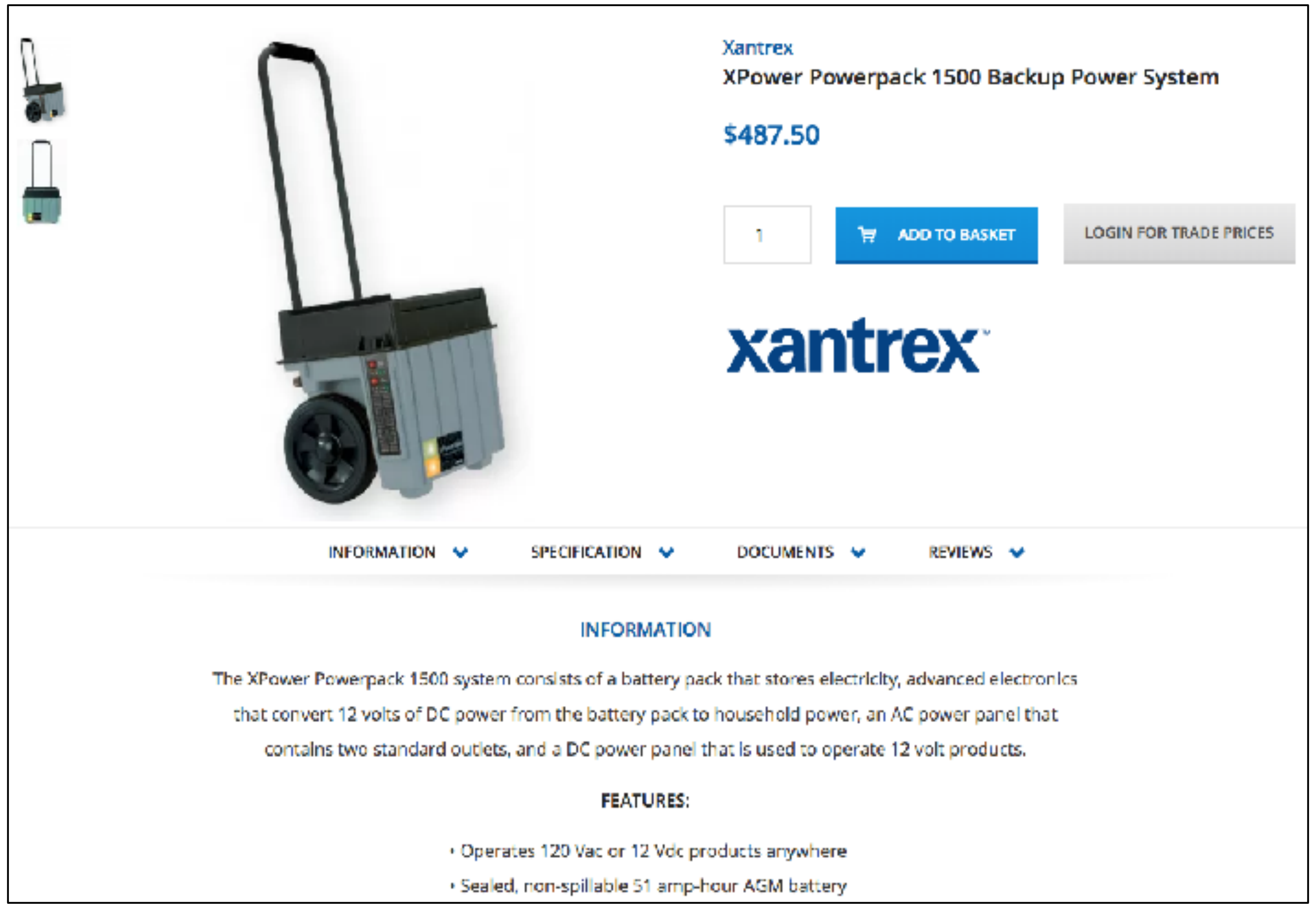
(Aside - electric vehicles aren't new!)



"At the beginning of the 20th century, 40 percent of American automobiles were powered by steam, **38 percent by electricity**, and 22 percent by gasoline. In the face of the gasoline car's unreliability, noise, and vibration and the steamer's complications and thirst, **the electric offered attractive selling points: notably, instant self-start, silent operation, and minimal maintenance.** The first automobile to exceed 100 km (60 miles) per hour was an electric (Camille Jenatzy's La Jamais Contente, 1899). An electric, also Jenatzy's, had been the easy winner in 1898 of a French hill-climb contest to assay the three forms of power." - Britannica

(And here's steam!)

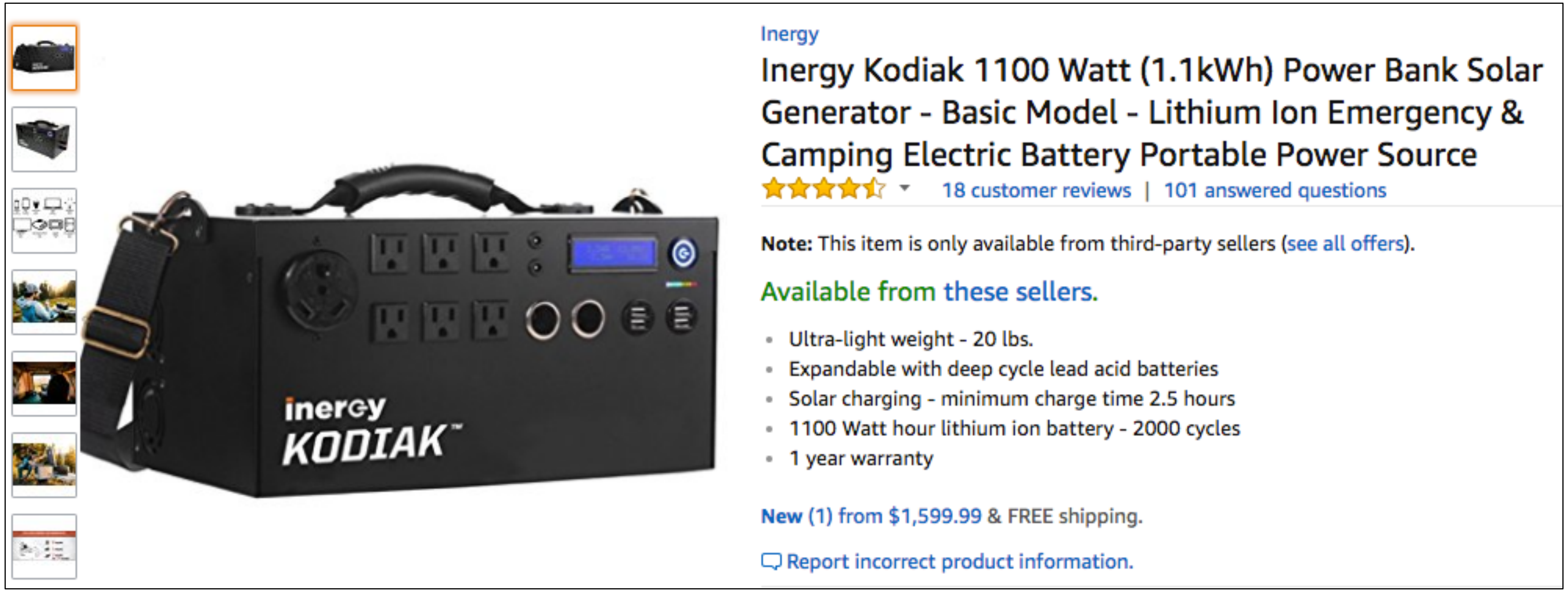




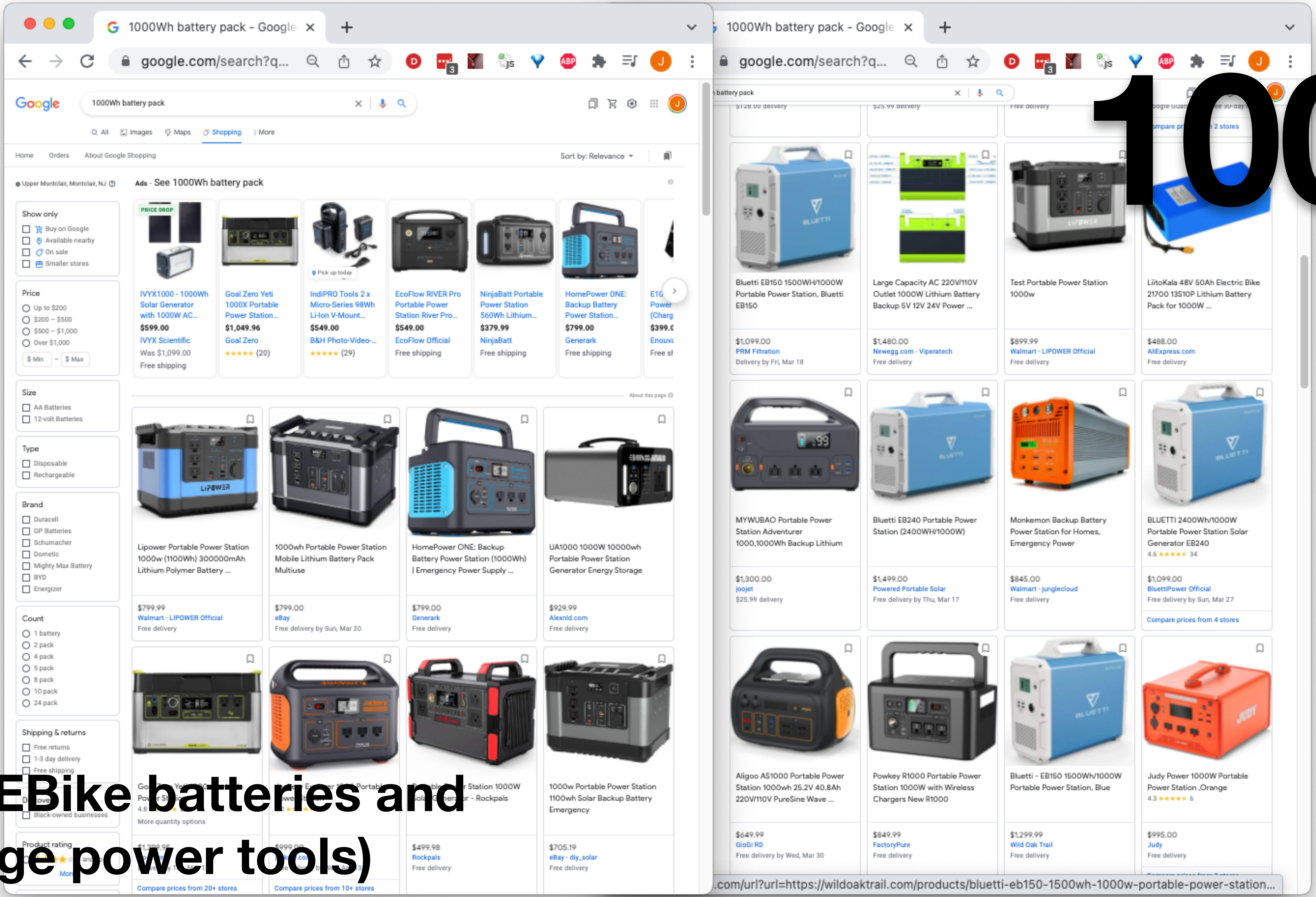
1000

~1kWh portable battery "generator"

A few years ago, hard to find…



1000



(Also: EBike batteries and large power tools)

2022 - plenty of options

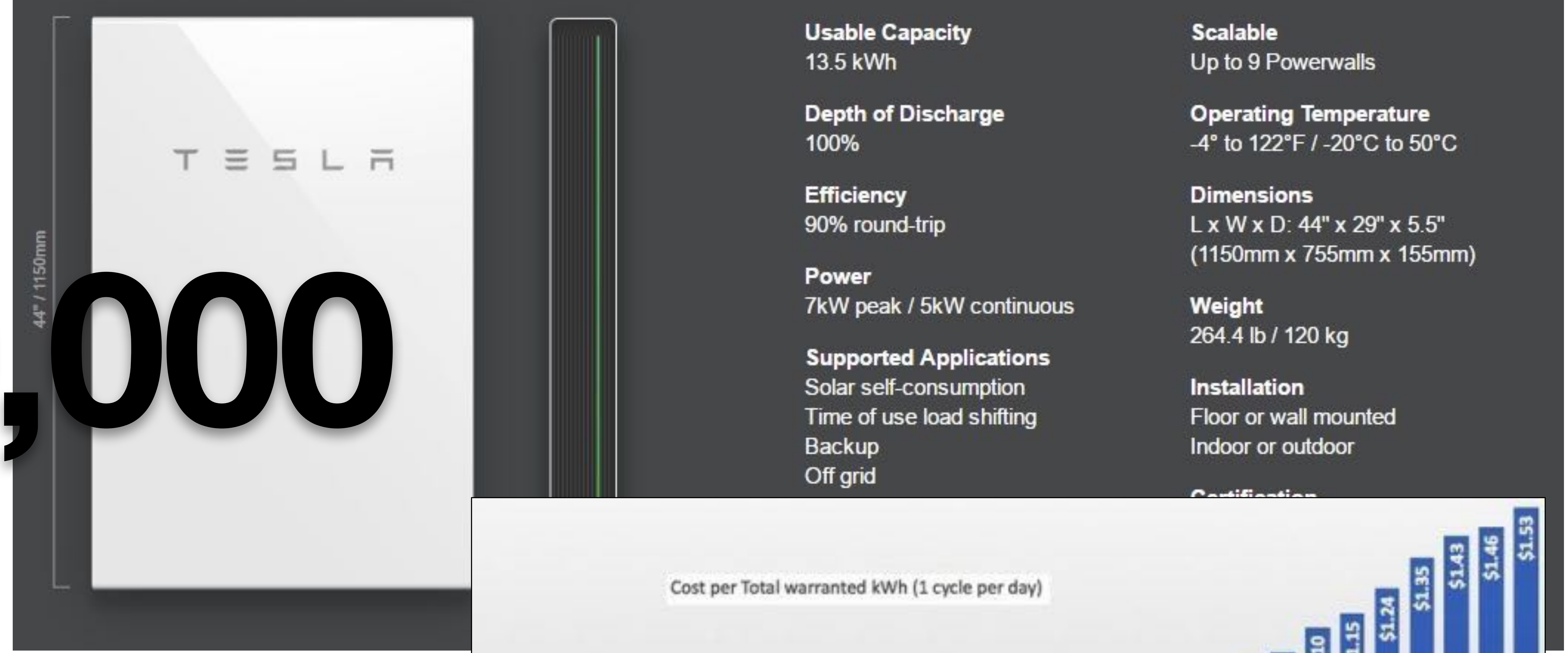
~300Wh
~300W
~$300 $189

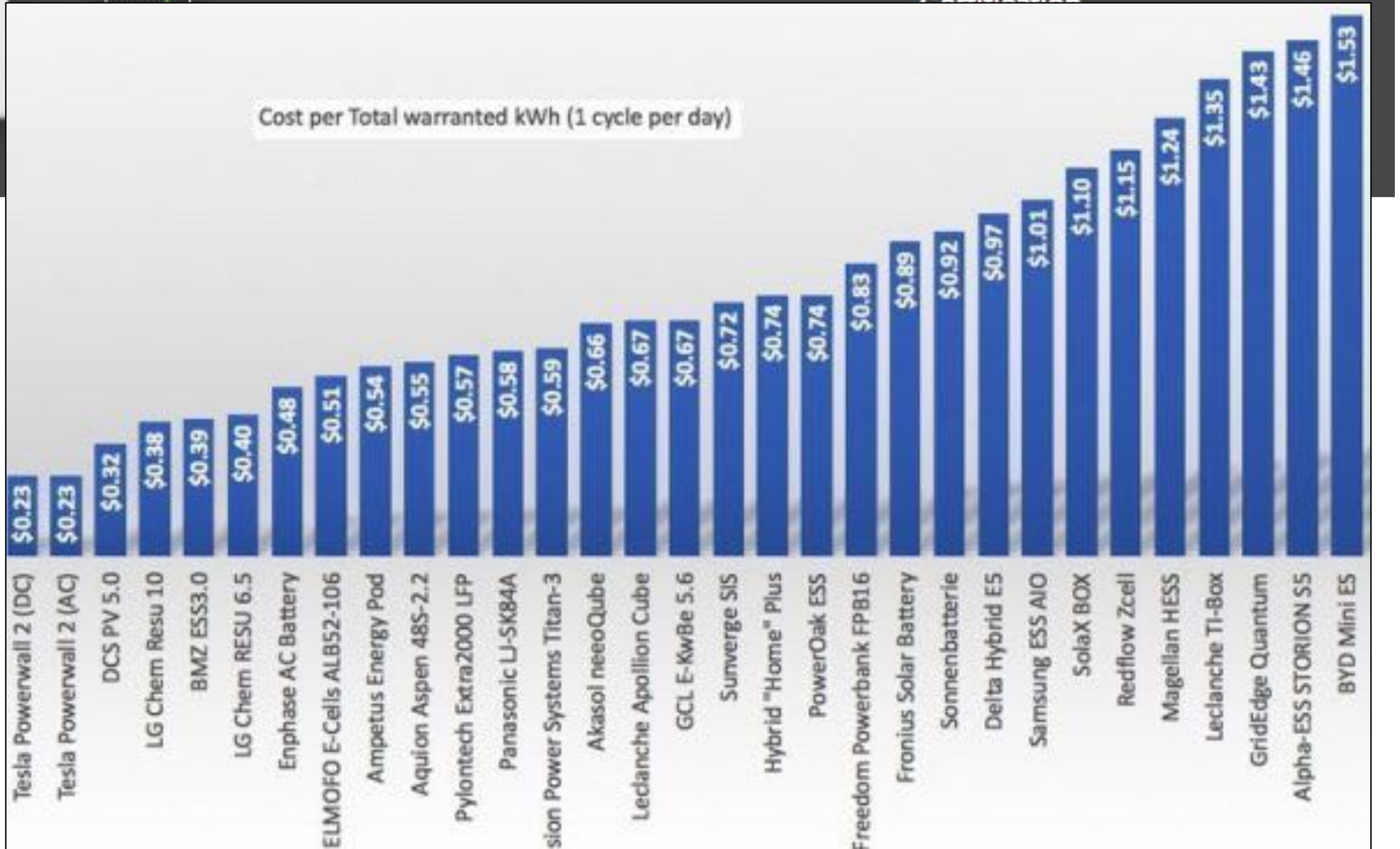
~1000Wh
~1000W
~$1000 $429

1500 Wh

37 lbs (16.5 kg)

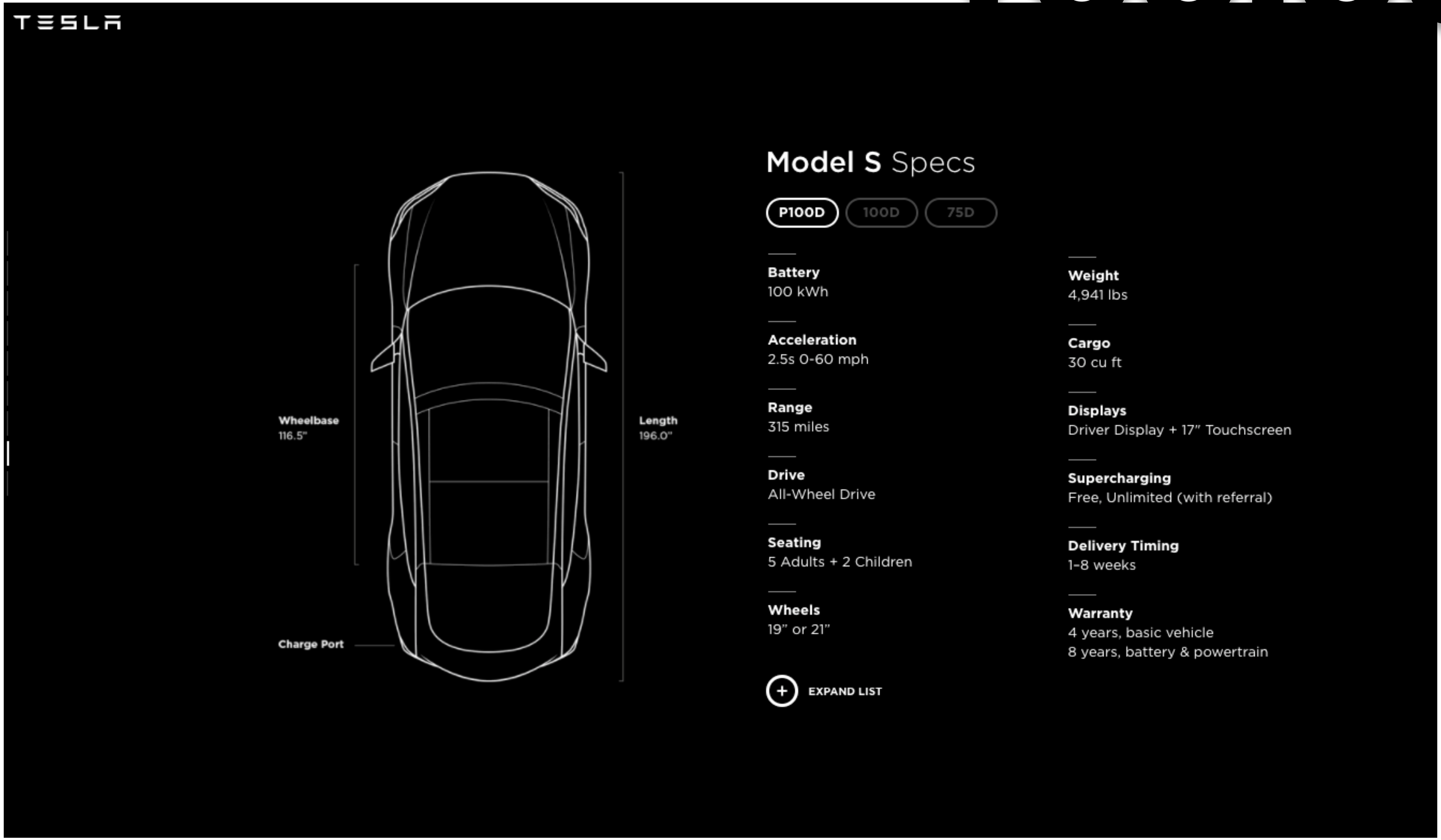
10,000





~10kWh home battery

100,000



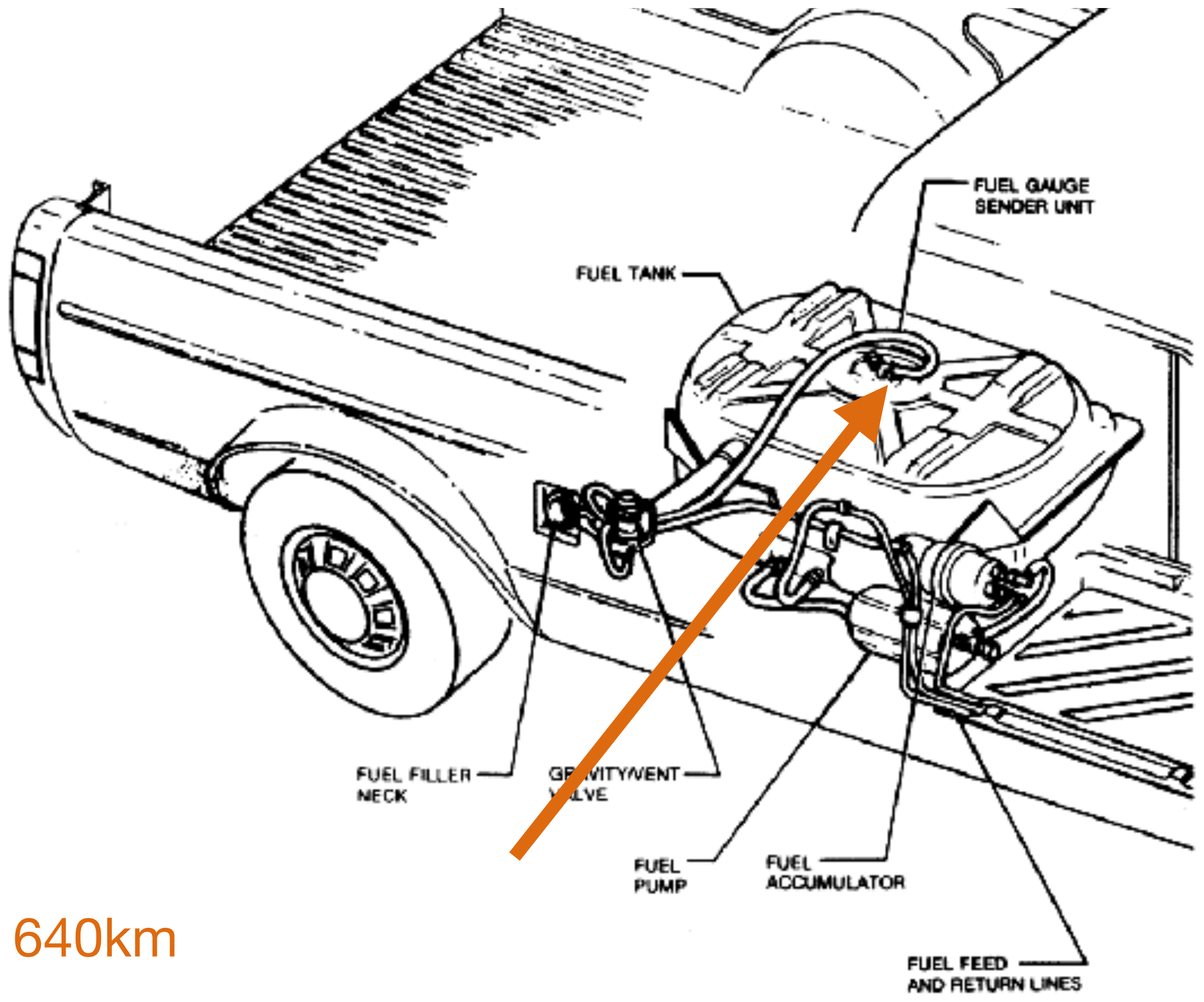
~100kWh EV

Hummer EV, Roadster, Large trucks
~150 - 200kWh

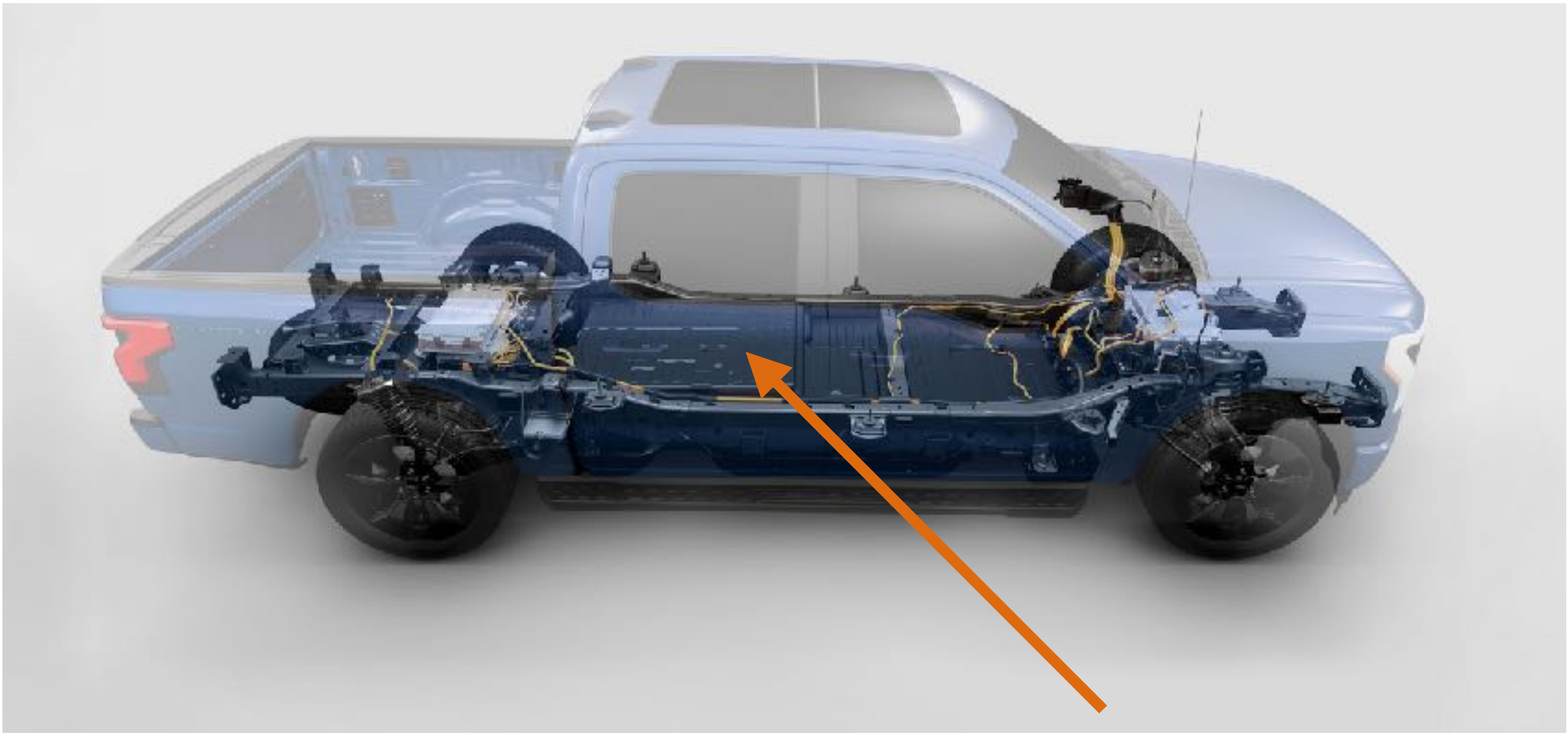
Many mass market EVs
~50 - 100kWh

Microcars
~5-20kWh

https://www.myevreview.com/comparison-chart/battery-capacity-usable-kwh



9 kg, 640km



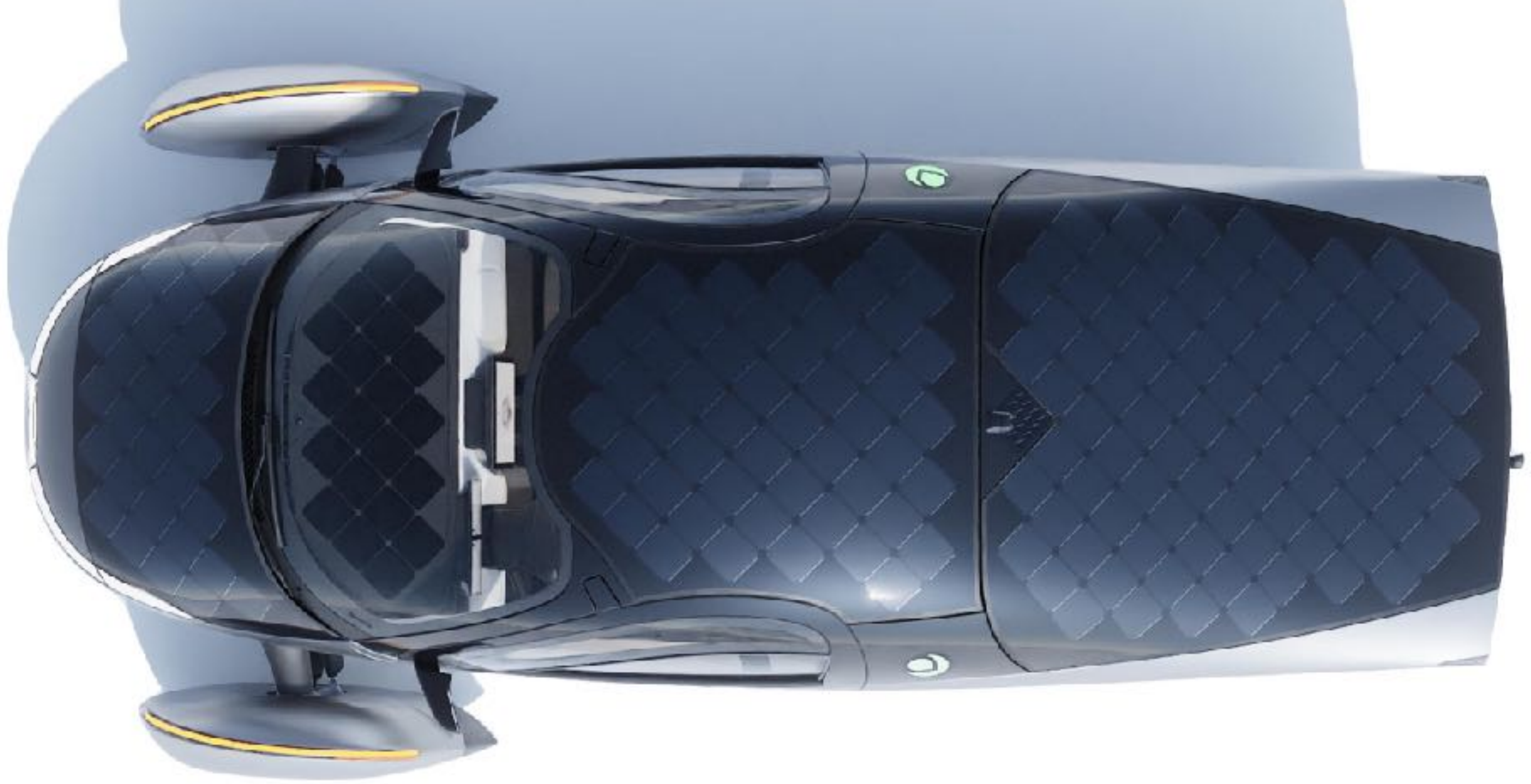
816 kg, 320 km

<800 kg

America's Favorite Pickup Truck Goes Electric

Edison had identified the problem with E.V.s then, and it's still the problem now. Gasoline has vastly more energy density than the best battery. About twenty gallons of gasoline, which weighs a hundred and twenty pounds or so, will convey my gas F-150 around four hundred miles: close to twice the target range of the Lightning's standard eighteen-hundred-pound battery.

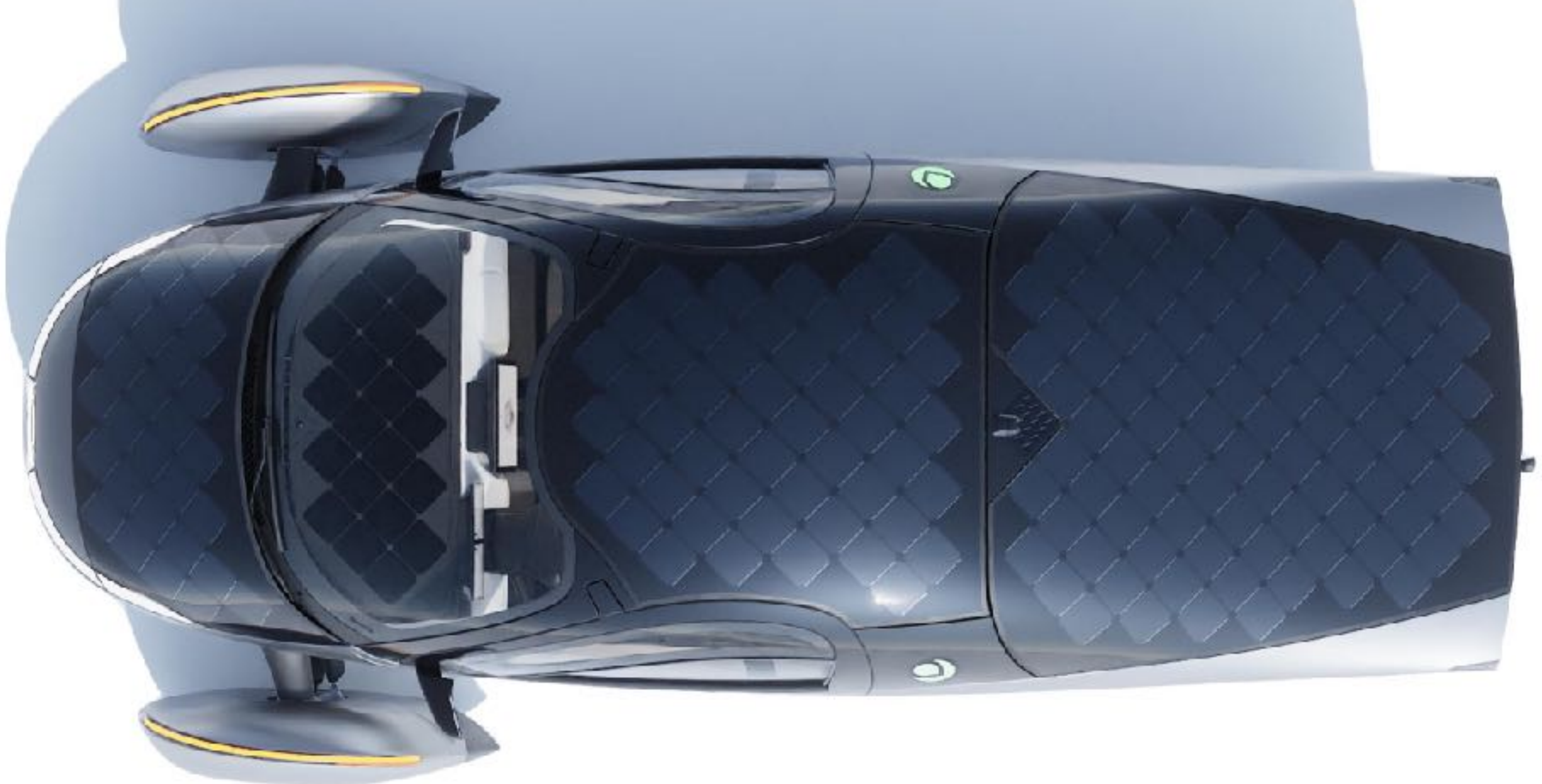
https://www.newyorker.com/magazine/2022/01/31/americas-favorite-pickup-truck-goes-electric



Claim: Aptera can gain 40 miles per day from solar charging.

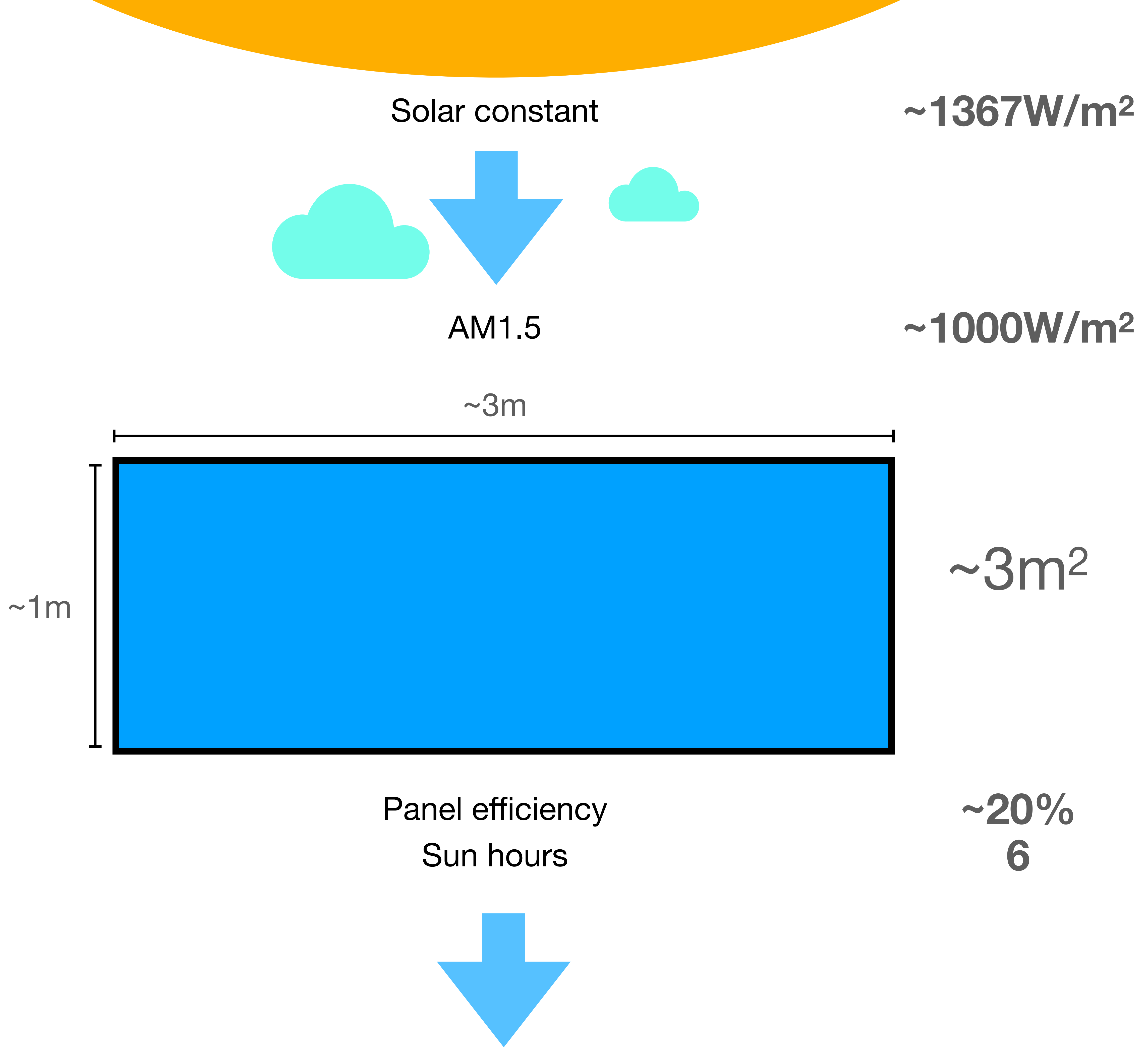
Is this reasonable?

What is the approximate area of the solar panels?
Under reasonable conditions, how much energy would that capture in a day?
(Use AM1.5 and 6 equivalent sun hours)
How many miles per kWh would Aptera need to achieve?




Claim: Aptera can gain 40 miles per day from solar charging.

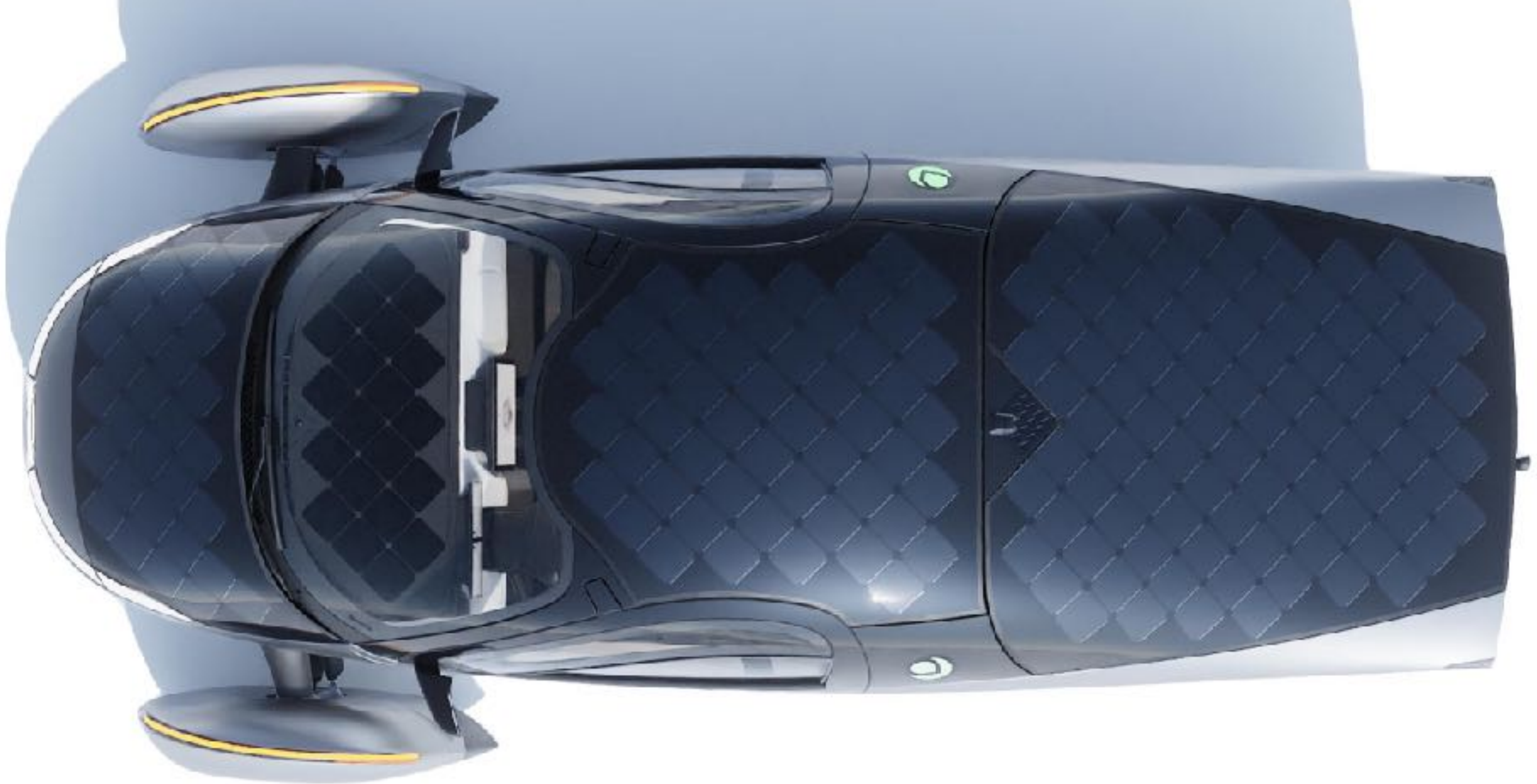
Jeff's calculations:



Energy captured per day

Vehicle efficiency 5m/kWh (best current)

40 miles per day?



Claim: Aptera can gain 40 miles per day from solar charging.

Jeff’s calculations:

Rough estimate let's say solar surface is about 3m long by 1 m wide, e.g. **3 square meters**.

So **solar input** at AM1.5 (1000W/m^2) is **3000 watts**.

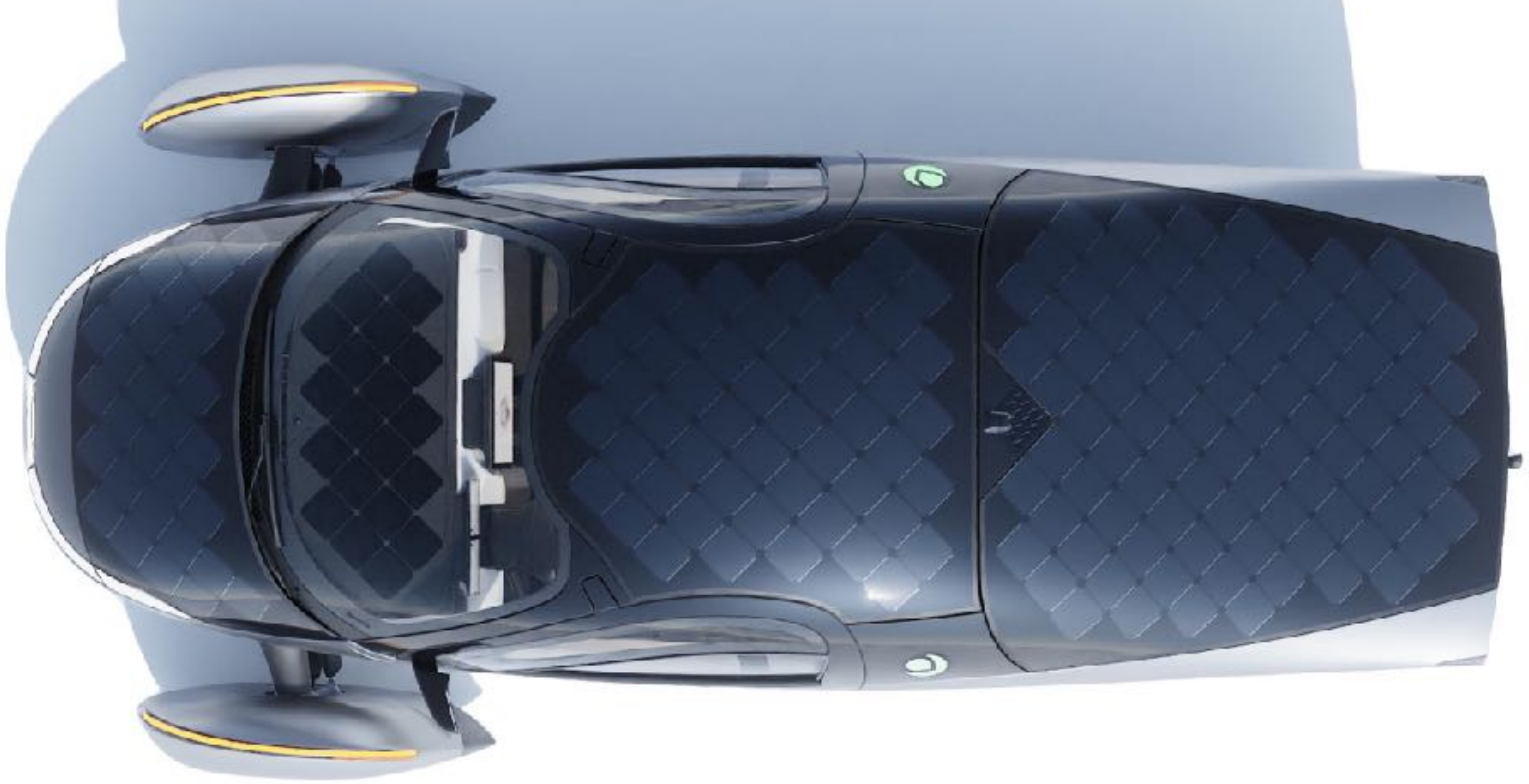
I’ll use **6 sun hours** as a good charging day, and **20%** as the solar panel efficiency.

20% of 3000 watts is 600 watts. At 6 sun hours is 3600 watt hours. **Or 3.6 kWh**.

A Tesla gets 3-4 miles per kWh, Lucid Air 5, so that would be about 10 - 18 miles.

In order to get 40 miles per day, the Aptera would need to be 2.5-4 times more efficient.

Given the unusual shape and ultralight design this seems possible. **Aptera passes the test!**



Claim: Aptera can gain 40 miles per day from solar charging.

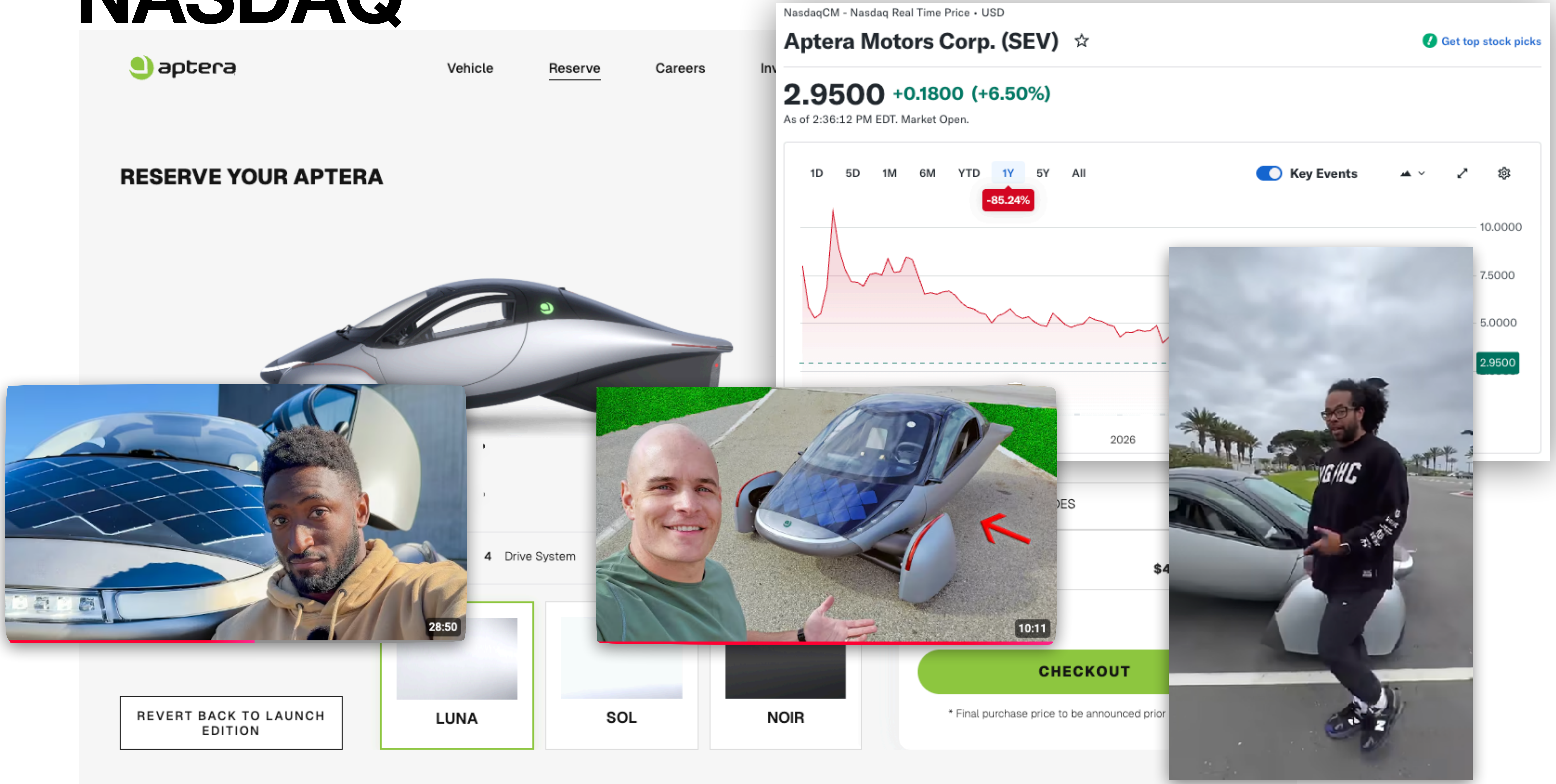
Aptera’s calculations:

After calculating my estimate I found the calculation from their chief engineer: 700W solar (my estimate was 600). 5.7 sun hours on a good charging day gives their figure of 4000 Wh. (Mine was 3600 Wh). Their figure of 100Wh/mile gives 40 miles (10 miles/kWh).

(See here: https://youtu.be/IrCVWgxlgoc)

“In optimal sunny locations, our solar can generate over 10,000 miles of driving per year, with over 1,000 miles per month in summer.”

2026 Update: Taking pre-orders, listed on NASDAQ

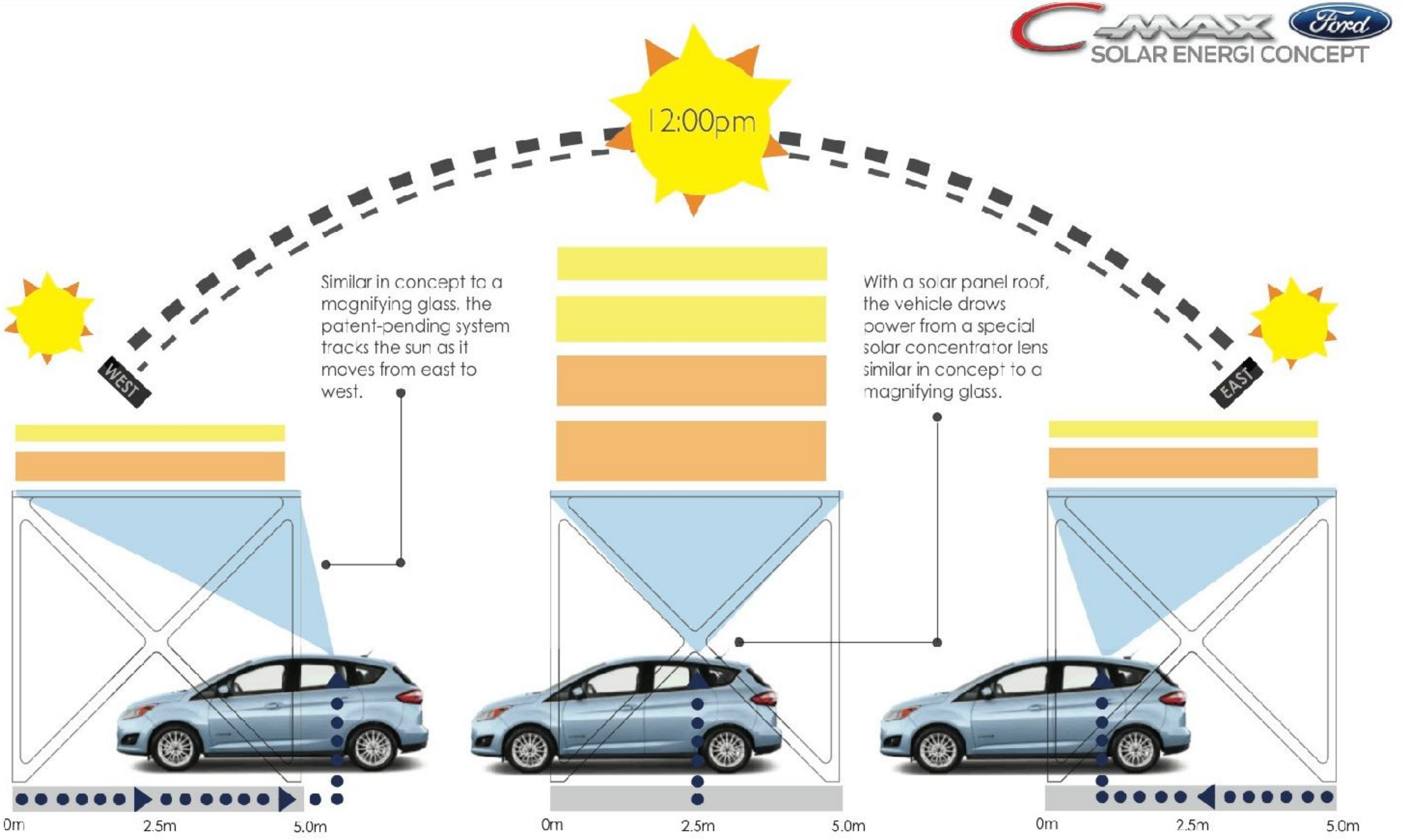


2014 Ford CMAX Solar Energi “Concept”
Claimed 8kWh charge per day from sun…
Compared to 4kWh for Aptera… hmmm…

https://media.ford.com/content/fordmedia/fna/us/en/news/2014/01/02/let-the-sun-in--ford-c-max-solar-energi-concept-goes-off-the-gri.html

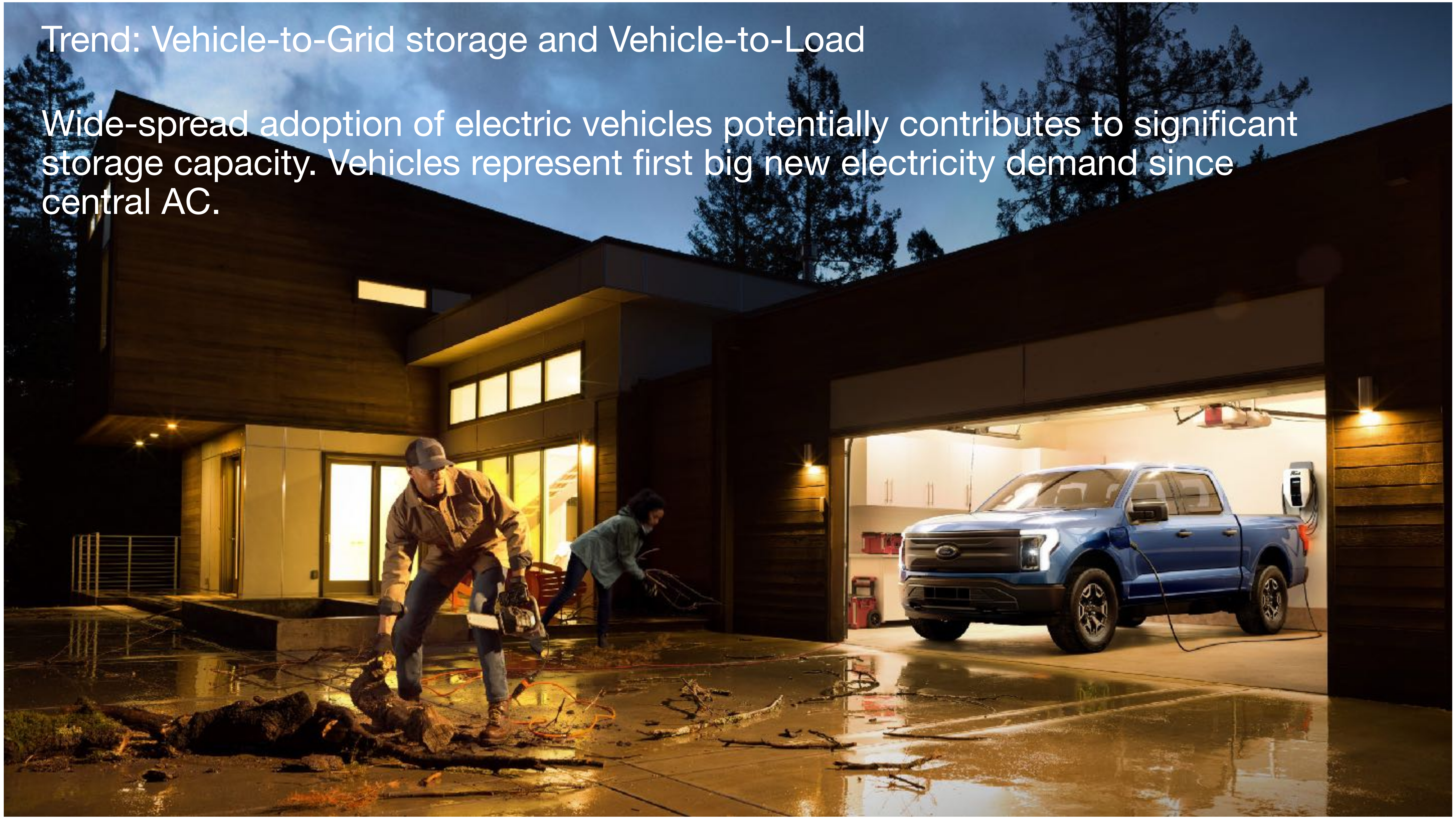
How it Works

The C-MAX Solar Energi optimizes the intake of solar power through a Fresnel lens concentrator by autonomously moving in the direct path of the sun's rays.



Trend: Vehicle-to-Grid storage and Vehicle-to-Load

Wide-spread adoption of electric vehicles potentially contributes to significant storage capacity. Vehicles represent first big new electricity demand since central AC.



"With the extended battery, the F-150 Lightning can fully power a home for 3-days, or up to 10-days if you use your electricity sparingly." - Ford

Grid-backup

1.6GW in US by 2020

017 in West Caldwell, NJ

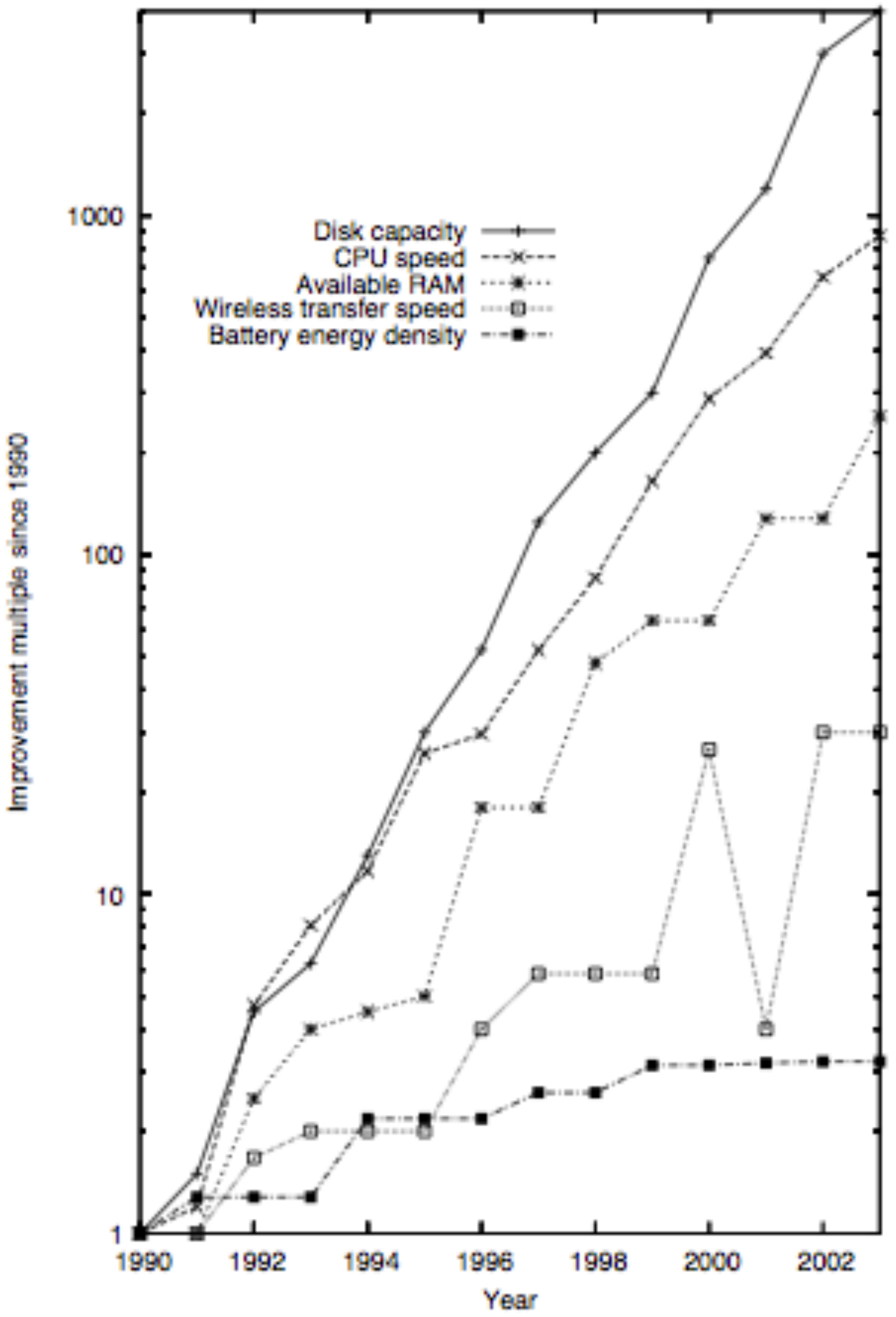
More data: http://css.umich.edu/sites/default/files/U.S._Grid_Energy_Storage_Factsheet_CSS15-17_e2017.pdf

COMPARISON OF LITHIUM CHEMISTRIES

CHARACTERISTIC	LFP ($LiFePO_4$)	NMC ($LiNiMnCoO_2$)	LCO (LiCo02)	LMO ($LiMn_2O_4$)	LTO ($Li_4Ti_5O_{12}$)
Voltage	3.2VPC (operating range 2.5-3.65VPC)	3.6VPC (operating range 3-4.2VPC)	3.6VPC (operating range 3-4.2VPC)	3.7VPC (operating range 3-4.2VPC)	2.4VPC (operating range 1.8-2.85VPC)
Specific Energy	90-120 Wh/kg	150-220 Wh/kg	150-200 Wh/kg	100-150 Wh/kg	50-80 Wh/kg
Energy Density	333 Wh/l	580 Wh/l	560 Wh/l	420 Wh/l	177 Wh/l
Charge Rate	1C	0.7-1C (>1C shortens life)	0.7-1C (>1C shortens life)	0.7-1C (3C Max)	1C (5C Max)
Charge Voltage	3.5-3.65VPC	4.2VPC	4.2VPC	4.2VPC	2.85VPC
Discharge Rate	1C (30C power cells); 2.0V cut-off	1C (2C on some cells); 2.5V cut-off	1C (>1C shortens life); 2.5V cut-off	1C (>1C shortens life); 2.5V cut-off	10C (30C 5 sec); 1.8V cut-off
Cycle Life (depending on depth of discharge)	2000-4000	1000-2000	500-1000	300-700	3000-7000
Thermal Runaway	270°C (518°F)	210°C (410°F)	150°C (302°F)	250°C (482°F)	NA
Prone to Thermal Runaway	No	Yes	Yes	Yes	No
Applications	Motive power and stationary needing needing high currents and endurance	E-bikes, medical devices, EVs, industrial	Mobile phones, laptops, tablets, cameras	Power Tools, medical devices, electric powertrains	UPS, electric powertrains, solar street lighting
Cost	$	$	$$	$$	$$$

https://relionbattery.com/resource-center/technology/why-choose-lithium https://batteryuniversity.com/

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1]		
				Cobalt	Manganese	Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to 122°F)	–20 to 65°C (–4 to 149°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		



"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