2. Battery and Energy Source

by Dr. James Wang

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Some Electrical Engineering Definitions

Current is measured in Amps (A)

Voltage is measured in Volts (V)

Power is measured in watts (W) or kilowatts (kw)

Power equals current x voltage

Battery capacity is measured in amp-hour (Ah)

Energy is measured in watts-hour (Wh)

Amp Hour

Ah (amp hour) is a measure of battery capacity <u>for a given voltage</u>

Examples:

a 1 Ah 12 volt battery => Can supply

- **1 amp current for one hour at 12 volt, or**
- **0.5 amp current for 2 hours at 12 volt, or**
- **2 amps current for half hour at 12 volt**

Amp Hour

Class question:

A 50 Ah 12 volt car battery with its 200 watts head light left on, how many hours will the battery last?

Answer:

Current draw = 200 watts / 12 volt = 16.67 amps

Duration = 50 Ah / 16.67 amps = 3 hours

Watt Hour

Wh (Watt hour) is measure of energy or battery energy capacity

Wh = Ah x Voltage

Example:

a 5 Ah 12 volt battery can provides 60 Wh energy

Watt Hour

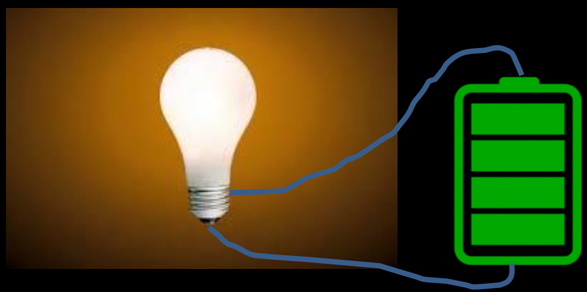
Wh (Watt hour) also tells you how long you can draw power from battery

Wh = Ah x Voltage

Wh = A x V x time

Wh = power x time

Watt Hour



Class question:

How long can a 100 watts lightbulb stay on when connected to a 500 Wh battery?

Answer:

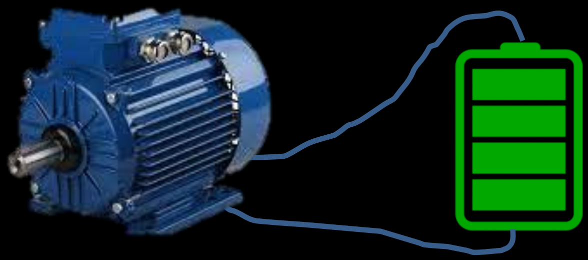
Wh = power x time

time = Wh / power

= 500 Wh / 100 watt

= 5 hours

Watt Hour



Class question:

How long can a one horsepower motor run when connected to a 750 Wh battery?

Answer:

Wh = power x time

time = Wh / power

= 750 Wh / 1 hp ← (Note: 1 hp = 746 watts)

= 1 hour

Watt Hour

Class question:

If this one-person eVTOL draws 100 amps at 600 volt and can fly for 30 minutes with no reserve left, then its battery must store how much energy?

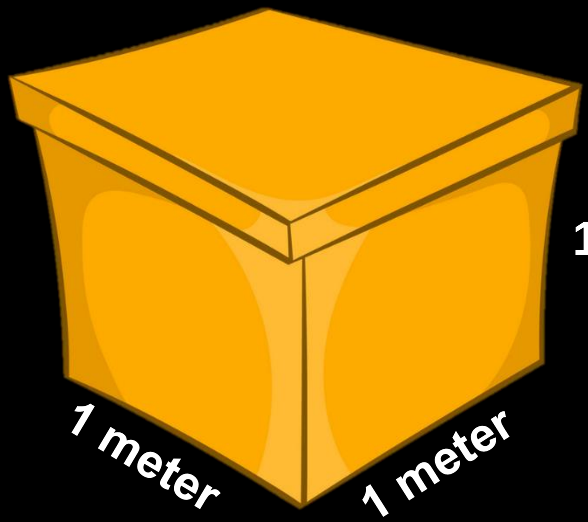
Answer:

Energy = Watt hour

= A x V x time

= 100A x 600V x 0.5hr = 30,000 Wh or 30 kWh

Energy density is the energy per unit volume of a fuel or a battery (MJ/m3)
The higher the better.

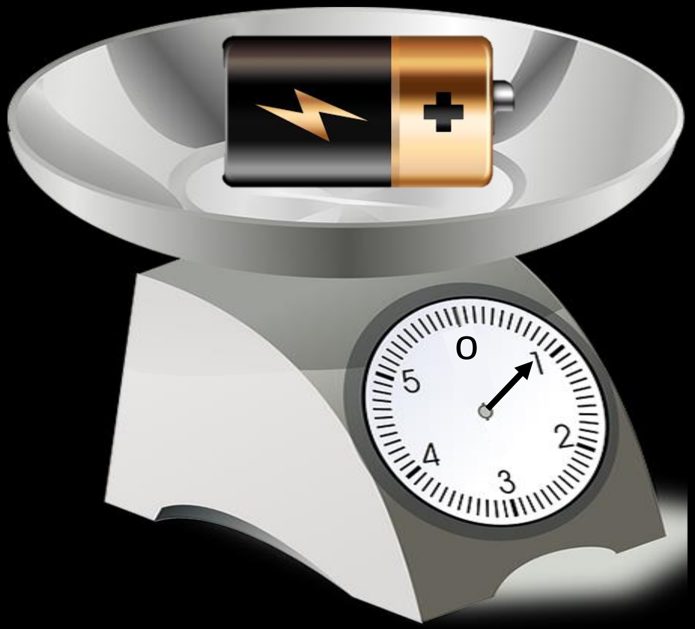


Note: MJ = mega joules, it's a measure of energy

Energy density and Specific Energy are not the Same !

For eVTOL, the useful measurement for battery is Specific Energy

Specific energy is the energy per unit mass of a fuel or a battery (MJ/kg or Wh/kg). The higher the better.

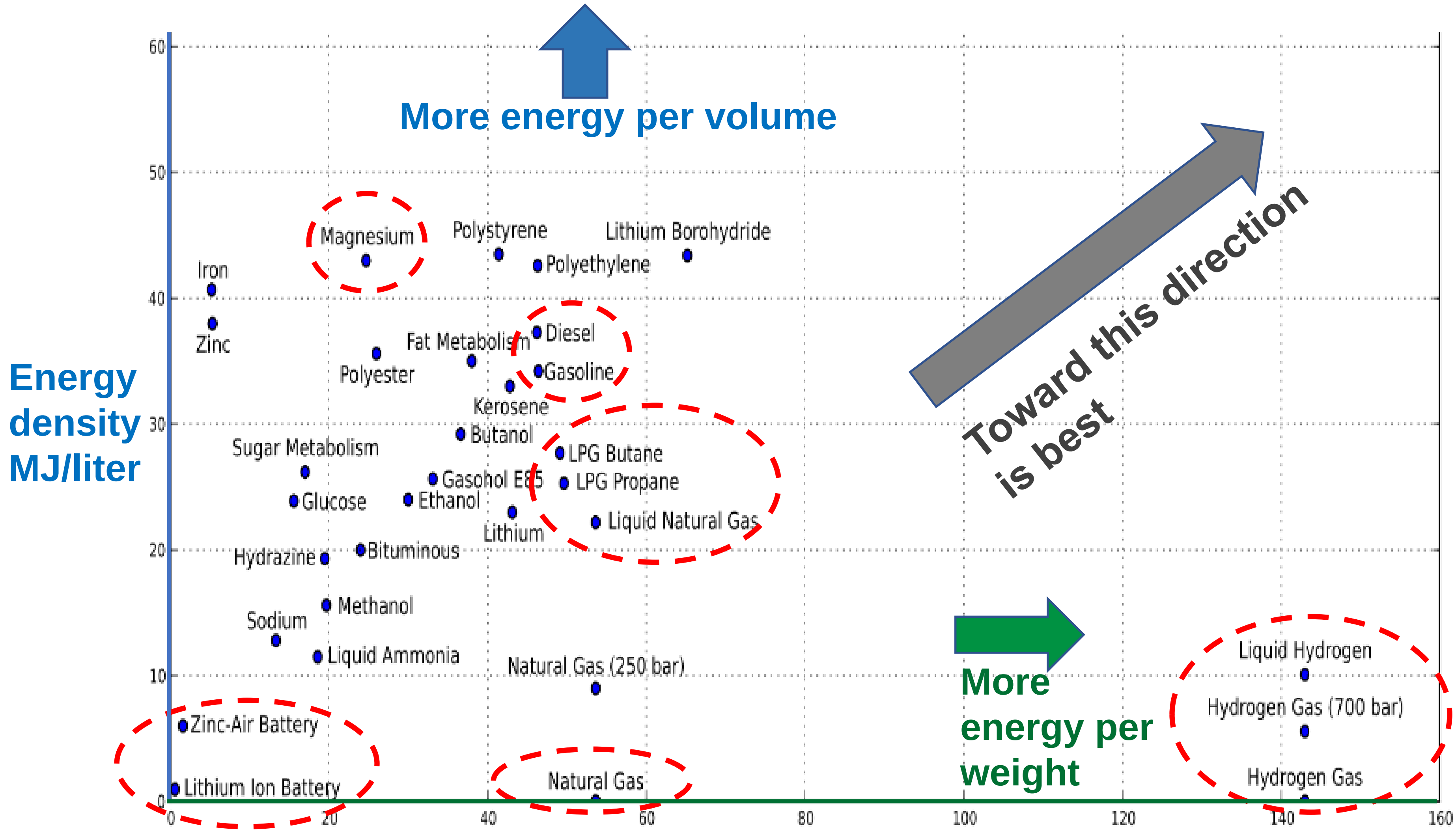


Note: for eVTOL we usually use specific energy and not energy density

Comparing Energy Sources

	Energy density	*Specific energy*
Diesel fuel	**37,184 MJ/m3**	**45 MJ/kg**
Coal	**36,450 MJ/m3**	**27 MJ/kg**
Wood	**9,000 MJ/m3**	**15 MJ/kg**
Propane	**29,449 MJ/m3**	**50 MJ/kg**

Want High Specific Energy & High Energy Density

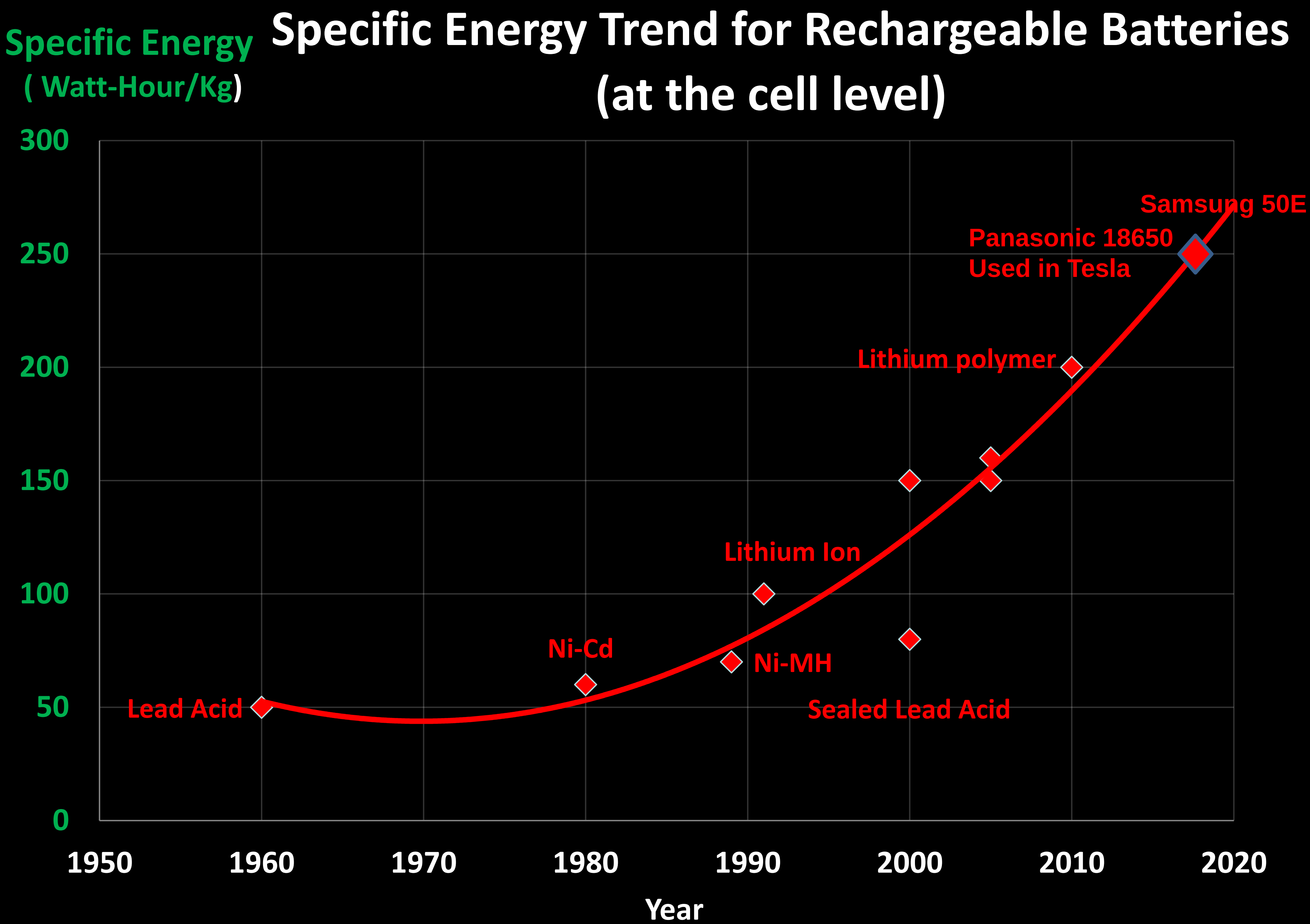


Lithium battery advantages: clean, simple and cost is going down. Con: needs higher specific energy, recycleability, and to be less volatile.

Today hydrogen and fuelcell still too expensive, difficult to transport to charging stations, highly flammable, and does not have the “power density” required for flight.

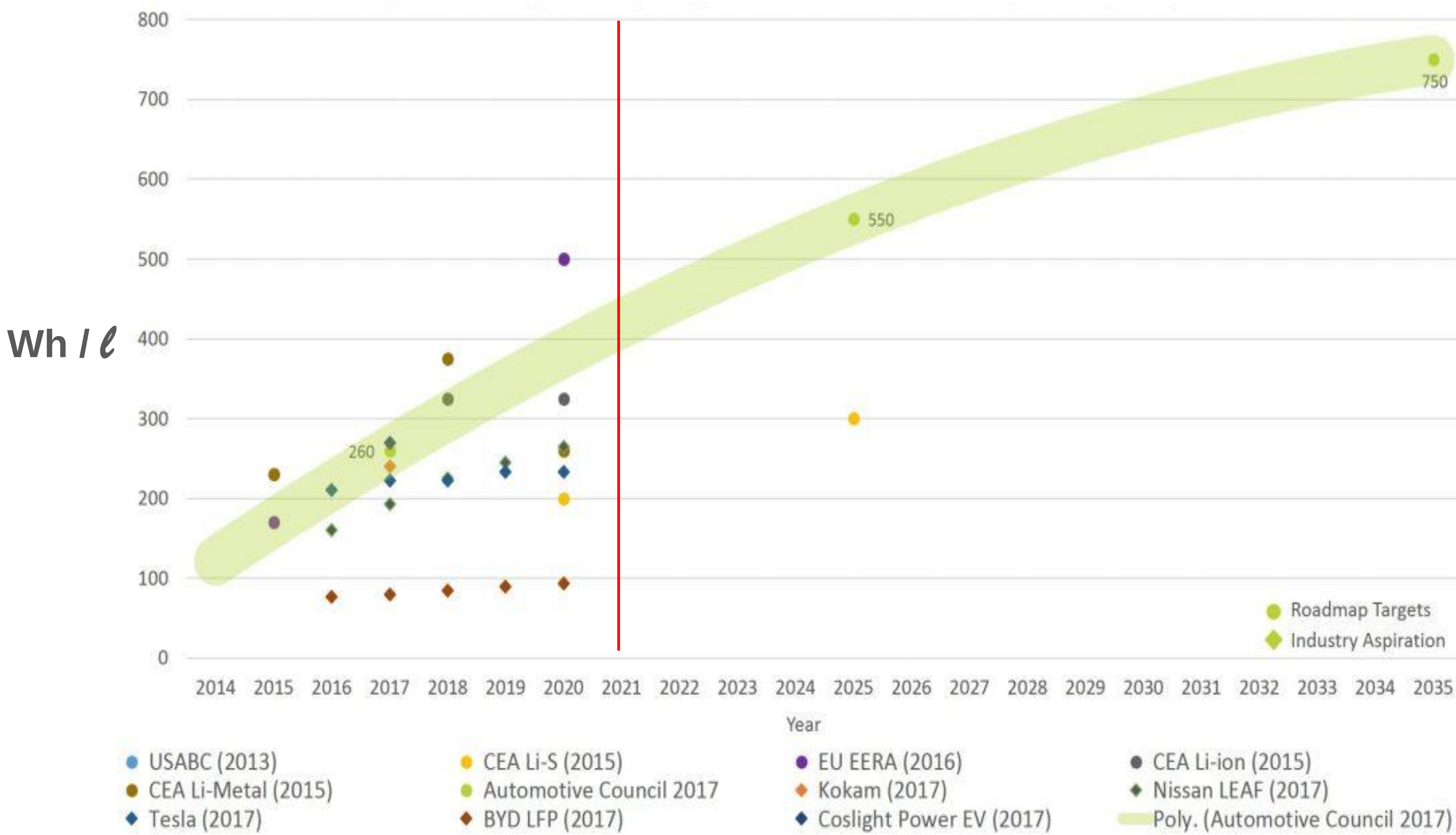
Comparing Specific Energy for

	(MJ/kg) or	*(Wh/kg)*
Propane	**50 MJ/kg**	**13,890 Wh/kg**
Diesel fuel	**45 MJ/kg**	**12,501 Wh/kg**
Coal	**27 MJ/kg**	**7,500 Wh/kg**
Wood	**15 MJ/kg**	**4,167 Wh/kg**
Lithium battery	**0.72MJ/kg**	**250 Wh/kg**


Specific Energy Trend for Rechargeable Batteries
(at the cell level)
Specific Energy
(Watt-Hour/Kg)
300
250
200
150
100
50
0
1950
1960
1970
1980
1990
2000
2010
2020
Year
Samsung 50E
Panasonic 18650
Used in Tesla
Lithium polymer
Lithium Ion
Ni-Cd
Ni-MH
Lead Acid
Sealed Lead Acid

Energy Density Trend

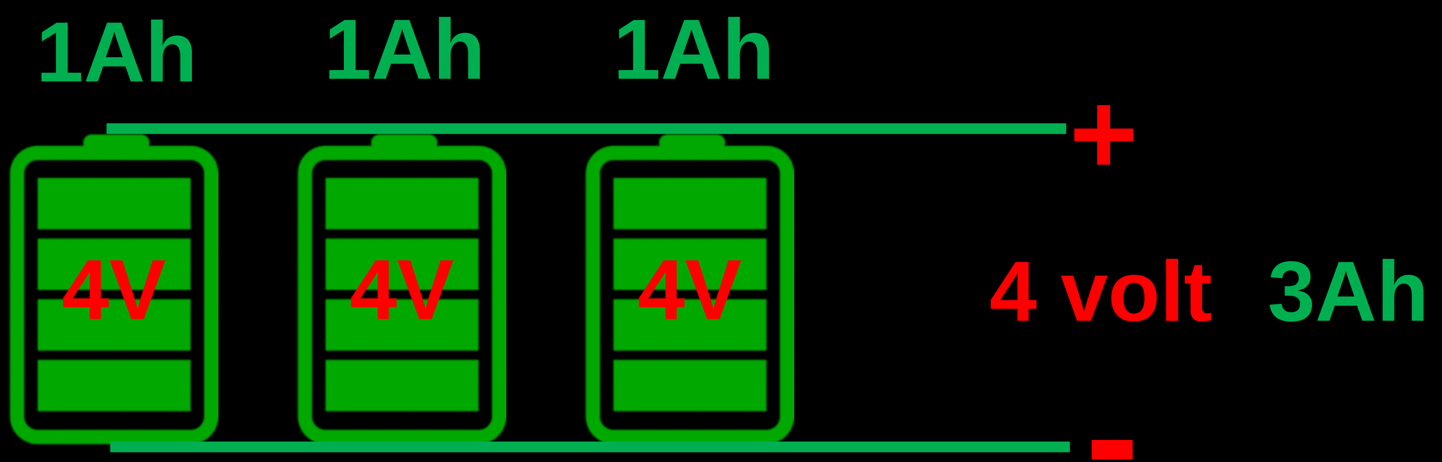
Rechargeable Automotive Lithium Batteries at Cell Level



Note, 400 Wh = 1.44 MJ

Battery Jargon

Connect in parallel => voltage remains the same, but Ah capacity increases.



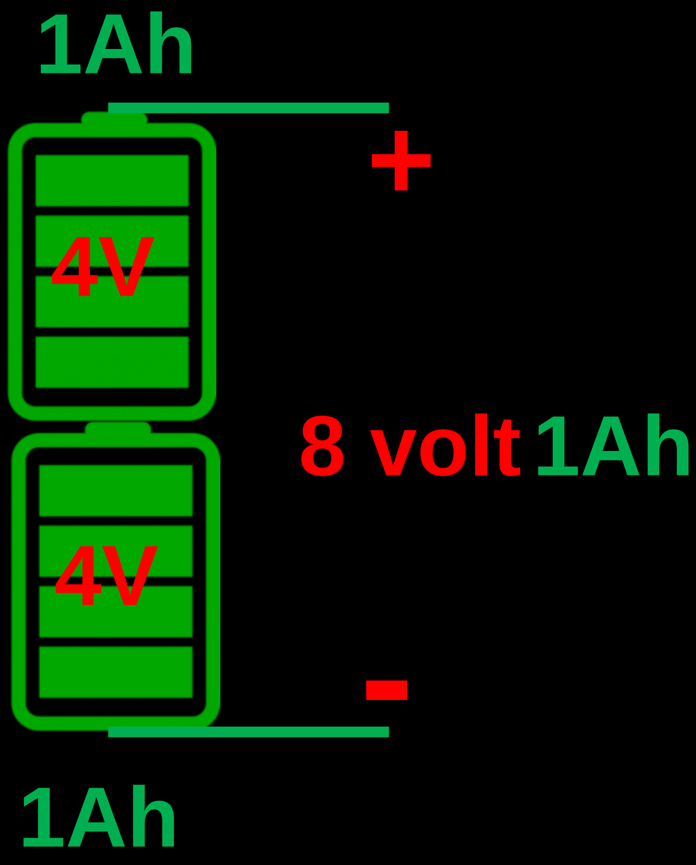
Example: this is a "3P"

(A fully charged lithium cell is around 4.2 volts. During use it is around 4 volts.)

Battery Jargon

Connect in series => voltage increases, but the Ah capacity remains the same.

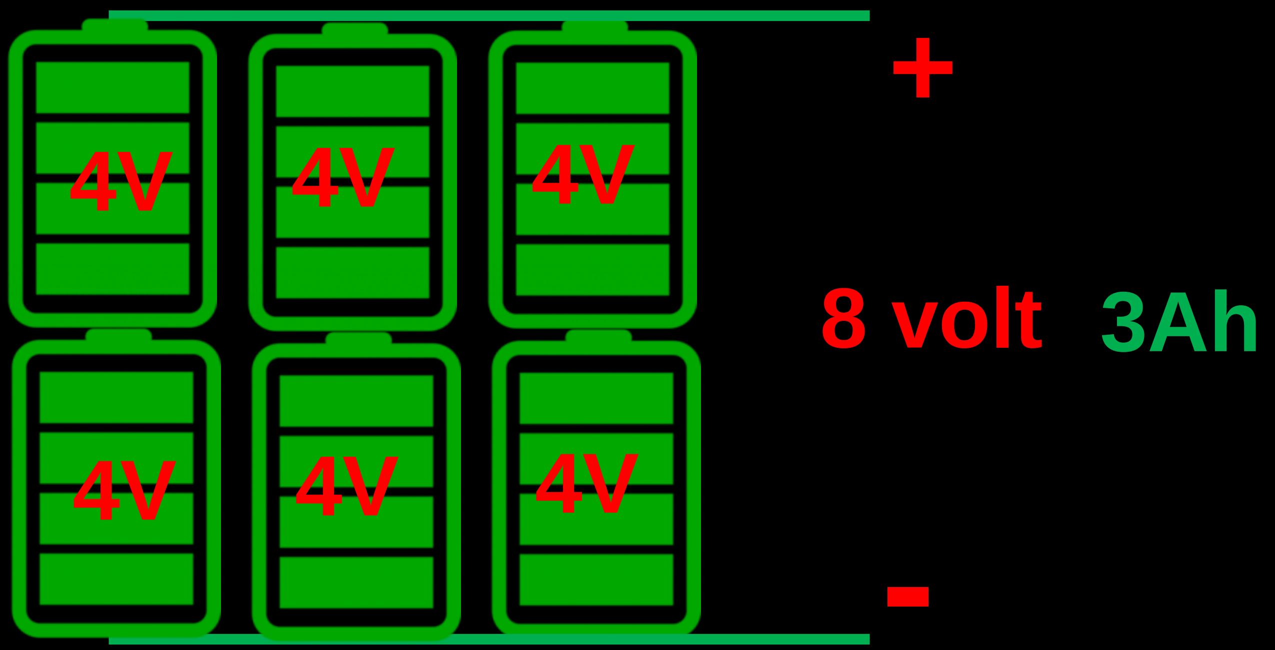
Example: this is a "2S"



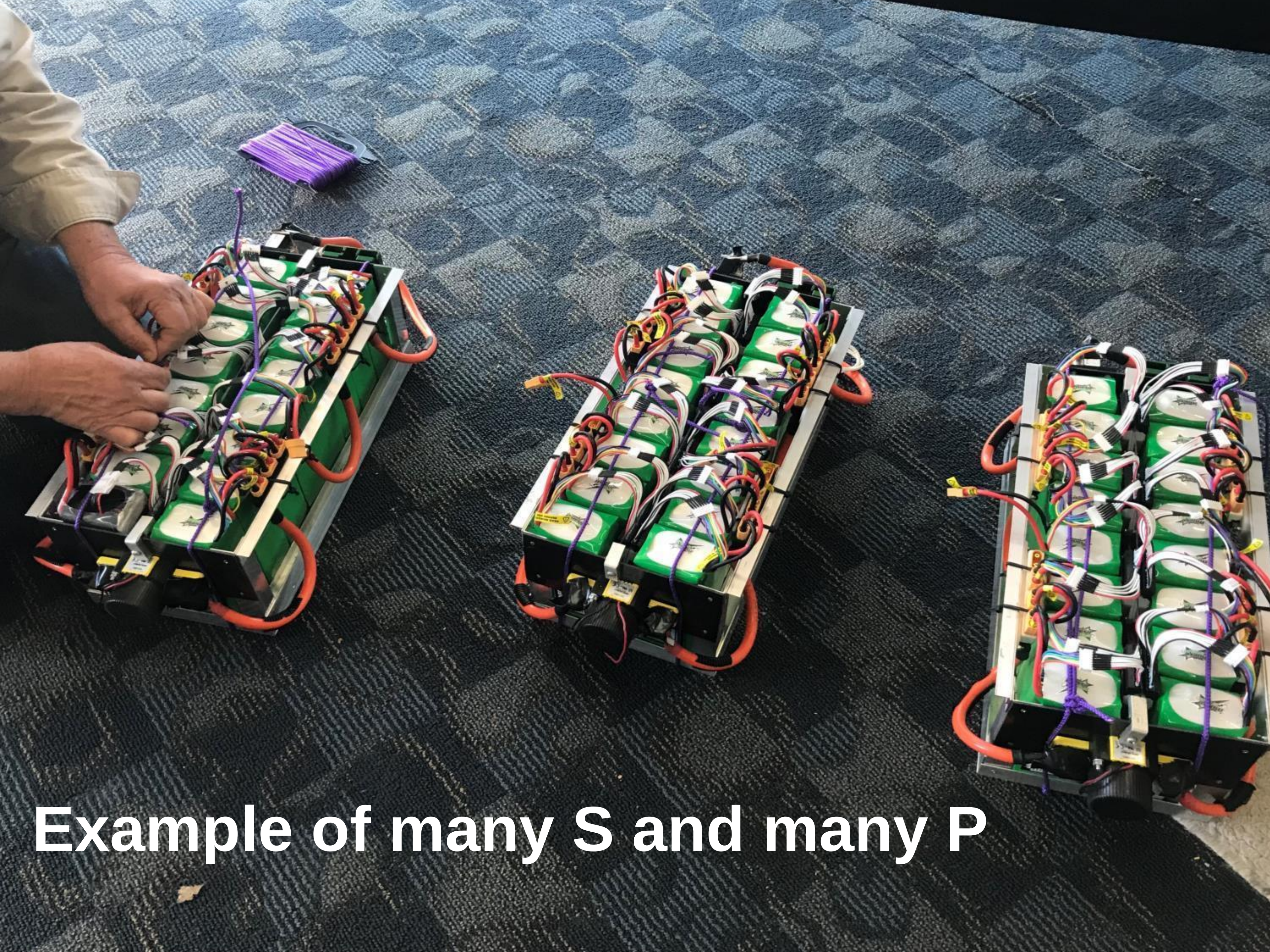
Battery Jargon

Connect in series and parallel => voltage increases, and Ah increases.
=> allows more power and endurance

"2S3P"



Example of a 5S pack


Example of many S and many P

Design Rule

1. Use as high a voltage as possible.

2. i.e. 800 volts (=200 cells in series).

3. Then increase the number of cells in parallel so the continuous current draw will not exceed 5C.

(I will explain later what 5C means)

In the future for electric vehicles and eVTOL, we probably use 800 volts instead of 400 volts to reduce current draw and wire weight.

If we need 800 kW of power to hover, then 800kW / 800V = 1,000 amps of total current draw during hover.

That's a lot of current!

To reduce the current through the wires, we use distributed architecture for eVTOL. Use 6 rotors and 6 motors, then each motor only needs to produce 800kW / 6 = 133kW of power

Then 133 kW/800V = 166 amps of steady current draw per motor during hover.

That's more manageable

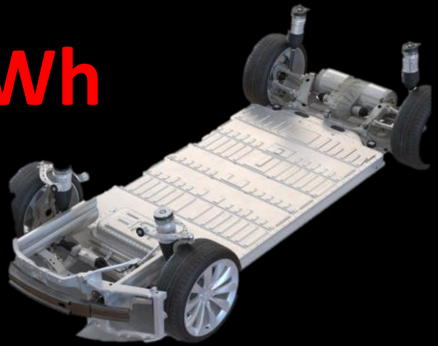
Can even use 6 separate battery packs for safety

How big a battery this eVTOL requires if it has to hover for 15 minutes with no reserve?

Answer

800V x 1,000 amp x ¼ hour = 200 kWh

Compare to a Tesla car has only 85 kWh

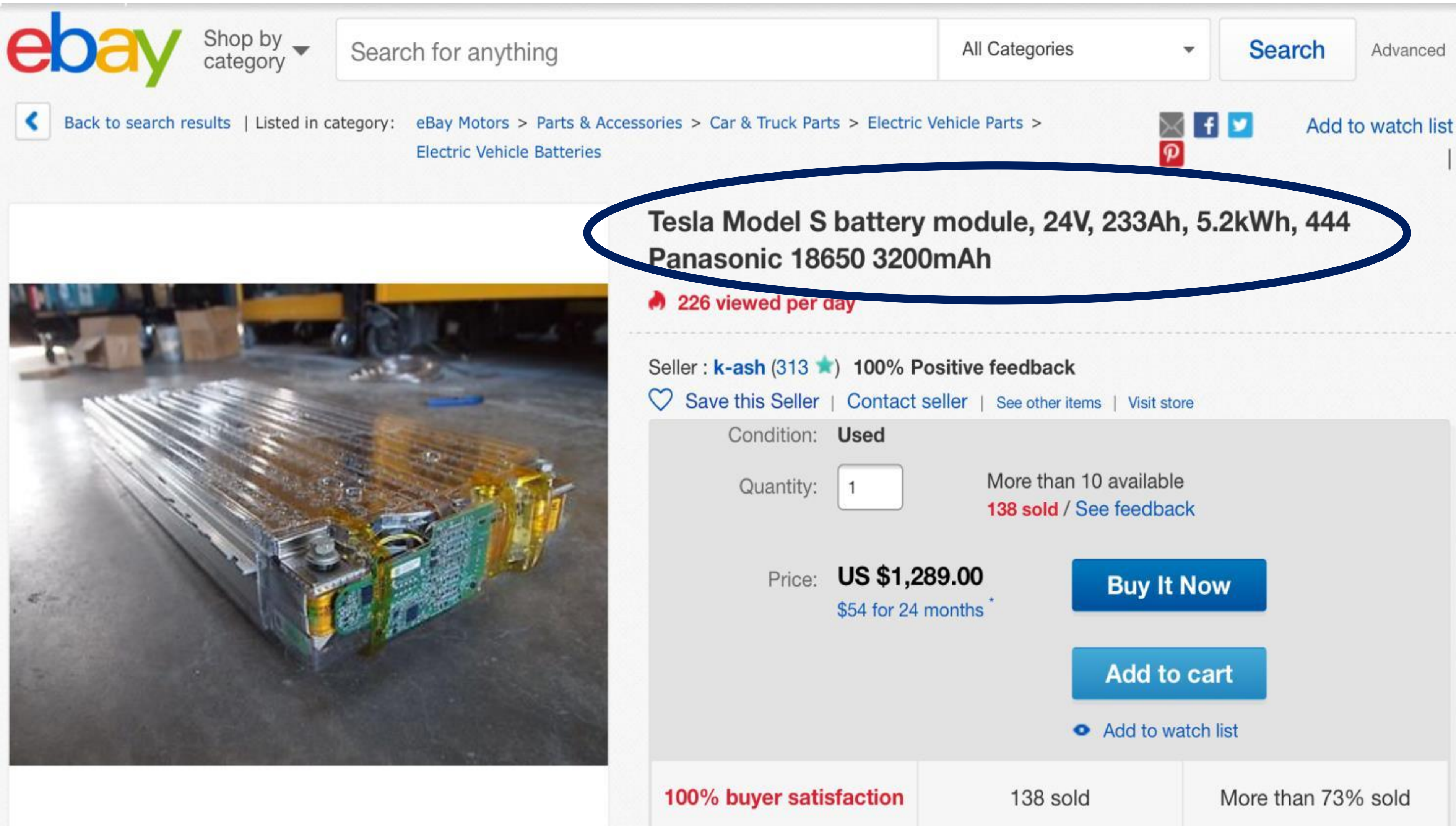


For Tesla Model-S car
Each cell 4v, 3200 mAh

444 cells per module in 6S74P (24v, 233 Ah)

16 modules in series (384v, 7104 cell, 85 kwh of energy, 1000 lbs)

You Can Buy This Battery Module on eBay



Nissen Leaf Uses Pouch Type Lithium Ion Cells

Source: 2 hrs video dissecting Nissen Leaf battery https://youtu.be/vYQJatWpBXY

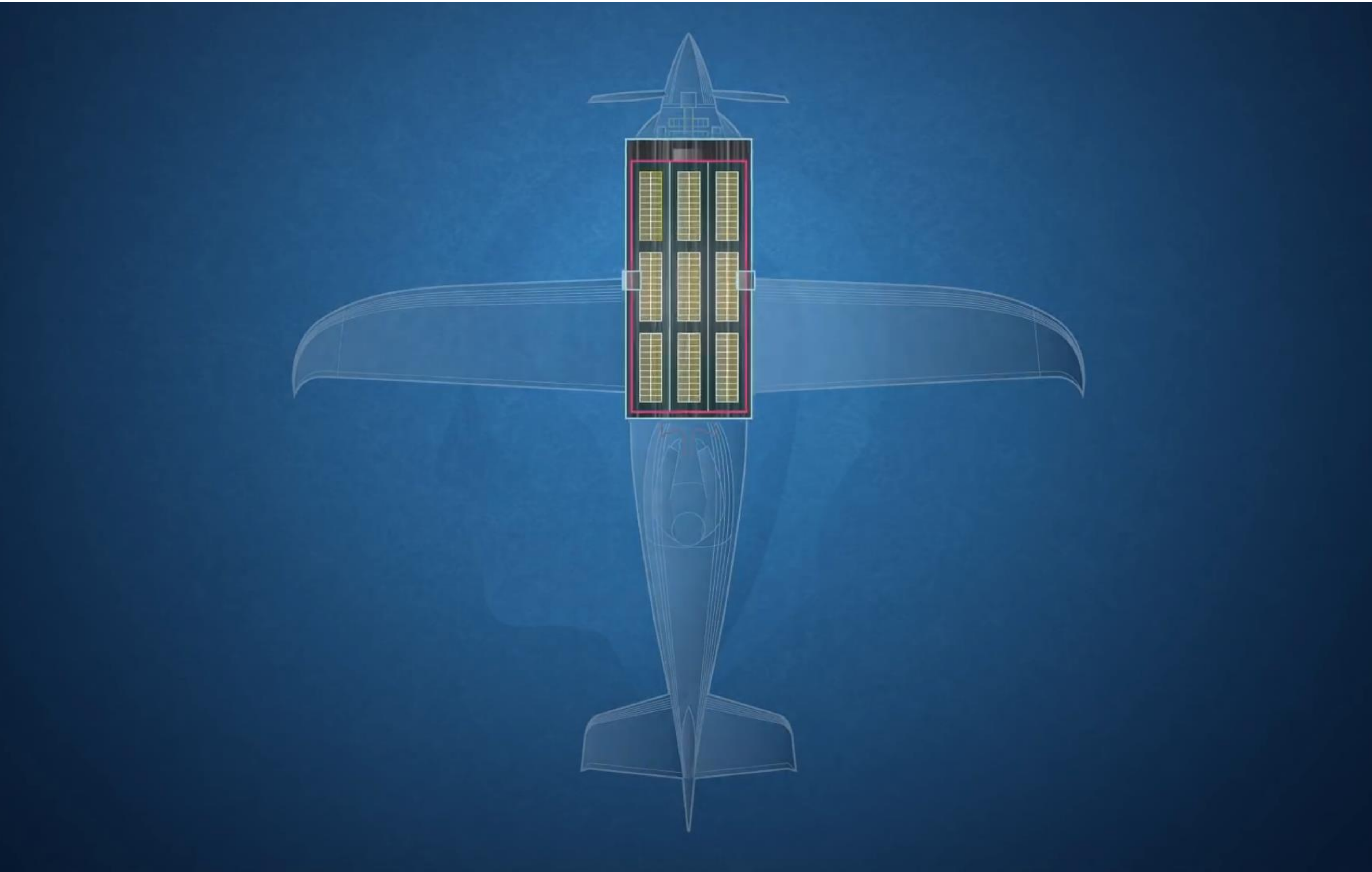
Nissen Leaf's 225 Amps, 450 Volt Fuse

Source: 2 hrs video dissecting Nissen Leaf battery https://youtu.be/vYQJatWpBXY

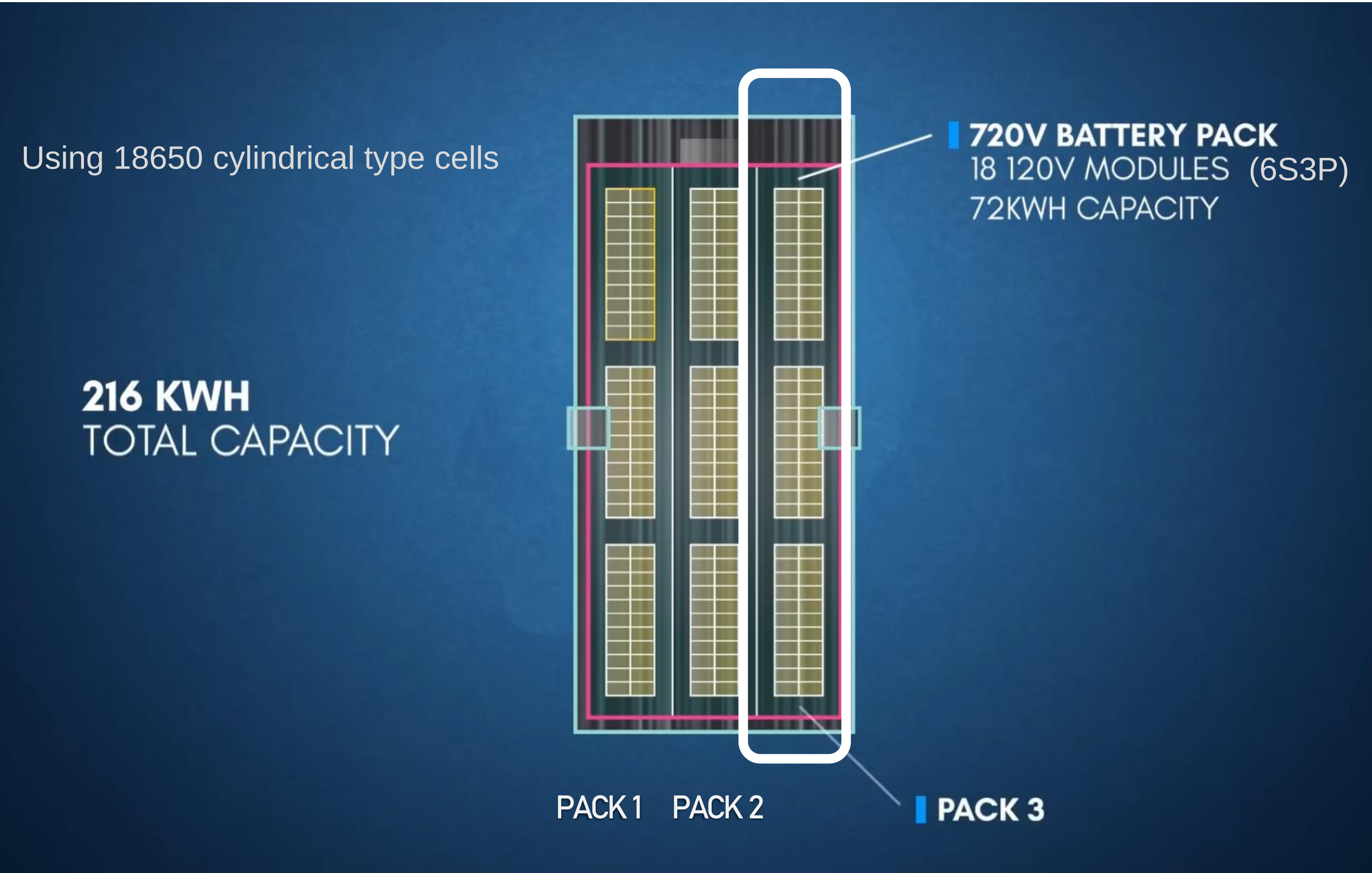
Example: An Electric Airplane

RR Spirit of Innovation Clocks 387 MPH

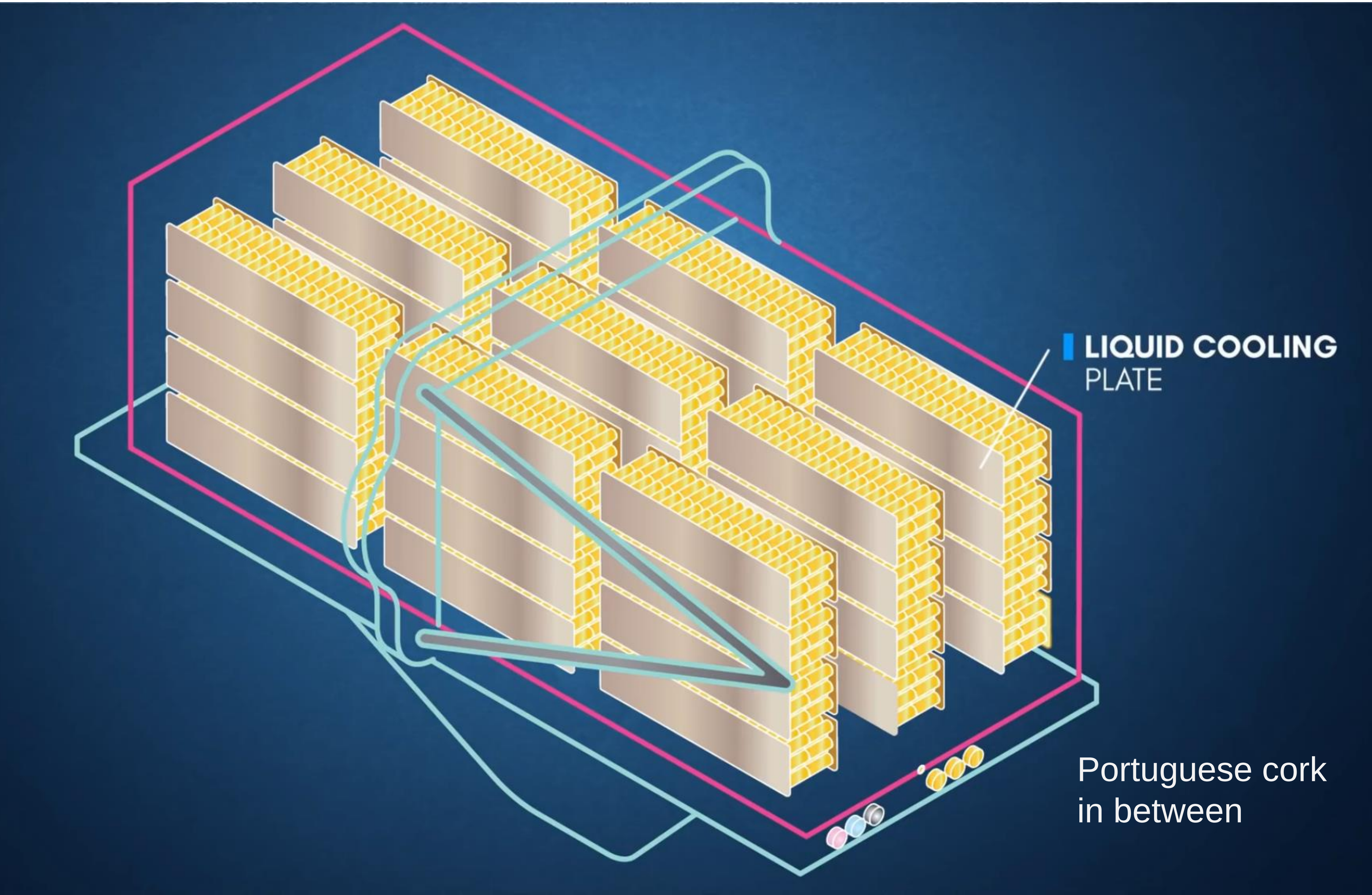
RR Spirit of Innovation has 216 kWh Battery



RR Spirit of Innovation has 216 kWh Battery

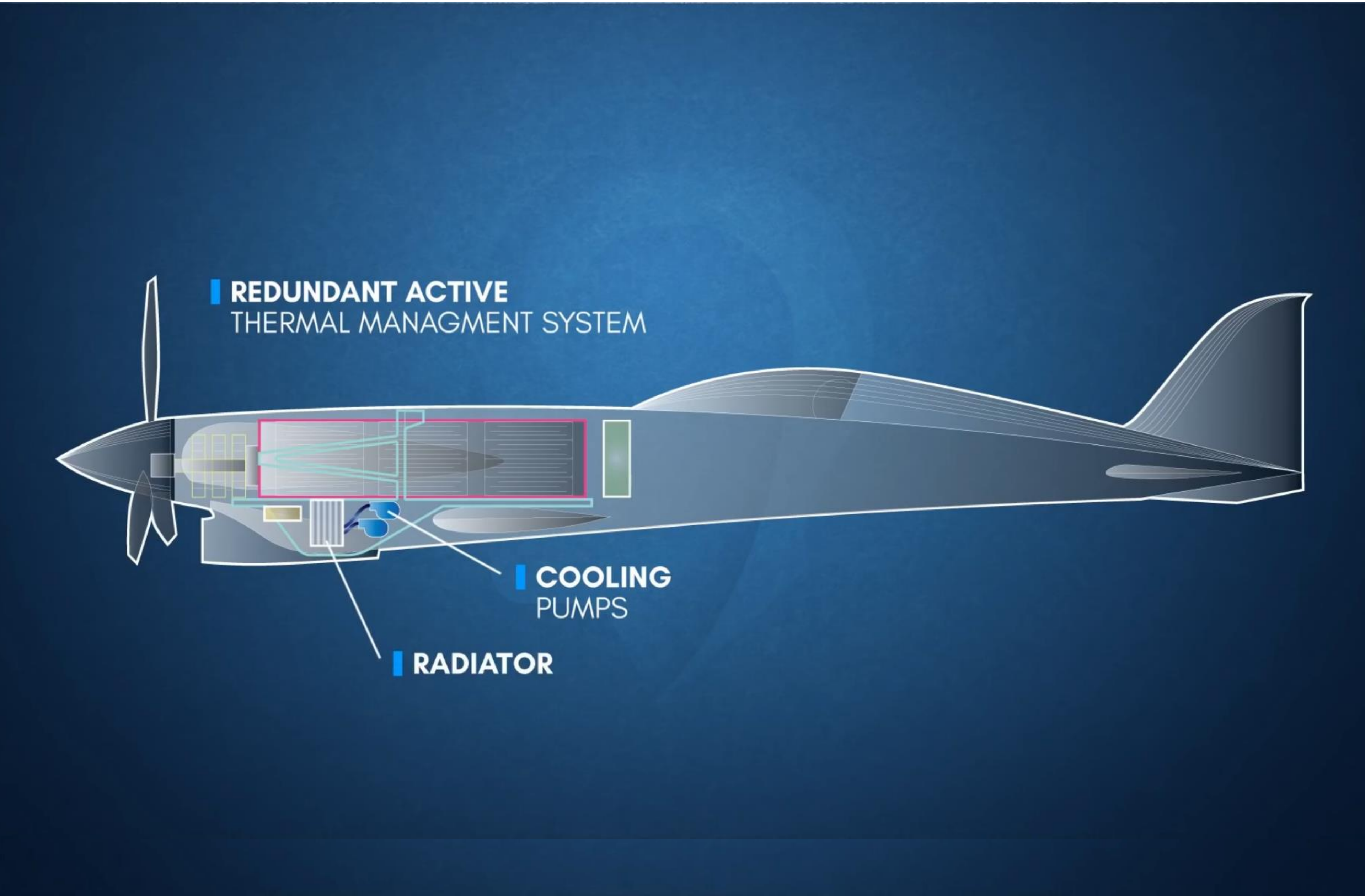


Liquid Cooled Battery Pack

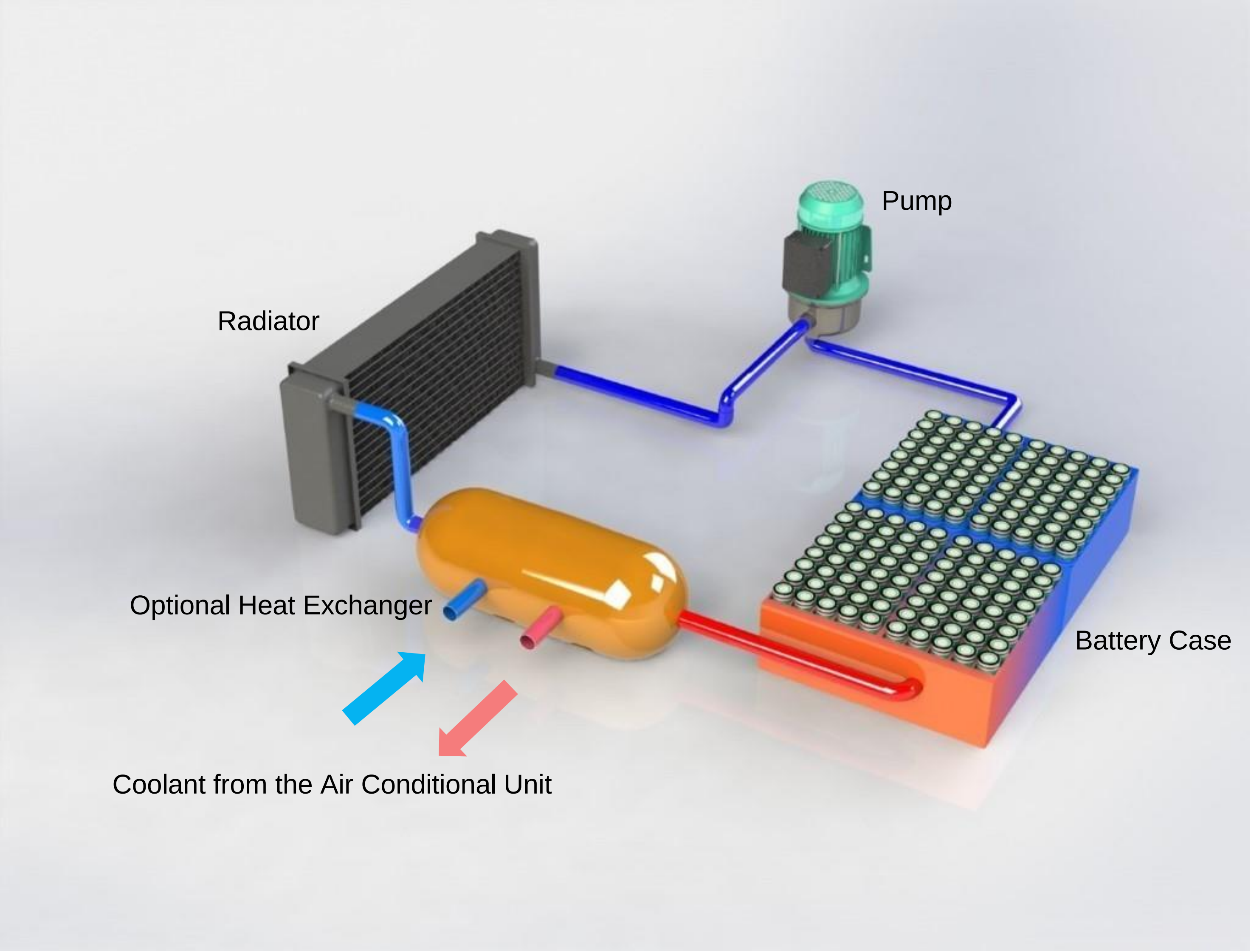


Portuguese cork
in between

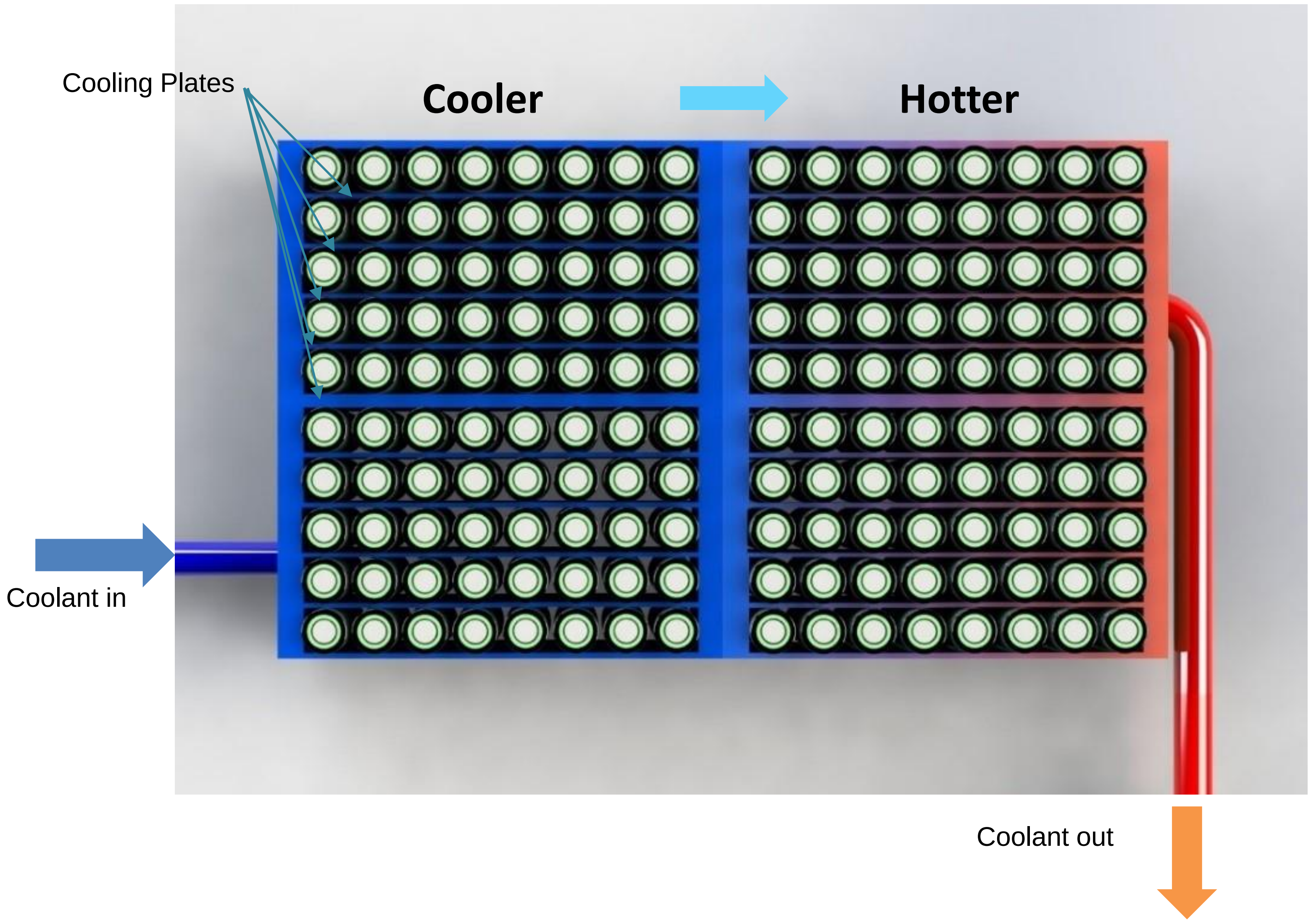
RR Spirit of Innovation Cooling System



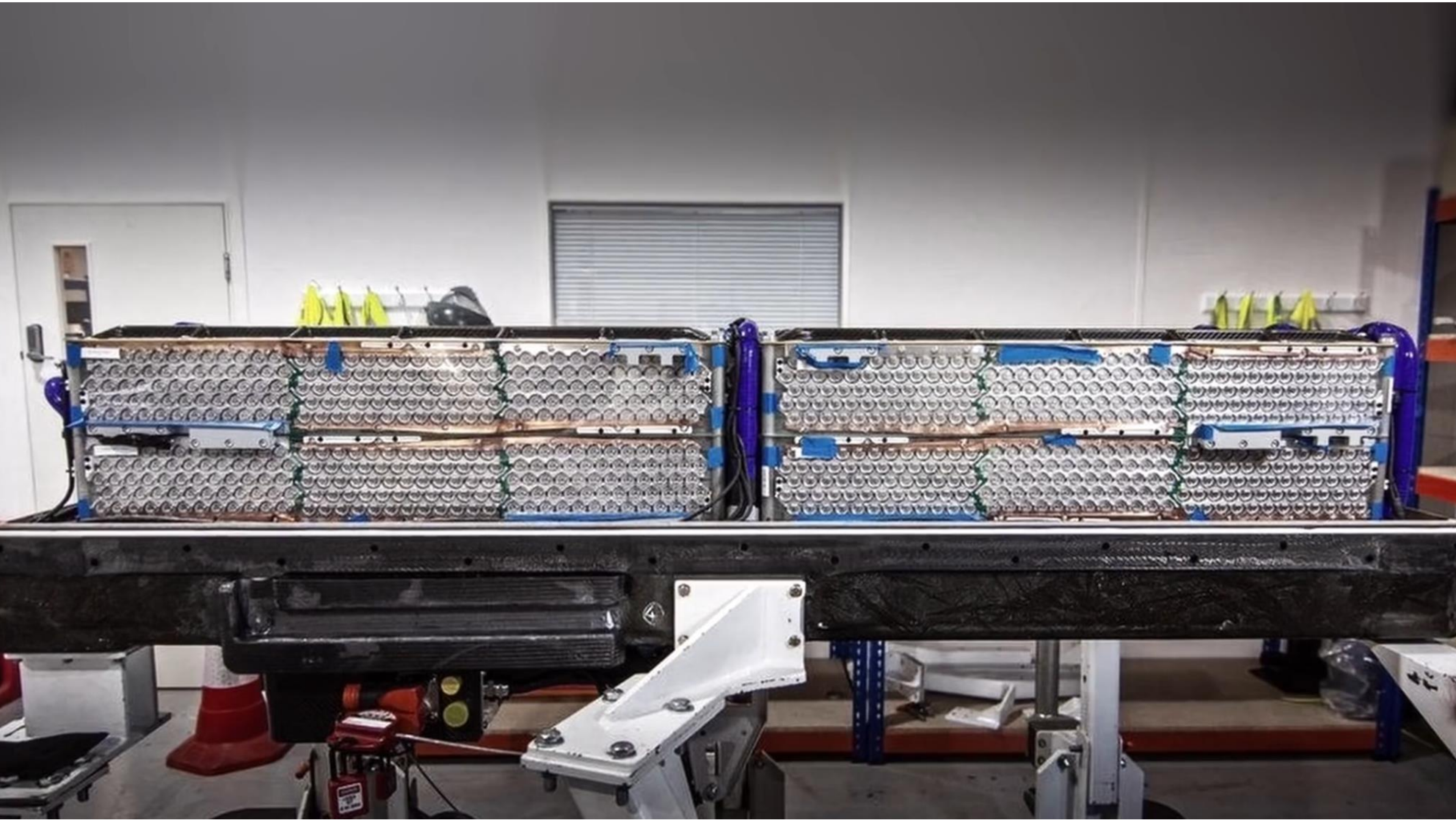
Liquid Cooling of Lithium Cells



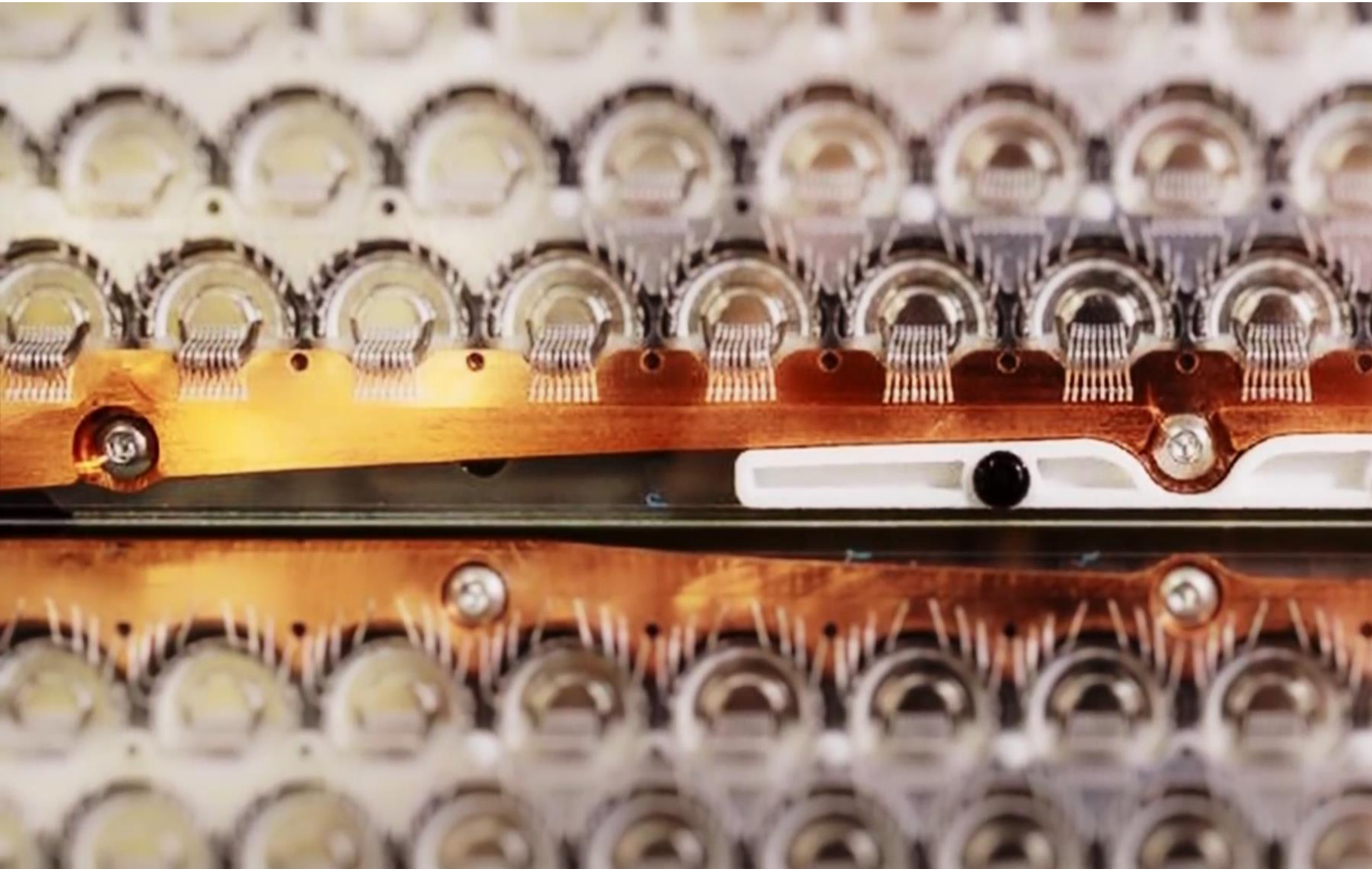
Thermal Gradient Problem



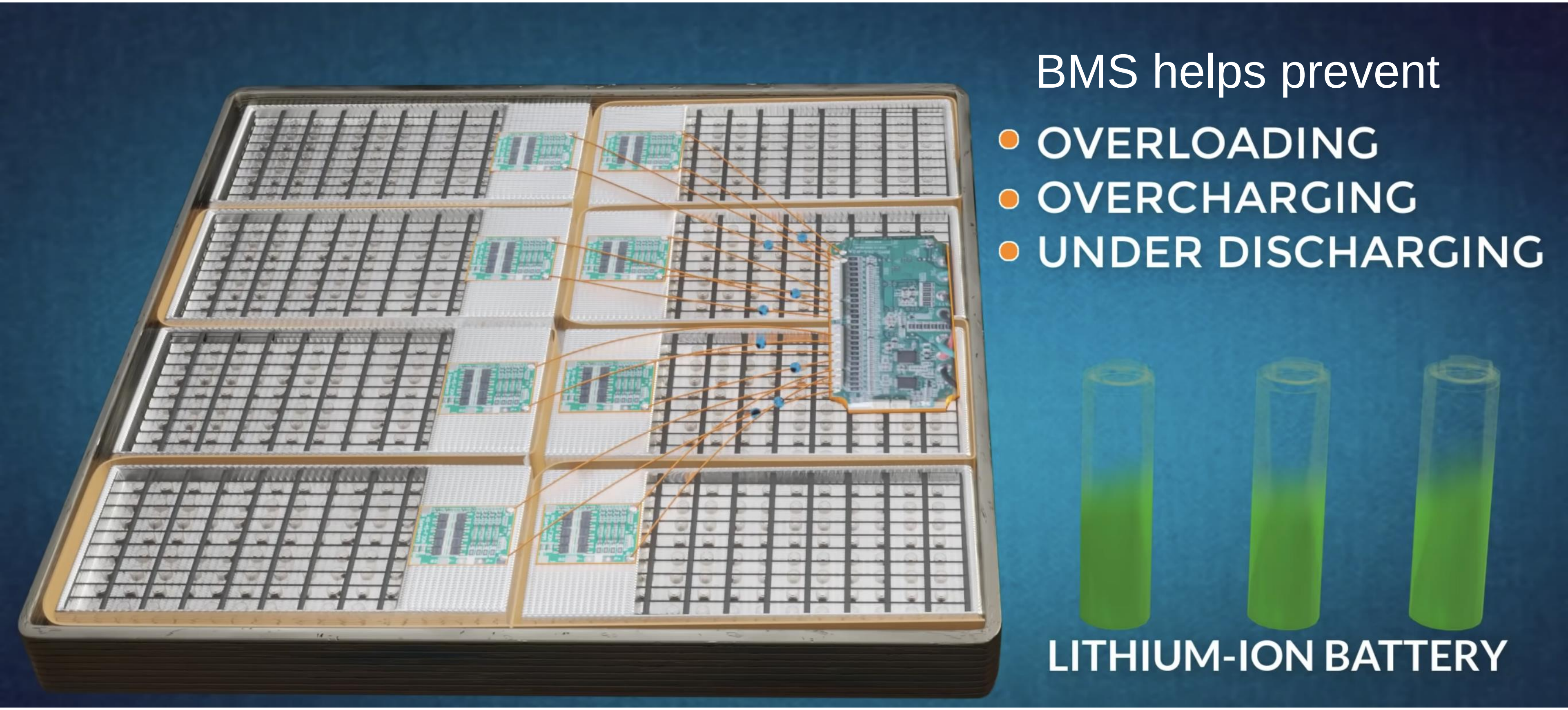
RR Spirit of Innovation Uses 18650 Type Cylindrical Cells



Each Cell is Connected to the BMS (Battery Management System)



BMS Monitors Each and Compares Every Cell



Single lithium
pouch cell
200wh/kg

3S battery pack without BMS

3S battery pack with BMS

Importance of Balancing Cells When Charging

Example of checking the cell voltages on a 6S battery pack.

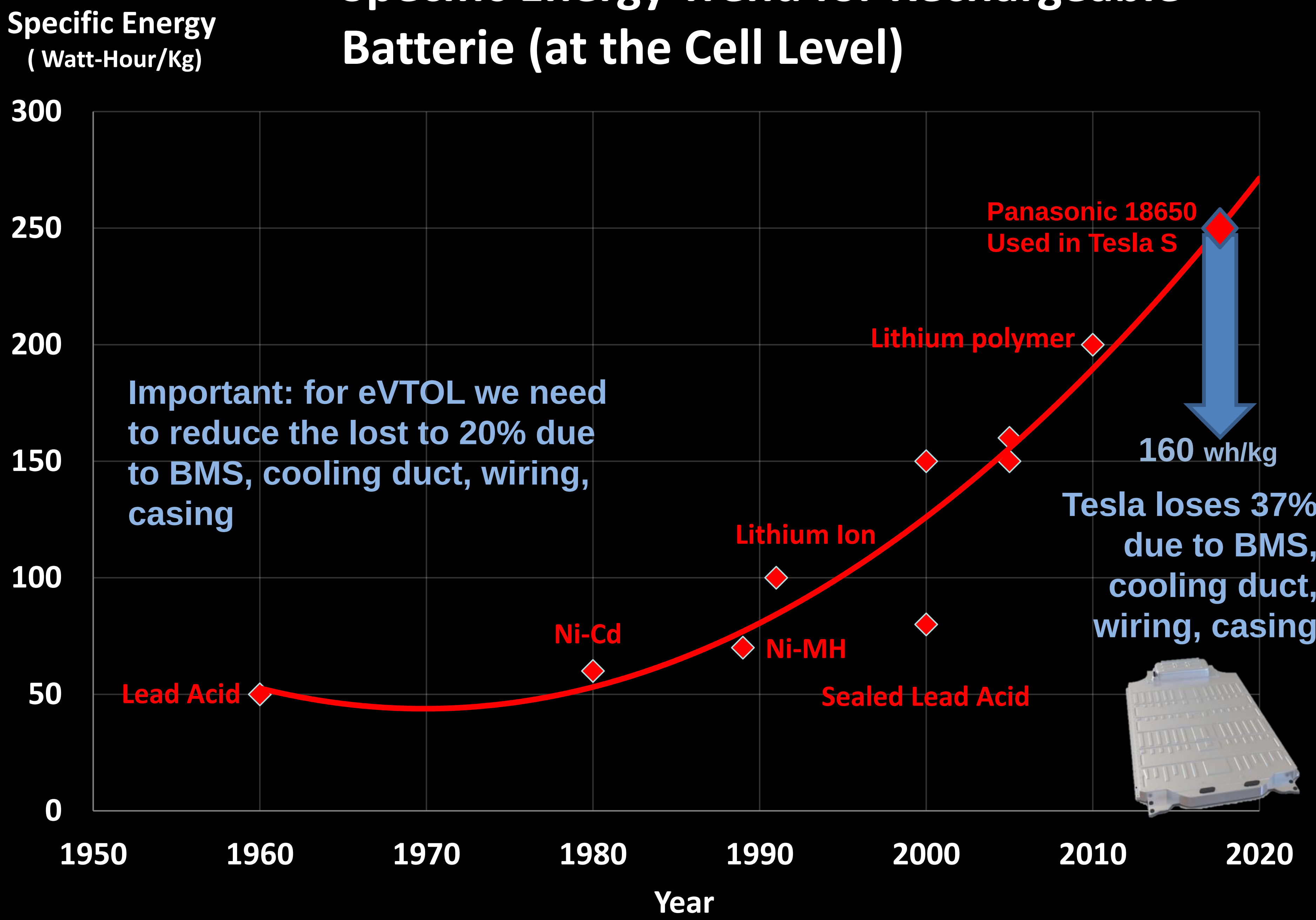
The voltage difference between cells should be less than 0.01 volt

All eVTOL battery pack should have a built-in battery managing system (BMS) to check and compare the health of every cell. There could be thousands of cells in an eVTOL.

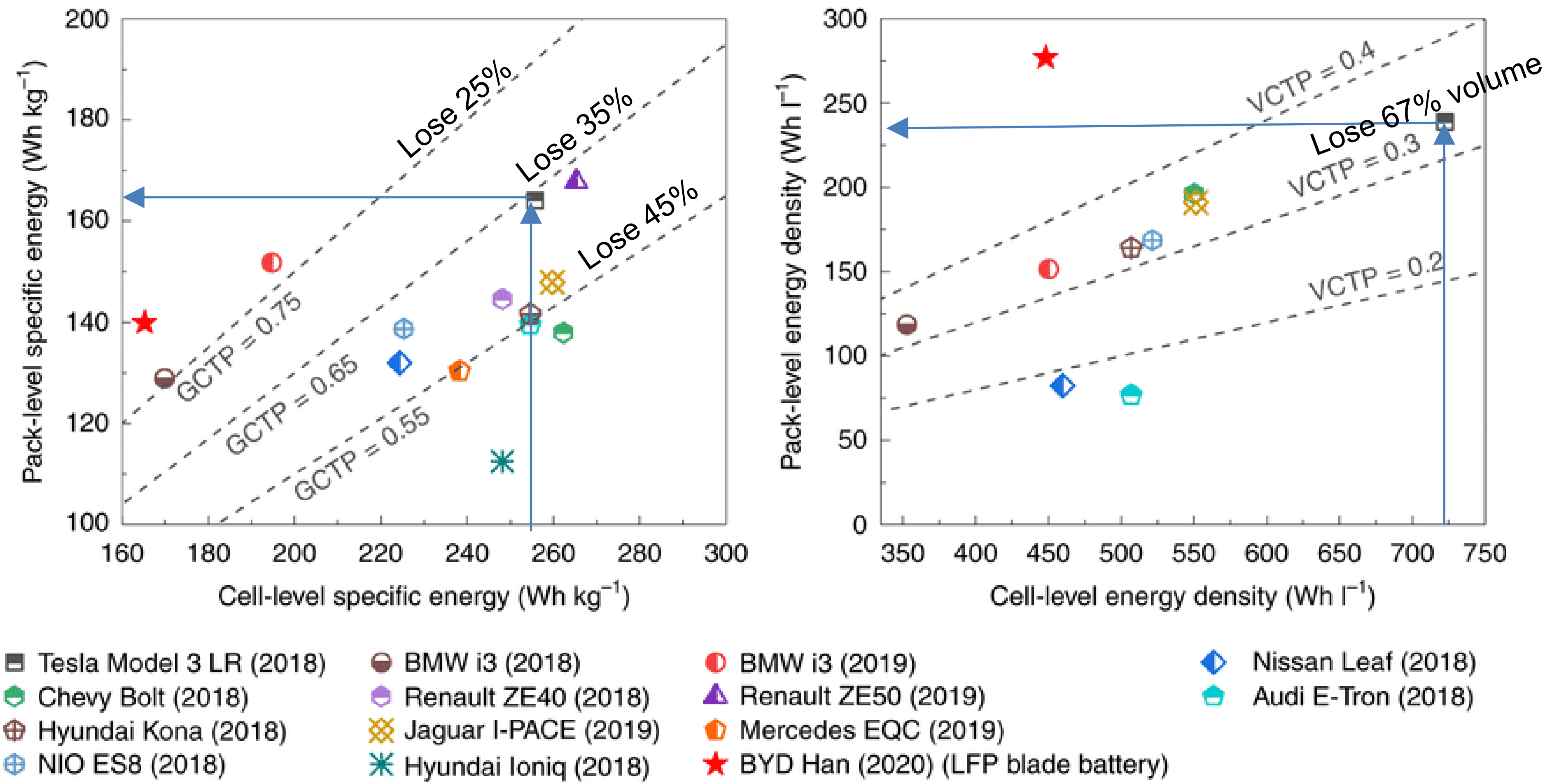
Don’t Let This Happen !

Example: Finished Car Battery Pack with BMS

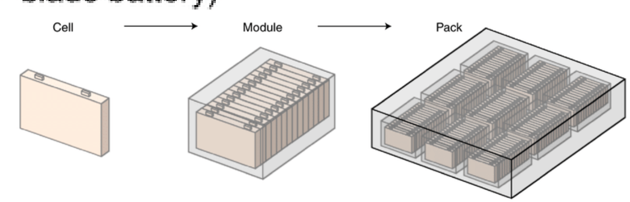
Specific Energy Trend for Rechargeable Batterie (at the Cell Level)



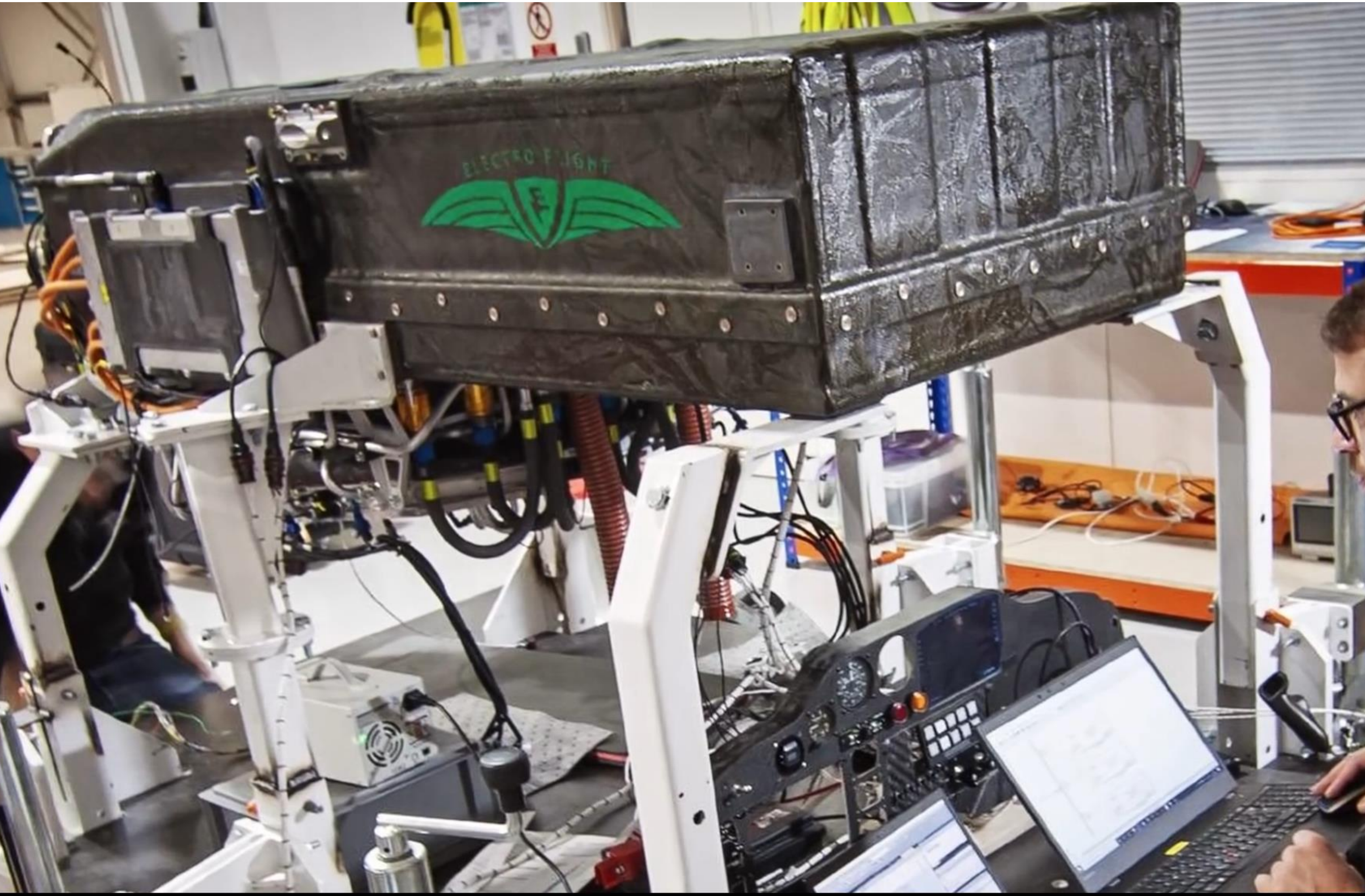
When Going from Cell Level to Pack Level Can Lose 45% to 25% in Specific Energy



Source: https://www.researchgate.net/figure/Cell-to-pack-technology-a-b-A-schematic-illustration-of-a-conventional-battery-pack-a_fig1_348584577



RR Airplane Achieves 168 Wh/kg at Pack Level



Advantage of Using Battery Modules for cars and electric aircraft

- Ease of manufacturing
- Safety in manufacturing
- Can distribute around the aircraft
- Safety in failure/crash
- Serviceability

What is C Rating

Definition of C Rate

0.1C = fully discharge or fully charge in 10 hour

1C = fully discharge or fully charge in 1 hour

10C = fully discharge or fully charge in 1/10 hour

100C = fully discharge or fully charge in 1/100 hr

Example: a 50 Ah battery discharging at 50 amps, will be fully emptied in 1 hour. That is called *discharged at 1C rate*

Example: a 50 Ah battery charging at 50 amps, will be fully charged in 1 hour. That is called *charging at 1C rate*

Definition of C Rate

Can also calculate C Rate if we know the power usage in watts.

Example: a 50 Ah 100 volt battery = 5000 Wh battery

A 5000 Wh battery discharging at 5000 Watts, will be fully emptied in 1 hour. That is called *discharged at 1C rate*

More Examples of C Discharge Rate

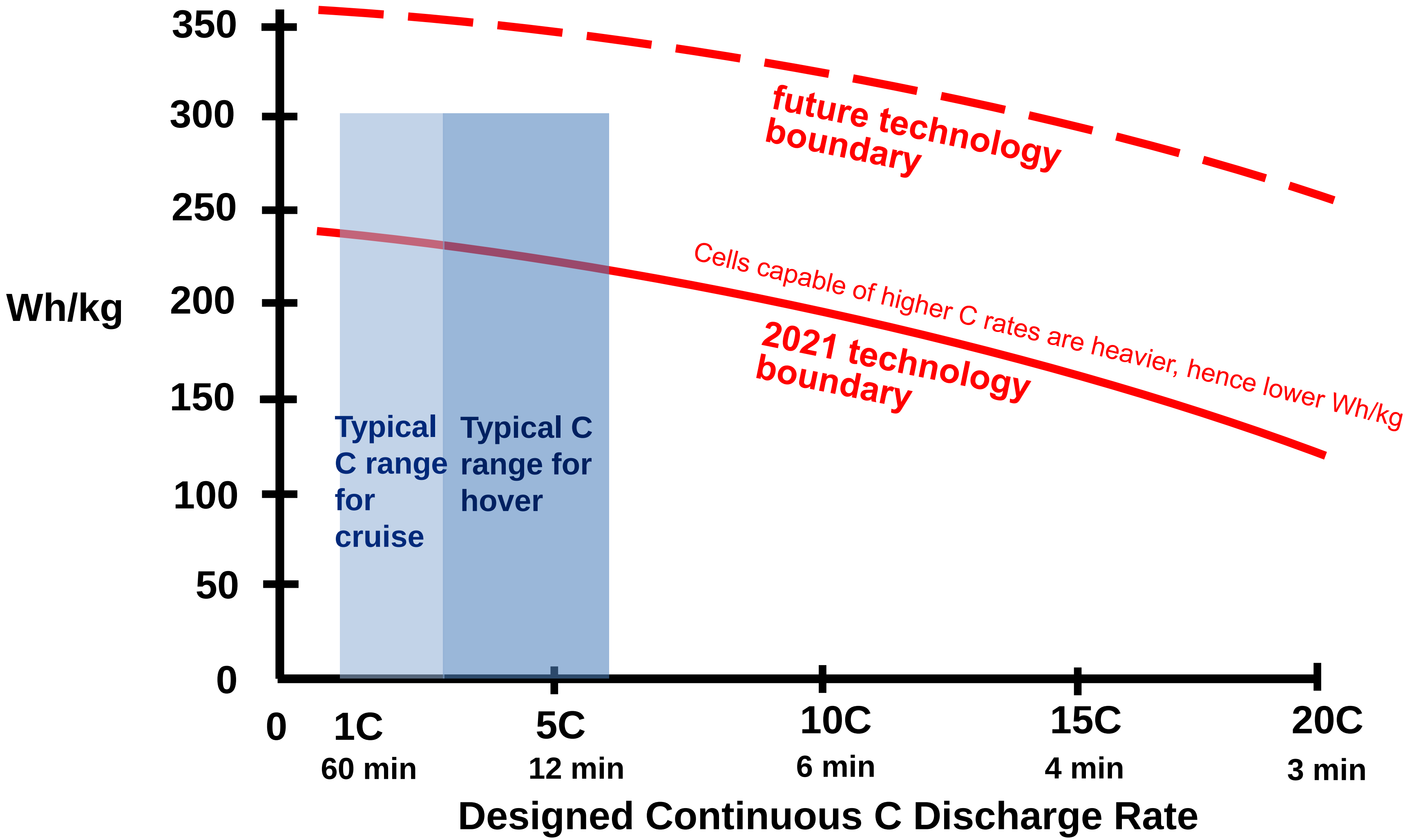
Example: a 50 Ah battery discharging at 500 amps (@10C) will be fully emptied in 1/10 hour (= 6 min)

Example: a 50 Ah battery discharging at 100 amps (@2C) will be fully emptied in 1/2 hour (= 30 min)

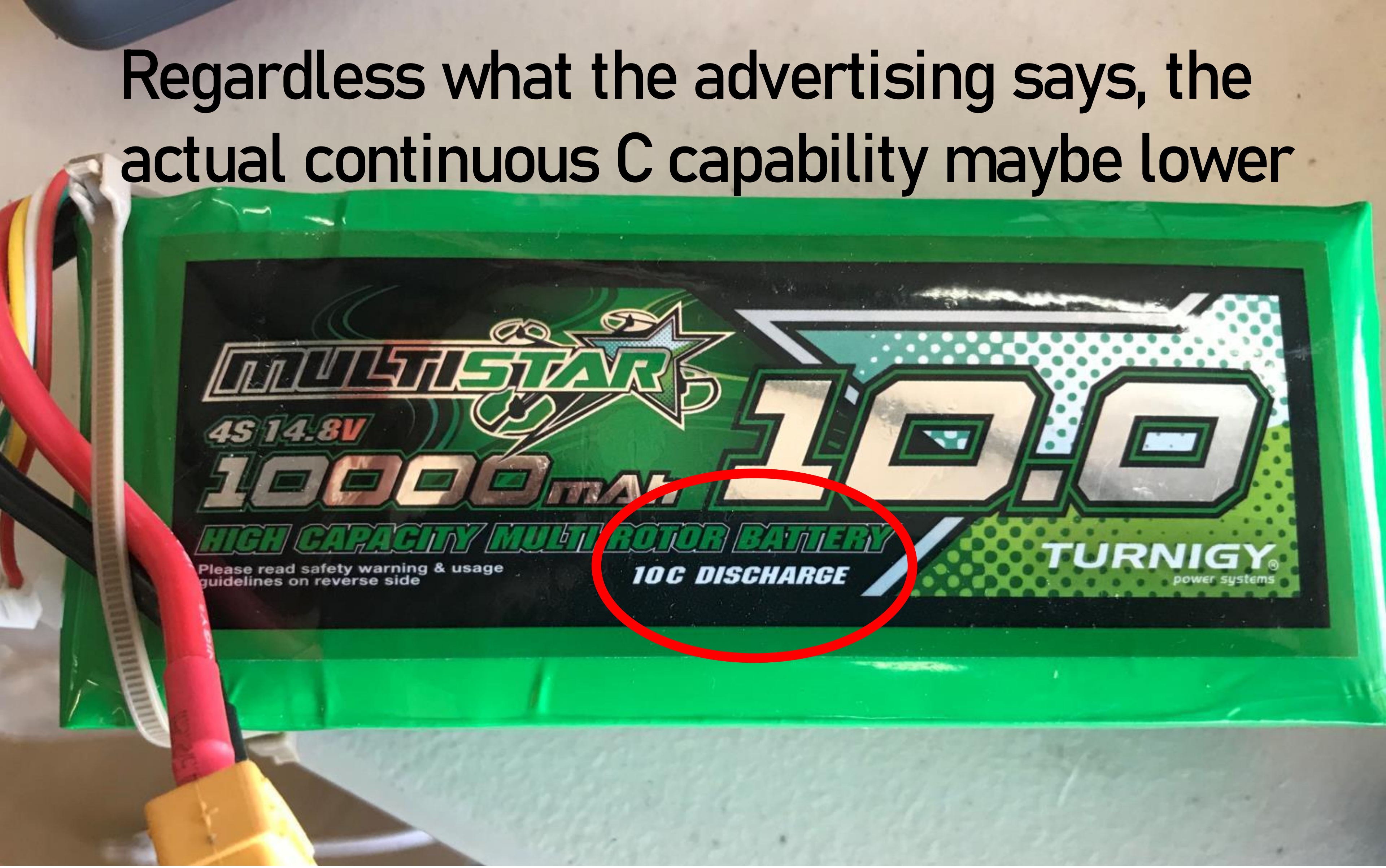
Example: a small eVTOL with a fully charged 800 volt, 50 Ah battery (40 kWh) discharging at 250 amps (@5C), it can fly for 12 minutes.

Warning: lithium battery should never be fully emptied! Avoid draining down to below 25% of its total capacity.

C Discharge Rate Affects Cell's Specific Energy



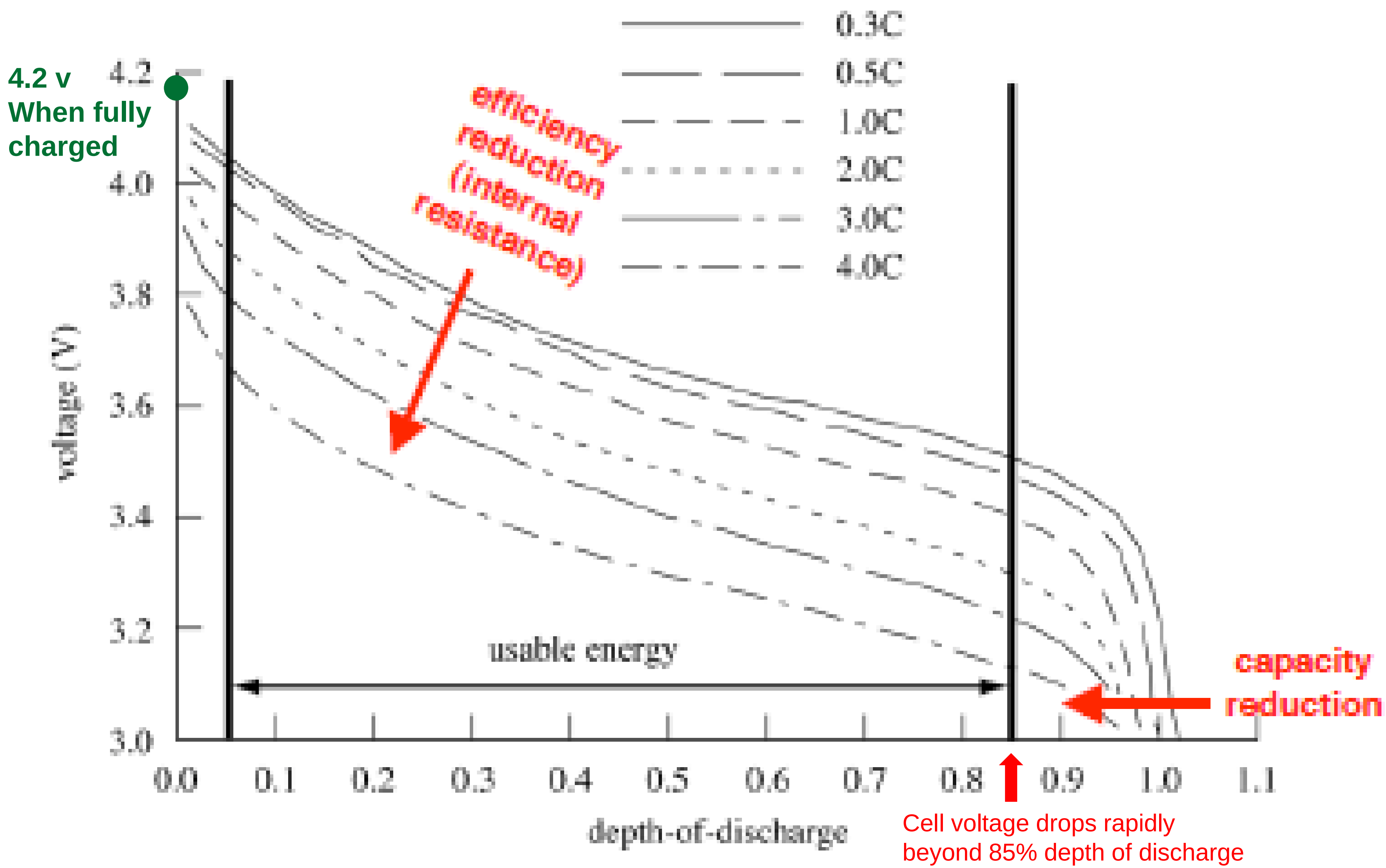
Regardless what the advertising says, the actual continuous C capability maybe lower



For today's lithium battery technology, it is best to keep your discharge rate under 5C.

A fully charged lithium cell is around 4.2 volts.
Minimal usable voltage 3.7 volts. Hence 3.7V x 4 = 14.8V

Lithium Cell Discharge Characteristics



Examples of C Charging Rate

Example: a 50 AH battery charging at 100 amps (@2C) will be fully charged in 1/2 hour (= 30 minutes)
Called fast charge, feasible today

Example: a 50 AH battery charging at 500 amps (@10C) will be fully charged in 1/10 hour (= 6 minutes) ***Super fast charge! Not popular yet !***

Example: a 50 AH battery charging at 5 amps (@ 0.1C) will be fully charged in 10 hour
Called slow charge. If even lower rate, then it is called trickle charge

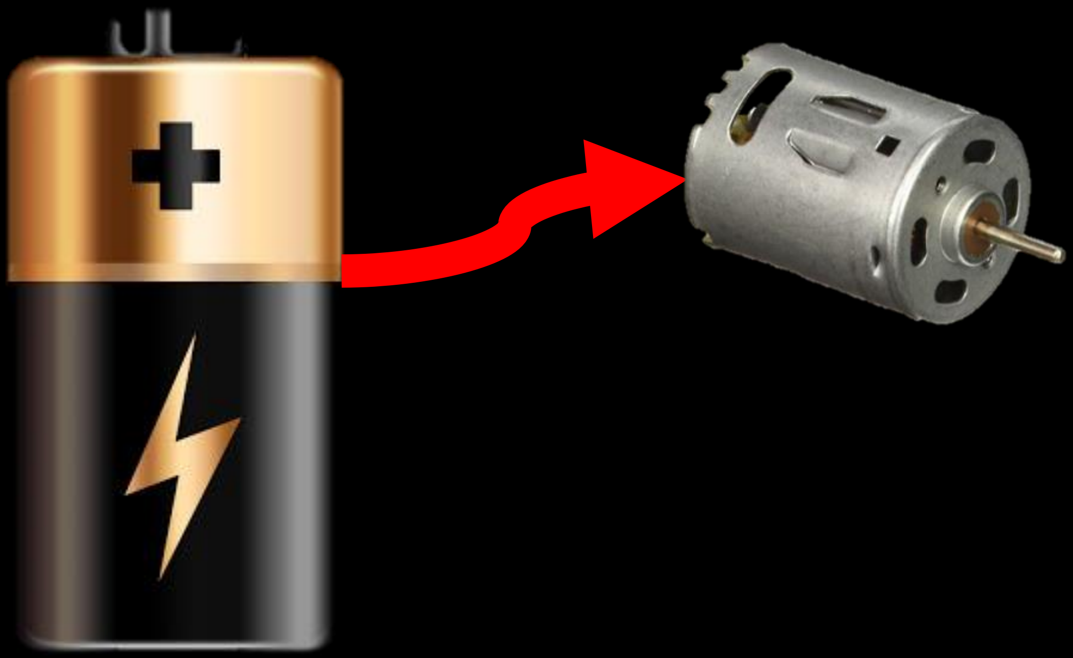
To permit high C charge and discharge rates, the cell is designed to have a lower internal impedance. This also helps prevent heat built up inside the cell.

Higher-C cells are 10 to 20% heavier.

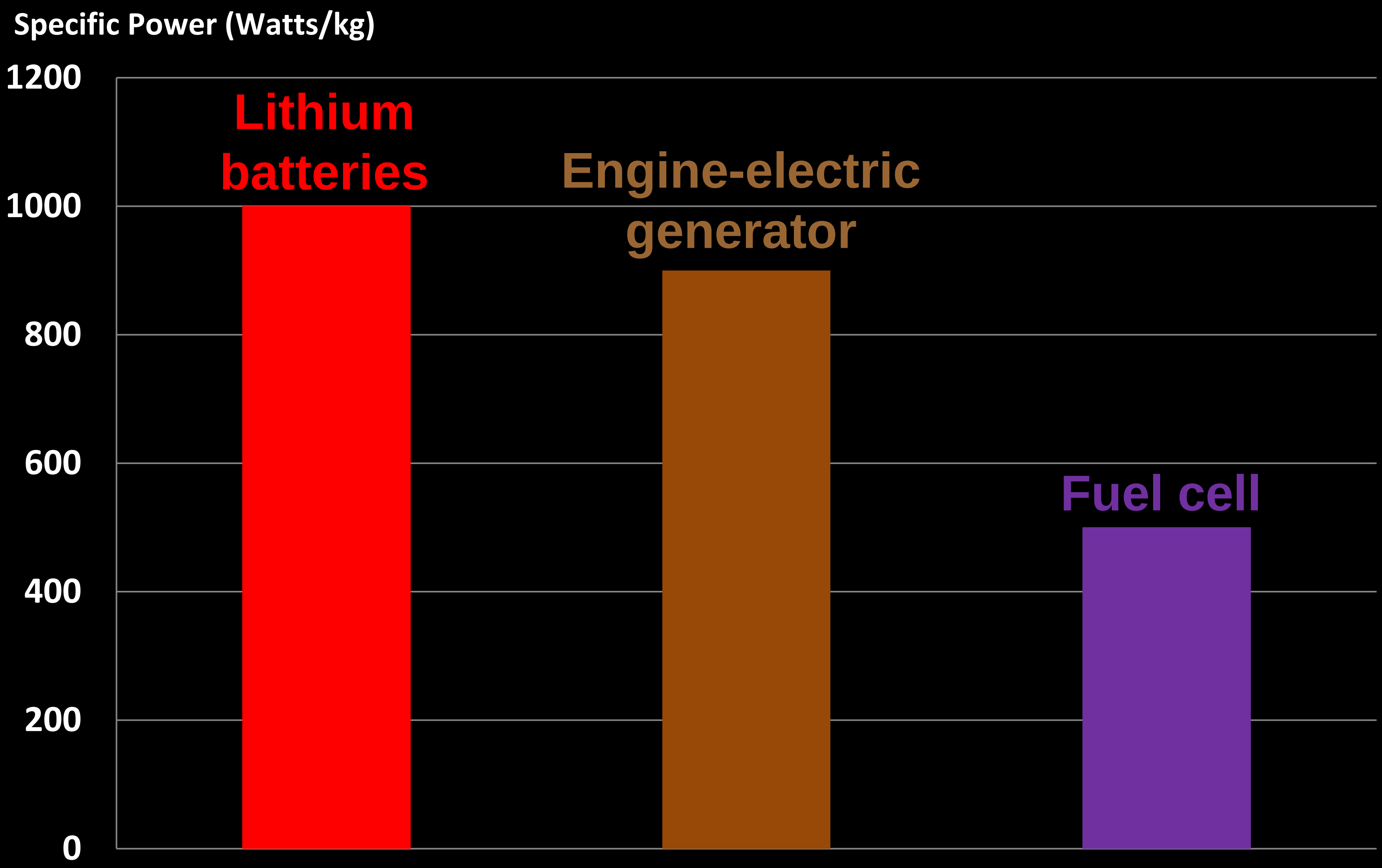
Super DC Charger Charges at 1C to 2C Rate

Specific Power

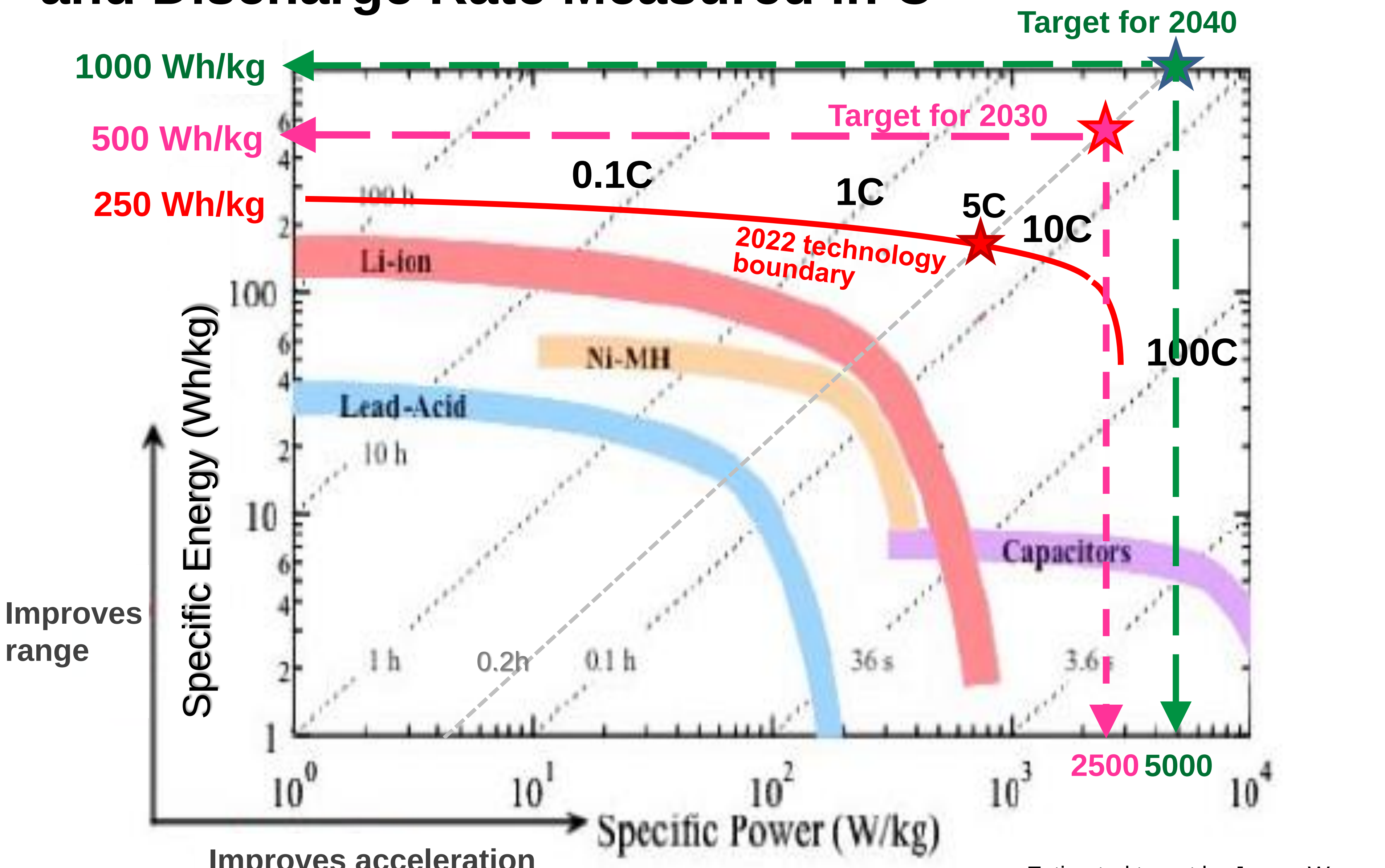
Specific Power is a measure of how quickly an energy source can supply power



Comparing Specific Power



Battery Targets for Specific Energy, Specific Power and Discharge Rate Measured in C



Estimated target by James Wang

Hydrogen Power

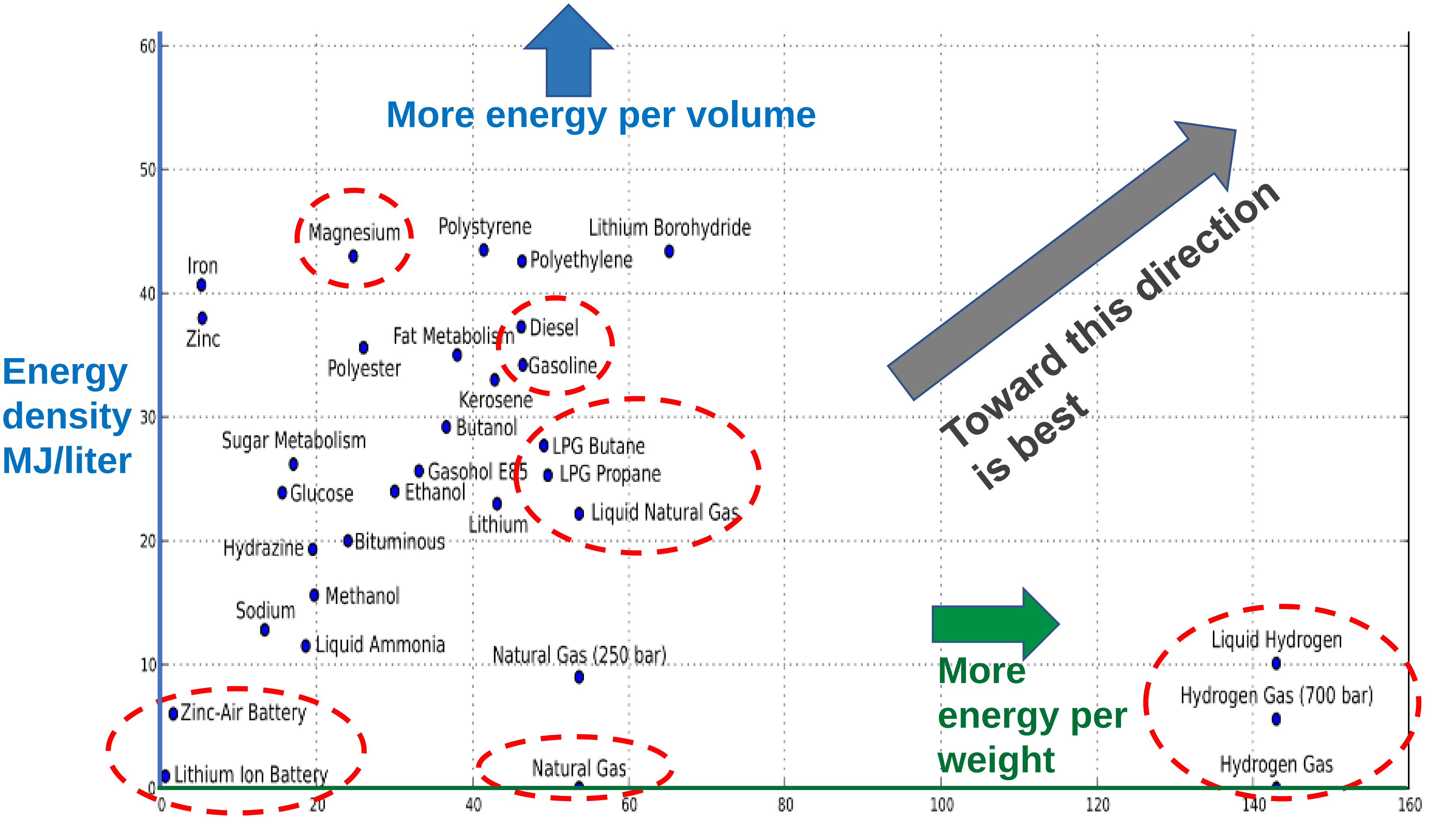
Hydrogen

Hydrogen is invisible, odorless, non-toxic, non-corrosive and non-hazardous. Nor does it ignite by itself, but when mixed with air it is an ignitable gas over a wide range of concentrations (from 4% to 75% by volume). The hazard potential of hydrogen is comparable to that of natural gas. Hydrogen must be produced, stored, transported and used carefully.

Without oxygen, hydrogen is non-explosive. Storing hydrogen in tank is therefore not dangerous in itself. Safety valves ensure that the hydrogen is blown off in a controlled manner at overpressure and volatilizes. However, escaping hydrogen can be ignited and flared by an ignition source without causing an explosion.

Safety precautions are designed accordingly, and handling is regulated by a comprehensive set of standards. In Europe, there exists special hydrogen pipelines totaling over 1,500 km in length.

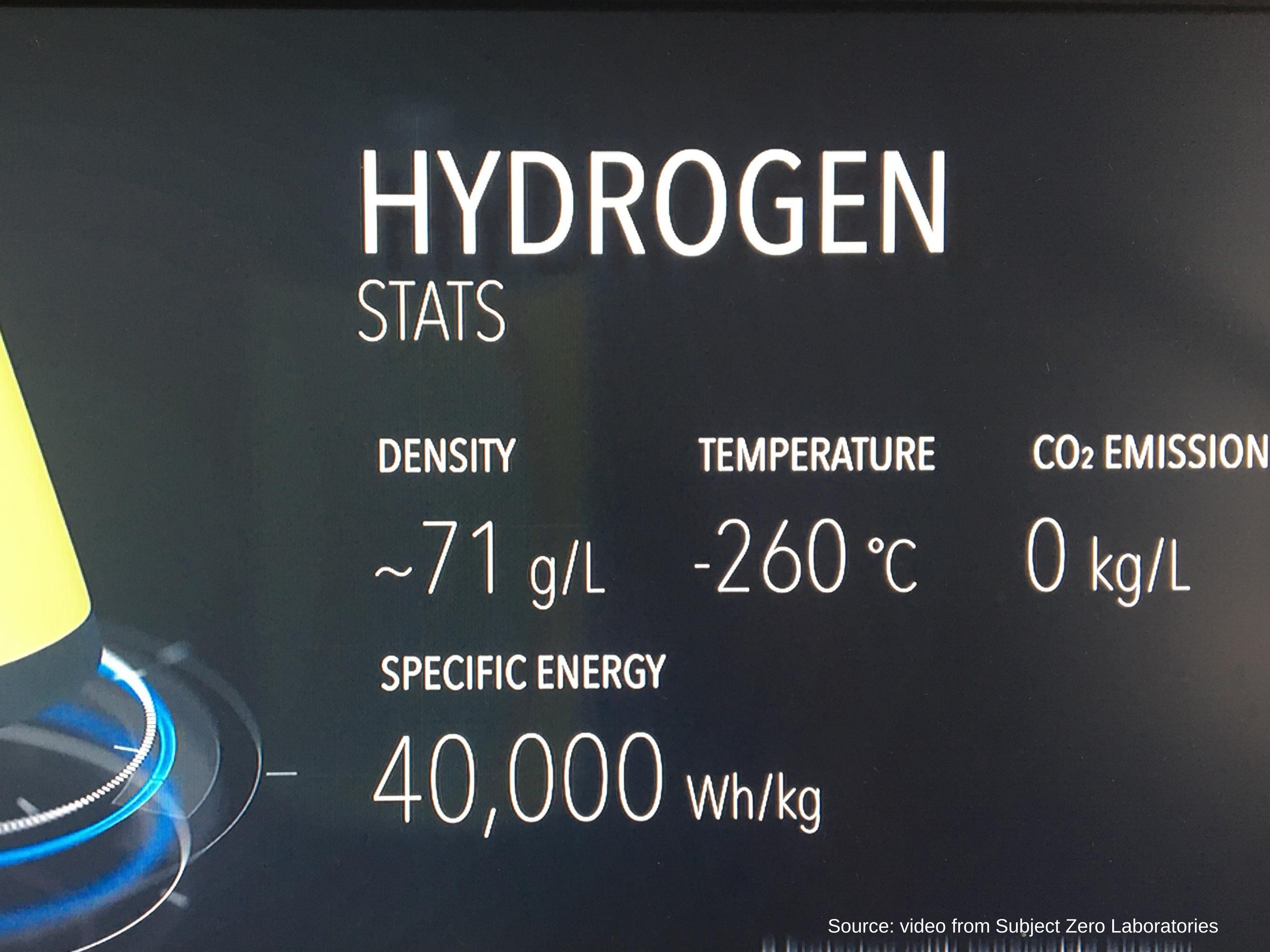
Want High Specific Energy & High Energy Density



Specific energy (MJ/kg)

Lithium battery advantages: clean, simple and cost is going down. Con: needs higher specific energy, recycleability, and to be less volatile.

Today hydrogen and fuelcell still too expensive, difficult to transport to charging stations, highly flammable, and does not have the "power density" required for flight.



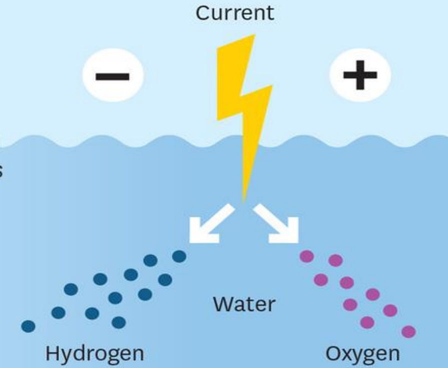
Source: video from Subject Zero Laboratories

How to Produce Hydrogen

Electricity can be used to collect hydrogen from water. Scientists are looking for smarter ways to make this happen.

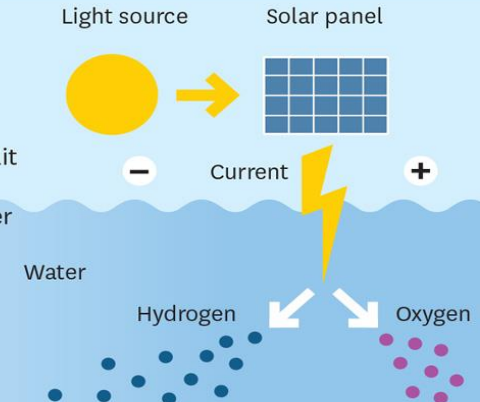
Electrolysis

An electrical current passed through water can split water into its components—hydrogen and oxygen. Researchers worldwide are studying catalysts to make the process more efficient and cheaper.



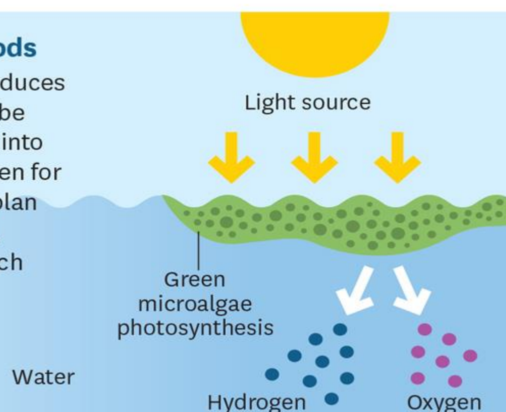
Photoelectrolysis

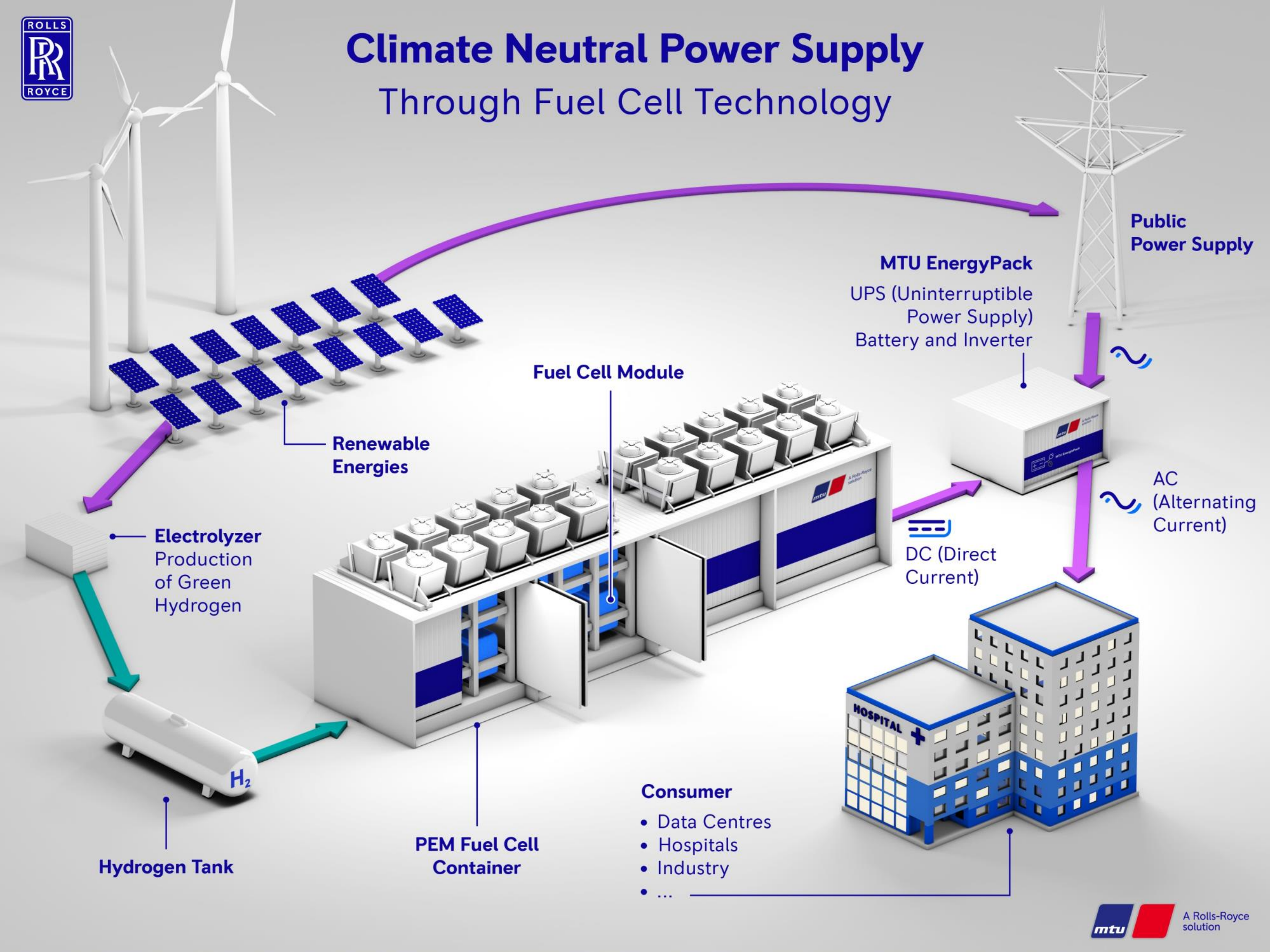
Some scientists are studying how to use sunlight to fuel reactions that can split water into hydrogen and oxygen. And other methods don't use electricity as an intermediary at all.



Biological Methods

Algae naturally produces hydrogen. It could be used to split water into hydrogen and oxygen for human use. Don't plan on it anytime soon, though: The research is preliminary.




ROLLS ROYCE
Climate Neutral Power Supply
Through Fuel Cell Technology
Public Power Supply
MTU EnergyPack
UPS (Uninterruptible Power Supply)
Battery and Inverter
Fuel Cell Module
Renewable Energies
Electrolyzer
Production of Green Hydrogen
AC (Alternating Current)
DC (Direct Current)
HOSPITAL
H2
Hydrogen Tank
PEM Fuel Cell Container
Consumer
• Data Centres
• Hospitals
• Industry
• ...
mtu A Rolls-Royce solution

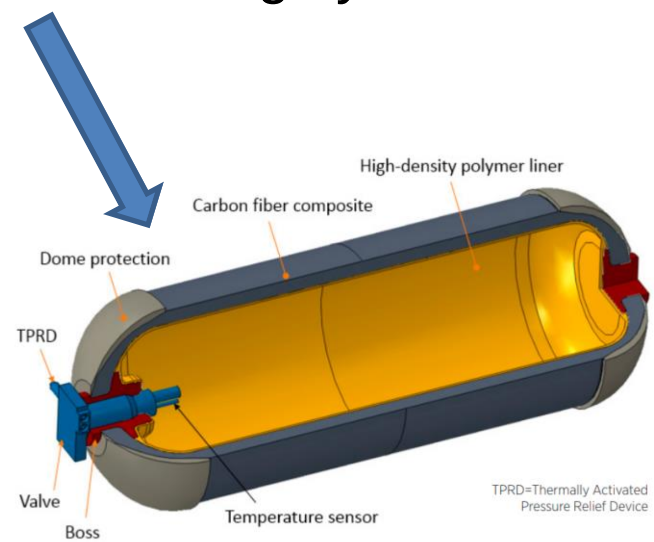
Hydrogen versus Liquid Fossil Fuel

Hydrogen gas has 3 times the specific energy (Wh/kg)

Compressed Hydrogen gas takes 6 times the volume (m^3)

To get the equivalent amount of energy, the tank volume for a hydrogen aircraft needs to be twice the volume.

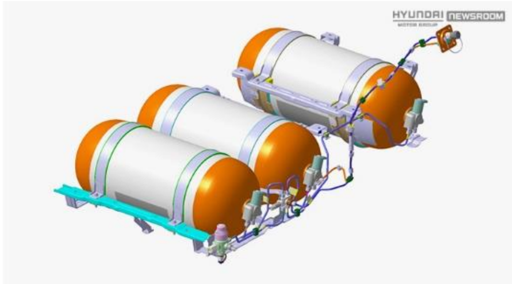
Compressed hydrogen must be stored in a strong cylindrical pressure vessel.

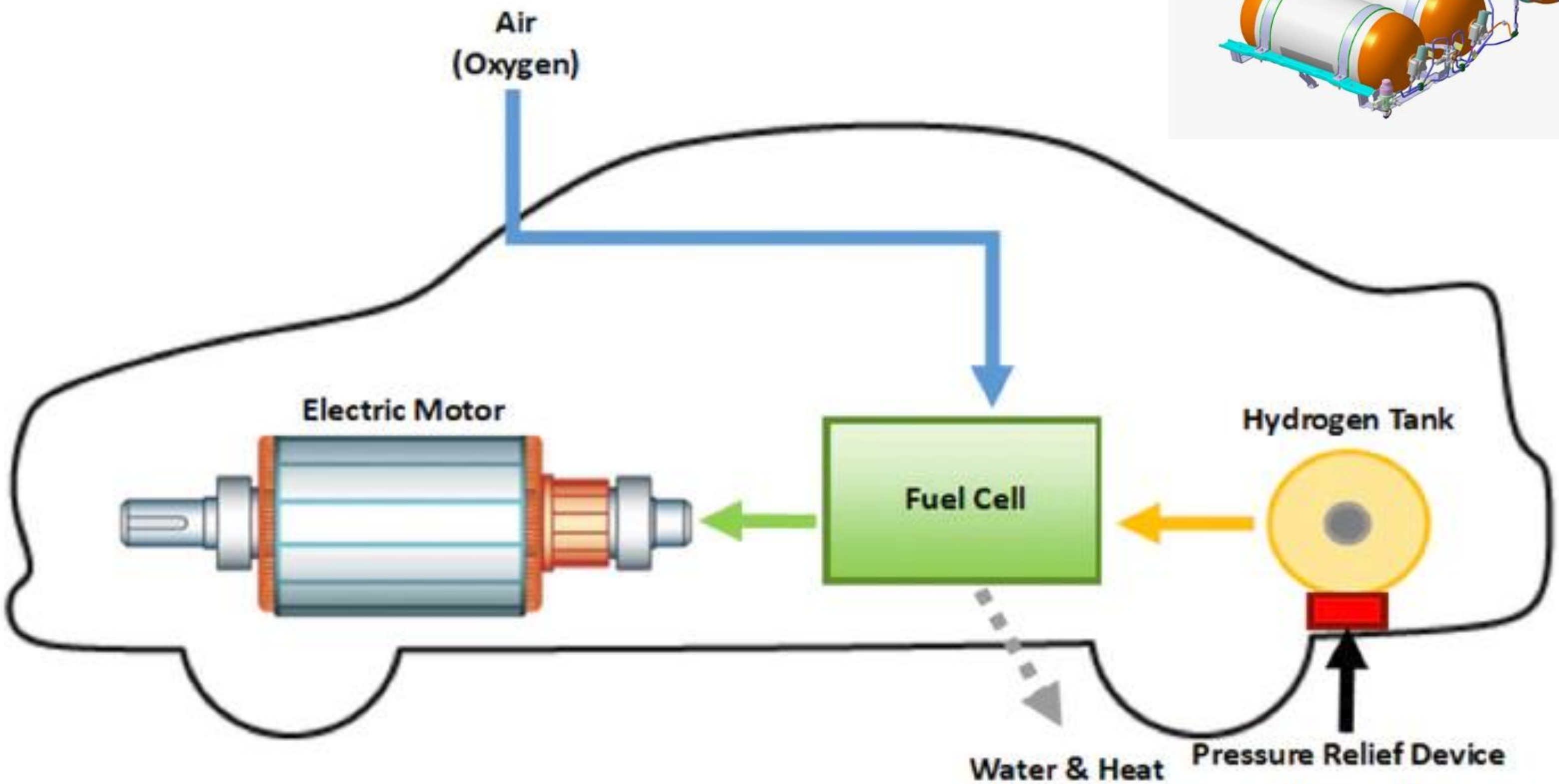


Aircraft wet wing tanks are not suitable for hydrogen

Hydrogen Fuel Cell as Substitute for Battery

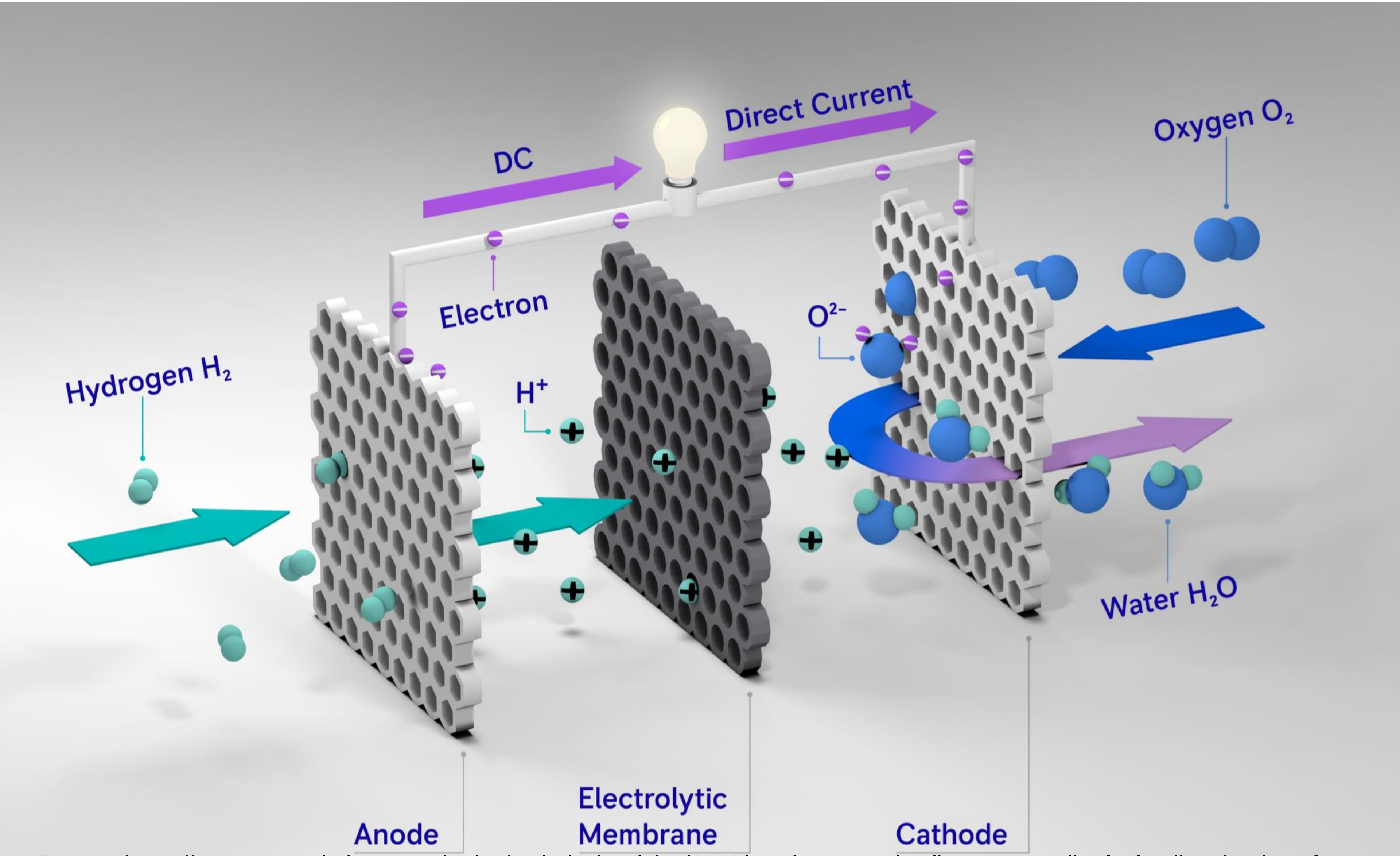
(Here one does not burn hydrogen like a fuel into an engine)





In California hydrogen cost around $16 per kg

Functional Principle for PEM Fuel Cell



Source: https://www.mtu-solutions.com/eu/en/technical-articles/2020/moving-towards-climate-neutrality-fuel-cell-technology-for-future-energy-and-propulsion-systems.html

Three Challenges of Hydrogen Fuel Cells

Source: video from Subject Zero Laboratories

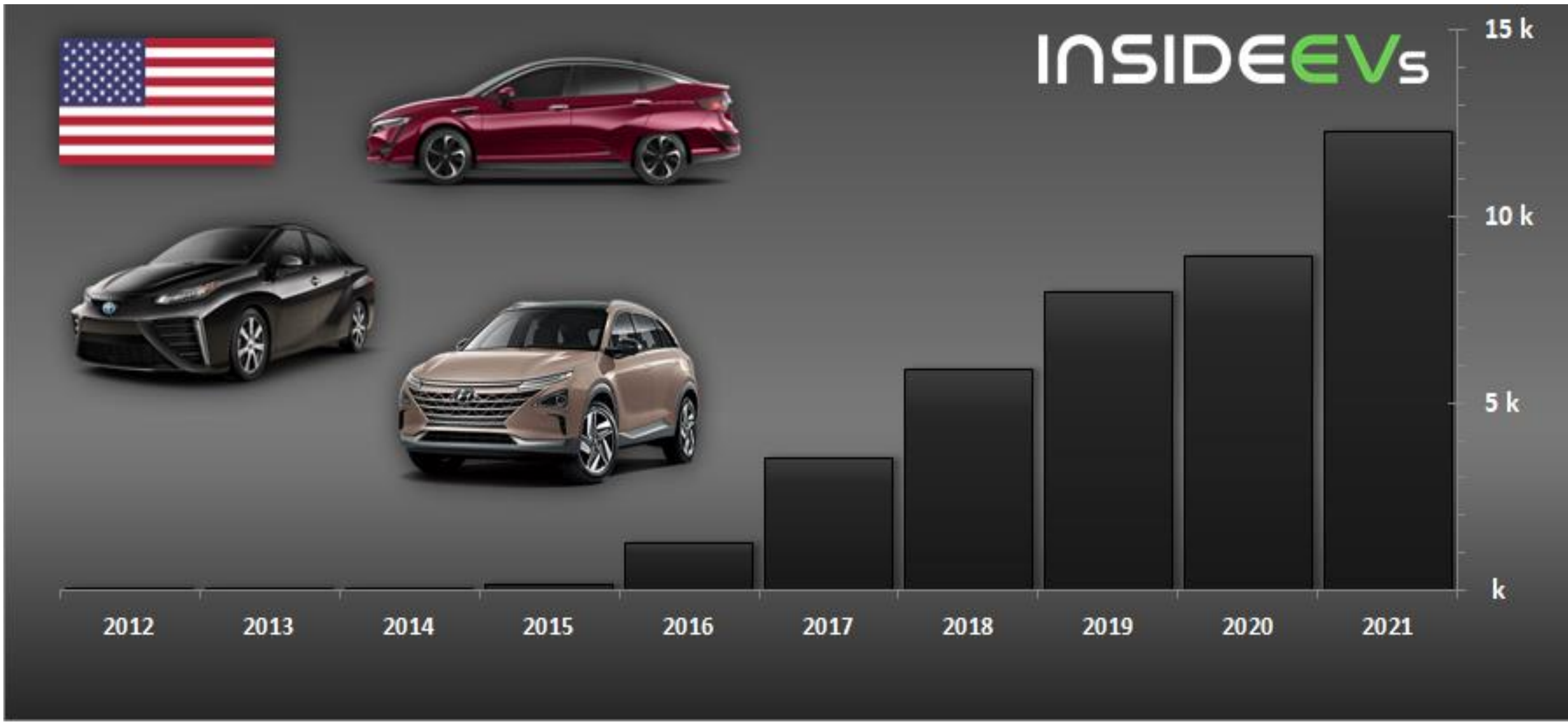
Hydrogen Powered Fuel Cell Cars

5 criterions that determine whether hydrogen cars may succeed or not: Price, convenience, performance, environment, competition.

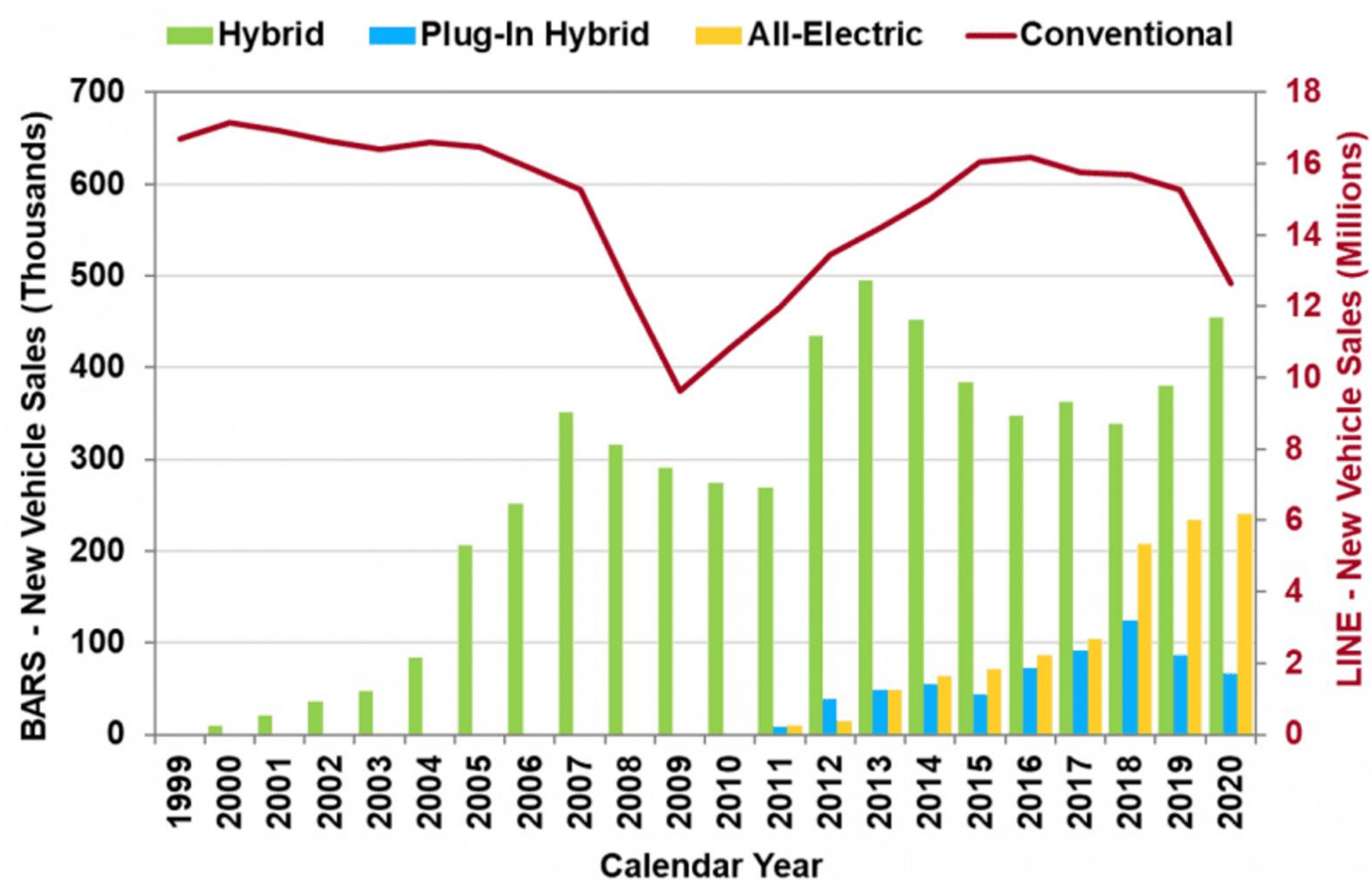
Currently, only 2 hydrogen cars on the market now, Toyota Mirai ($50k) and Hyundai Nexo ($59k). Honda Clarity ($71k) was discontinued at end of 2021 due to high price and poor sale.

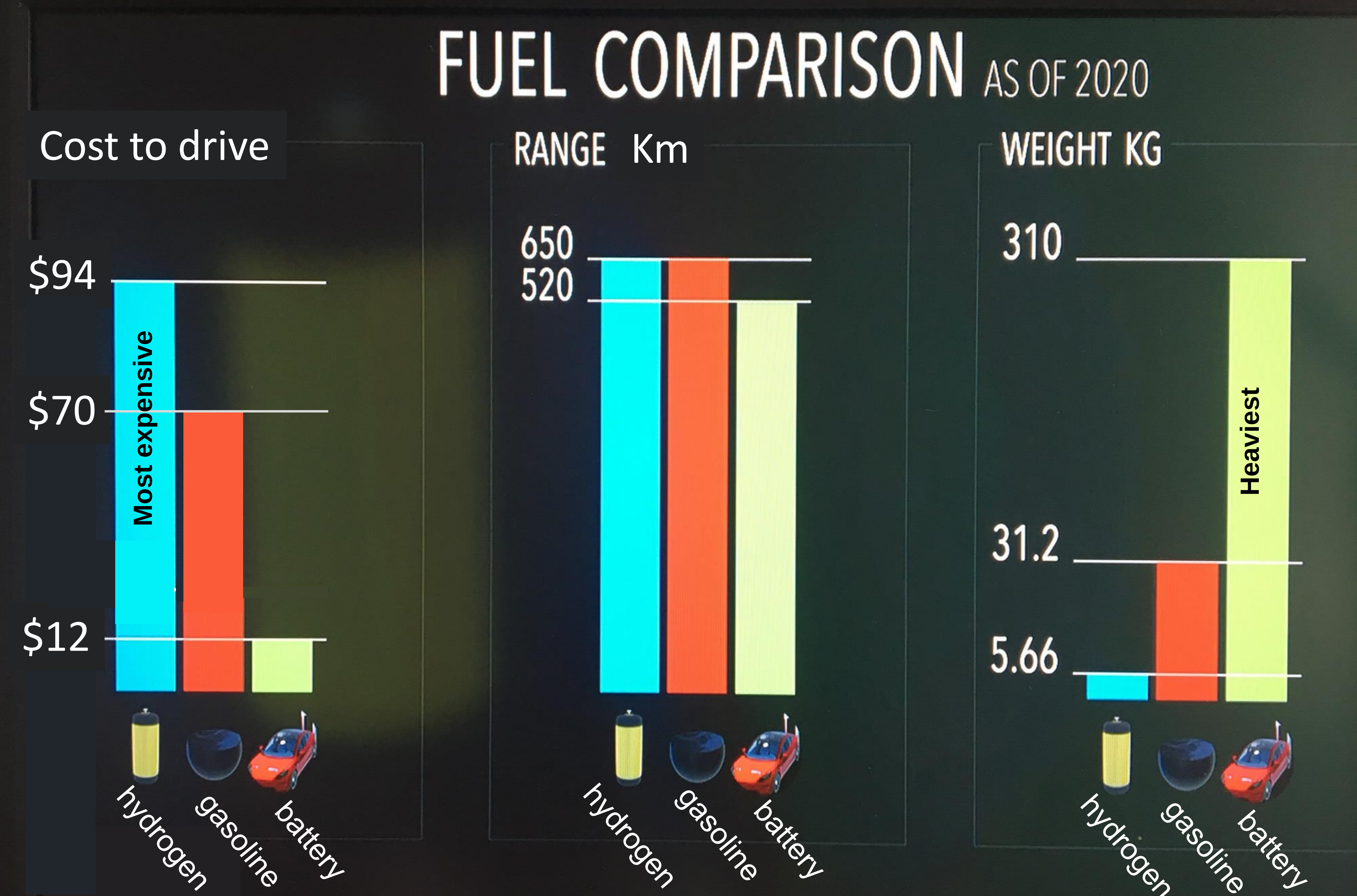
Currently hydrogen is $16/kg in California
Each car can hold 5-6 kg of H_2 and good for 400 miles.
At Dec 2021, only 86 hydrogen refuel stations in USA (60 in CA)

Hydrogen Fuel Cell Vehicle Sales in US, Cumulatively



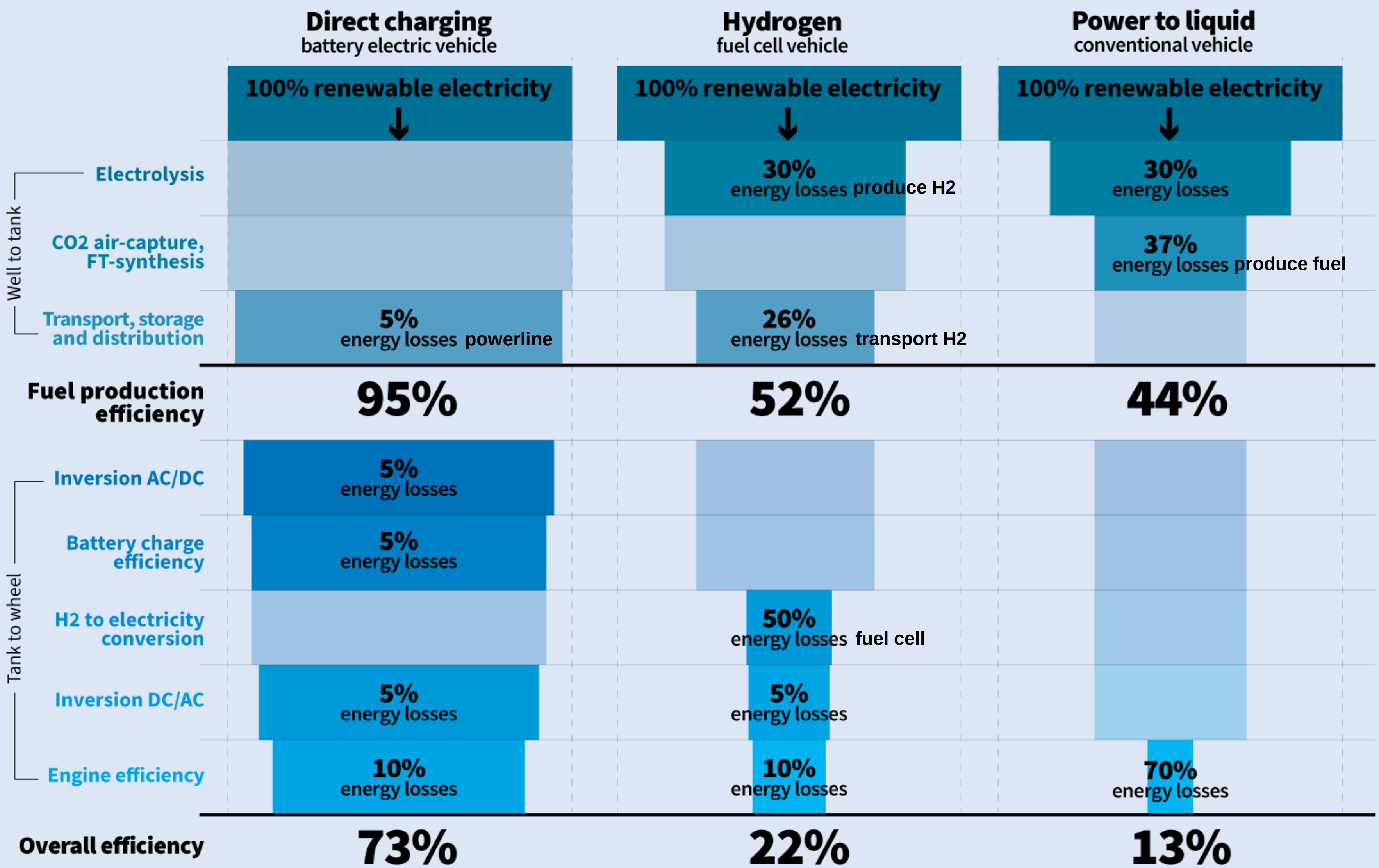
New US Vehicle Sales by Technology Type 1999-2020





Source: from Subject Zero Laboratories

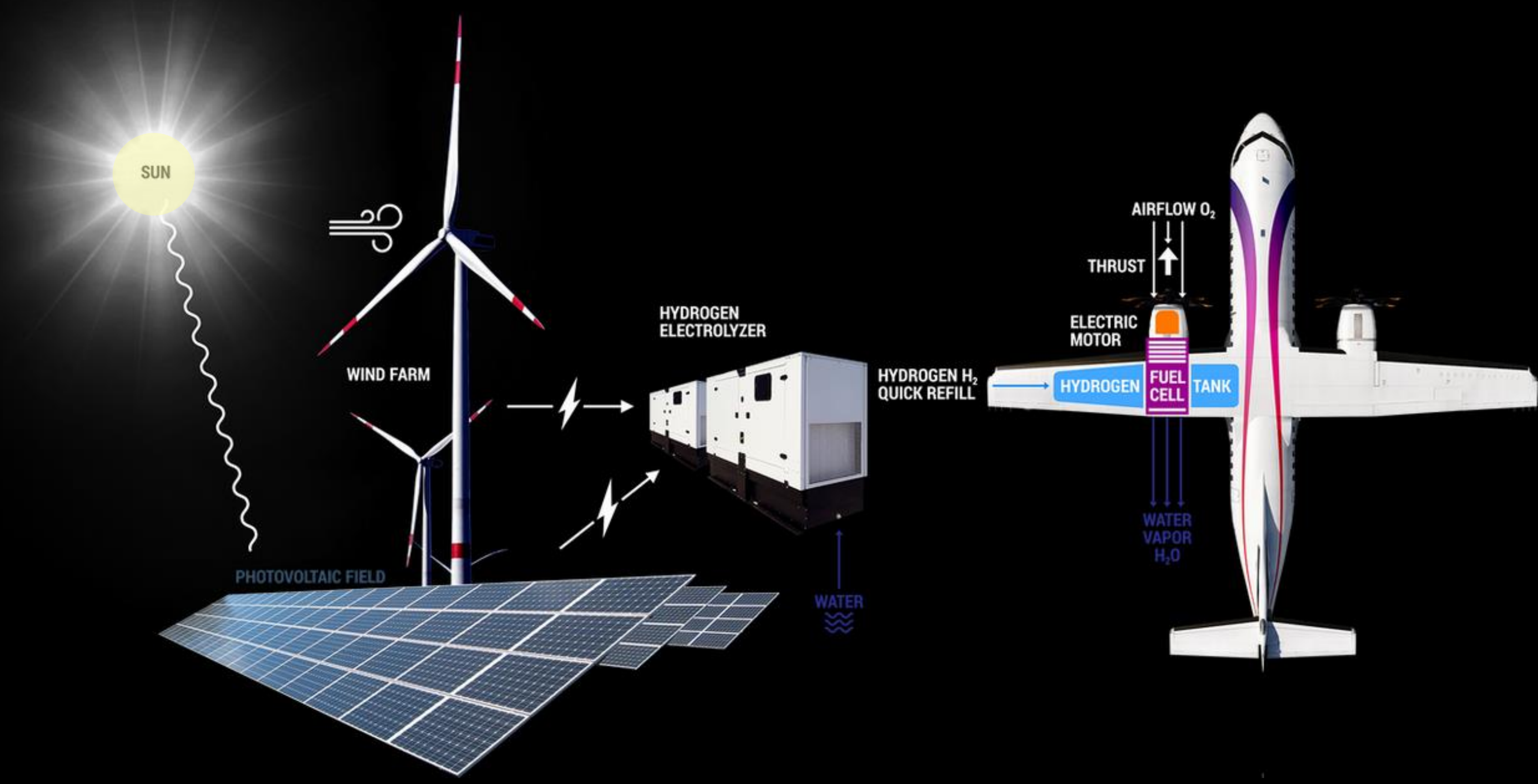
Comparing Well-to-Wheel Efficiency



TRANSPORT & ENVIRONMENT @transenv @transenv transportenvironment.org

Sources: https://www.burchfisher.com/news/how-efficient-are-electric-cars-well-to-wheels
https://www.transportenvironment.org/sites/te/files/publications/Full_%20Roadmap%20freight%20buses%20Europe_2050_FINAL%20VERSION_corrected%20%282%29.pdf

Well-to-Prop Cost for Fuel Cell Electric Aircraft



Source: video from ZeroAvia

Hydrogen Maybe Suited to Larger Aircraft

Airbus ZEROe Concept

Turbofan
Two hybrid hydrogen turbofan engines provide thrust. The liquid hydrogen storage and distribution system is located behind the rear pressure bulkhead.

Turboprop
Two hybrid hydrogen turboprop engines, which drive the six bladed propellers, provide thrust.

Blended-Wing Body (BWB)
The exceptionally wide interior opens up multiple options for hydrogen storage and distribution. Here, the liquid hydrogen storage tanks are stored underneath the wings. Two hybrid hydrogen turbofan engines provide thrust.

Source: announcement by Airbus on September 2020

Introducing Airbus ZEROe

Maybe entering service by 2035

Source: announcement by Airbus on September 2020

Use hydrogen as fuel <u>or</u> in fuel cells may have much higher Specific Energy than lithium batteries, but

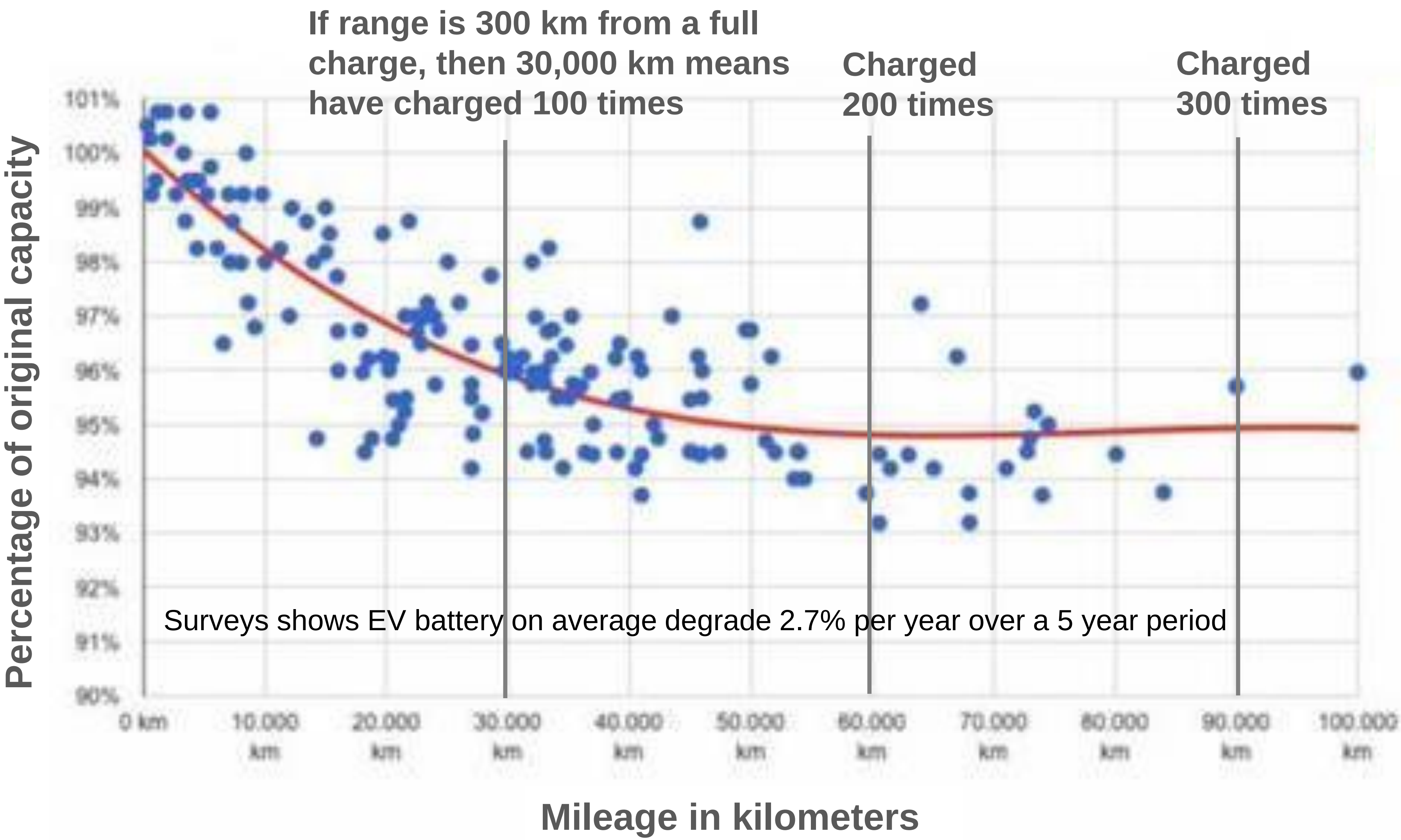
- **fuel cells' specific power is lower**
- **the more electric power supplied from fuel cells, the more heat generated**
- **in cold weather temperature, have to warm up the fuel cell stacks first**
- **expensive to manufacture due the high cost of catalysts (platinum)**
- **fuel cells technology still being refine**
- **difficult to economically manufacture hydrogen at local charging stations**
- **lack of infrastructure to support the distribution of hydrogen to charging stations. Extremely difficult to get hydrogen to roof top vertiports**

Use hydrogen as fuel or in fuel cells may have much higher Specific Energy than lithium batteries, but

- can lose hydrogen in storage just due to “boiloff”
- NASA requires 30 meters safety zone for fueling hydrogen
- Helen Leadbetter of UK ATI says takes 175 minutes to fill the hydrogen tank for a regional aircraft
- not practical to do produce hydrogen at local airport or vertiport because it takes megawatts to do electrolysis
- purity of hydrogen is also an issue, hard to get aerospace grade H2
- hydrogen fire can be difficult to see in day light
- Double the aircraft hydrogen tank size can double the range

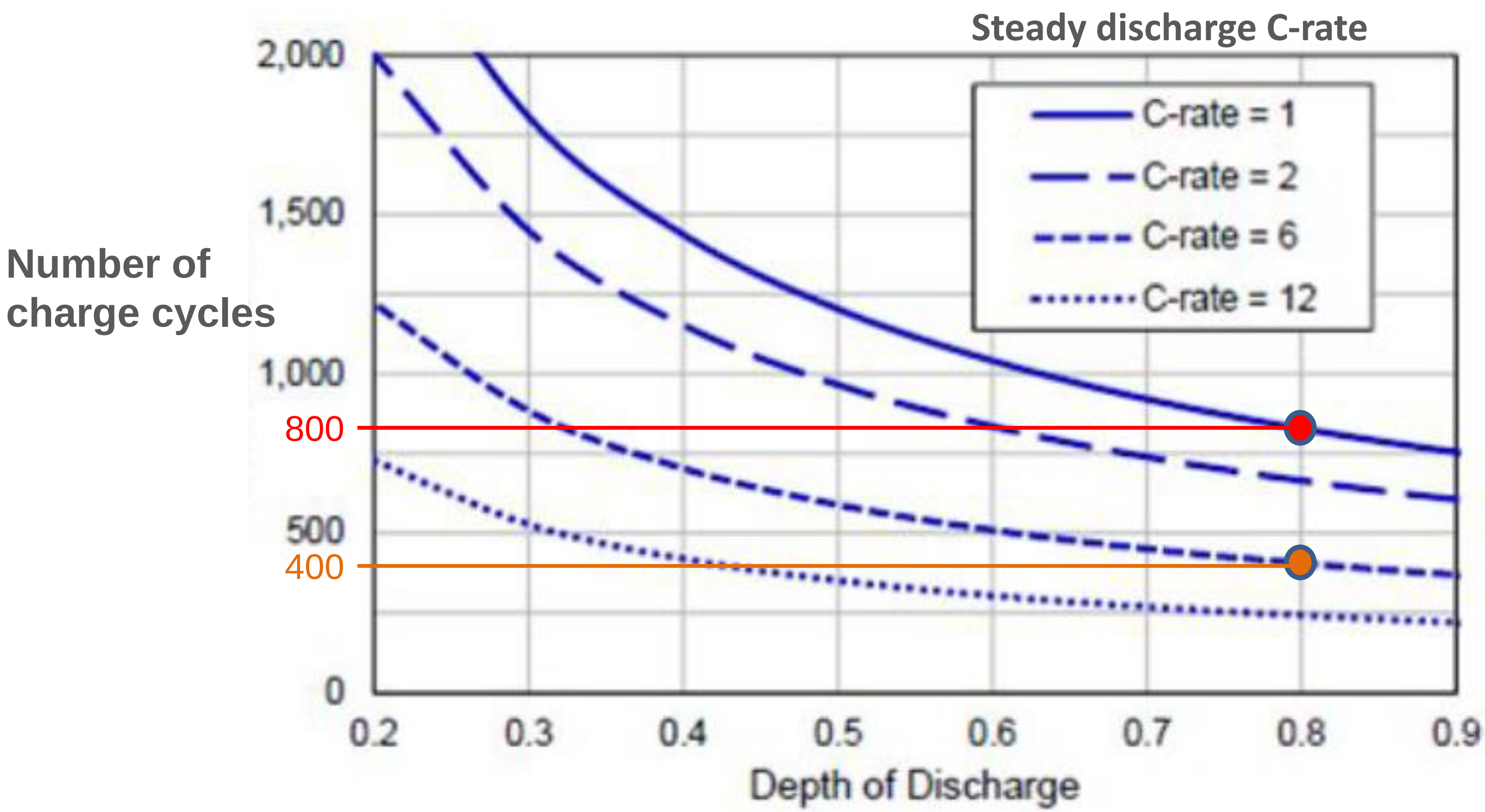
Battery Life

Lithium Battery Capacity Degrades Over Time



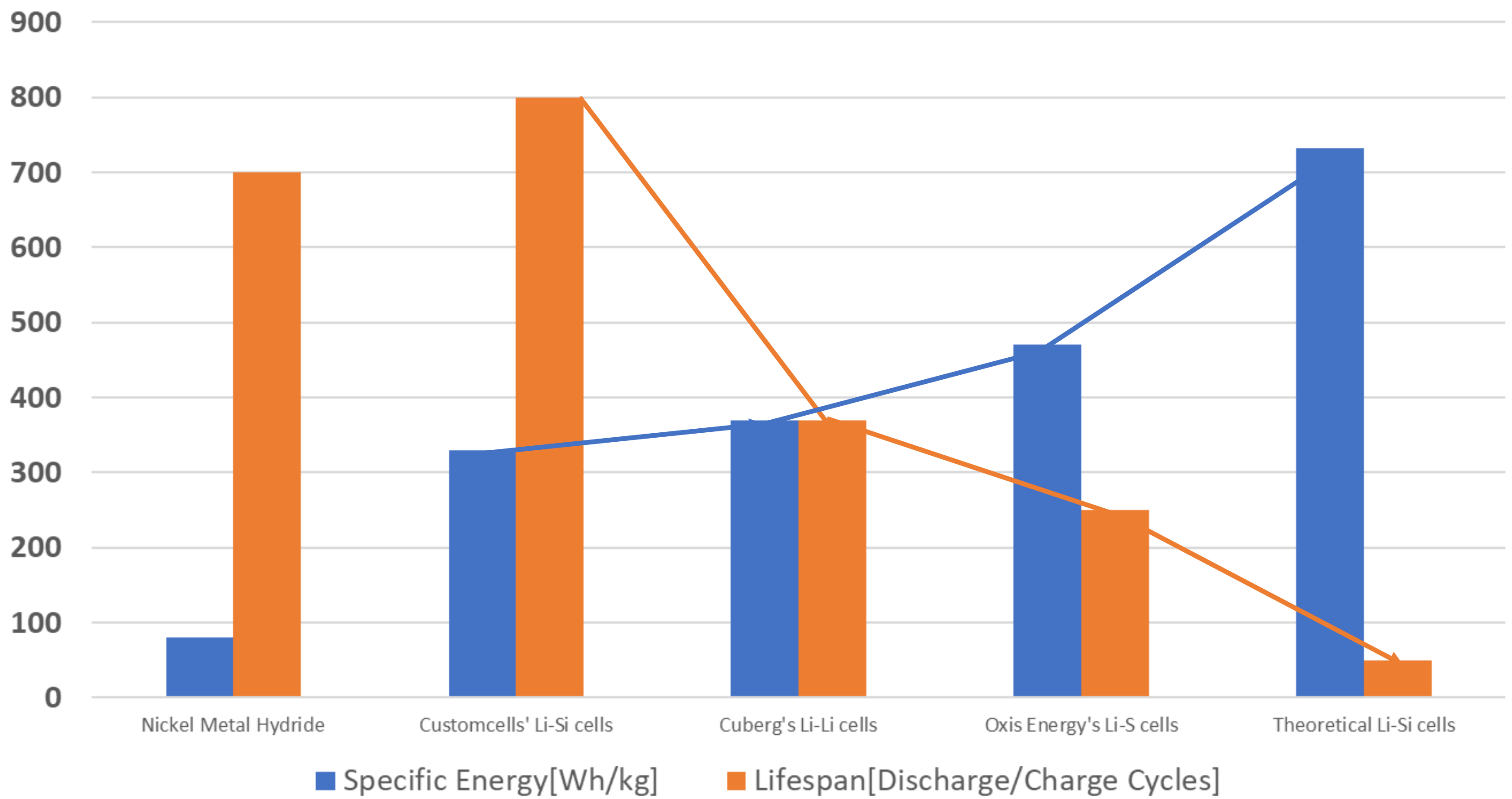
Note, it is very bad for lithium batteries to run them completely empty and then charge. Should not run them beyond 80% depth of discharge.

Effect of Discharge Rate on Charge Cycles



1.Scott, R.C.., Vegh., J.M., "Progress Toward a New Conceptual Assessment Tool for Aircraft Cost," 76th Annual Vertical Flight Society Forum, 2020.
2.Liu, Z., Tan, C., Leng, F.,"A Reliability-Based Design Concept for Lithium-Ion Battery Pack in Electric Vehicles," Reliability Engineering & System Safety, vol. 134, pp. 169-177, 2015.
3.Singh, P., Chen, C., Tan, C. & Huang S., "Semi-Empirical Capacity Fading Model for SoH Estimation of Li-Ion Batteries," Applied Sciences, vol. 9, 2019.
4.Zhou, C., Qian, K., Allan, M., Zhou, W. "Modeling of the Cost of EV Battery Wear Due to V2G Application in Power Systems," IEEE Transactions on Energy Conversion, vol. 26, no. 4, pp. 1041-1050, Dec. 2011.
5. Vegh., J. M., "VFS Short Course on Introduction to Practical Cost Estimating Methods for VTOL" June 2021

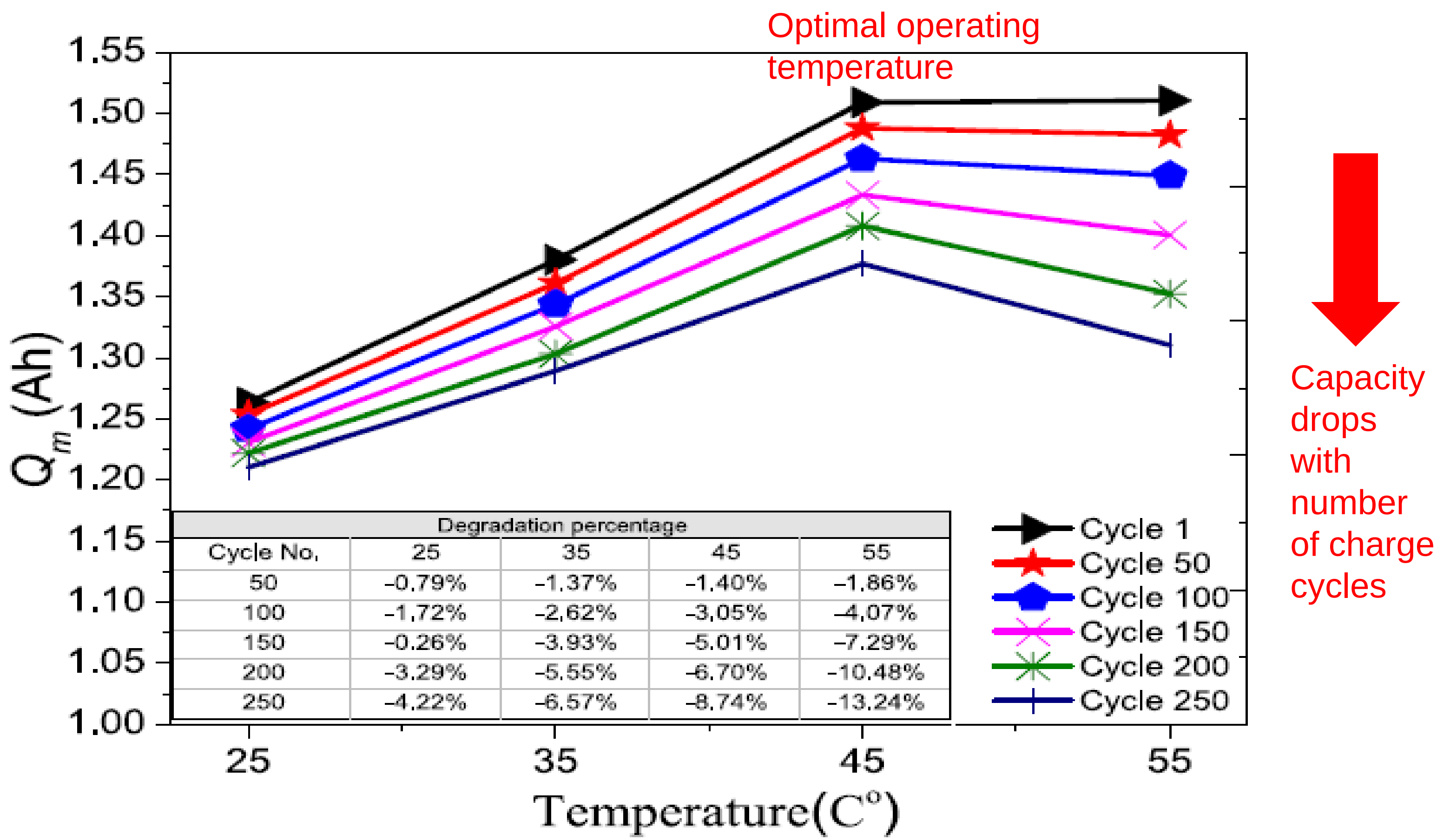
Higher Specific Energy -> Fewer Charge Cycles



Today's lithium cells may last hundreds of full cycle charges if they are treated gently.

For now, do not count on them to last over 400 charges for eVTOL usage.

Maximum Charge Storage Capacity as a Function of Cell Operating Temperature

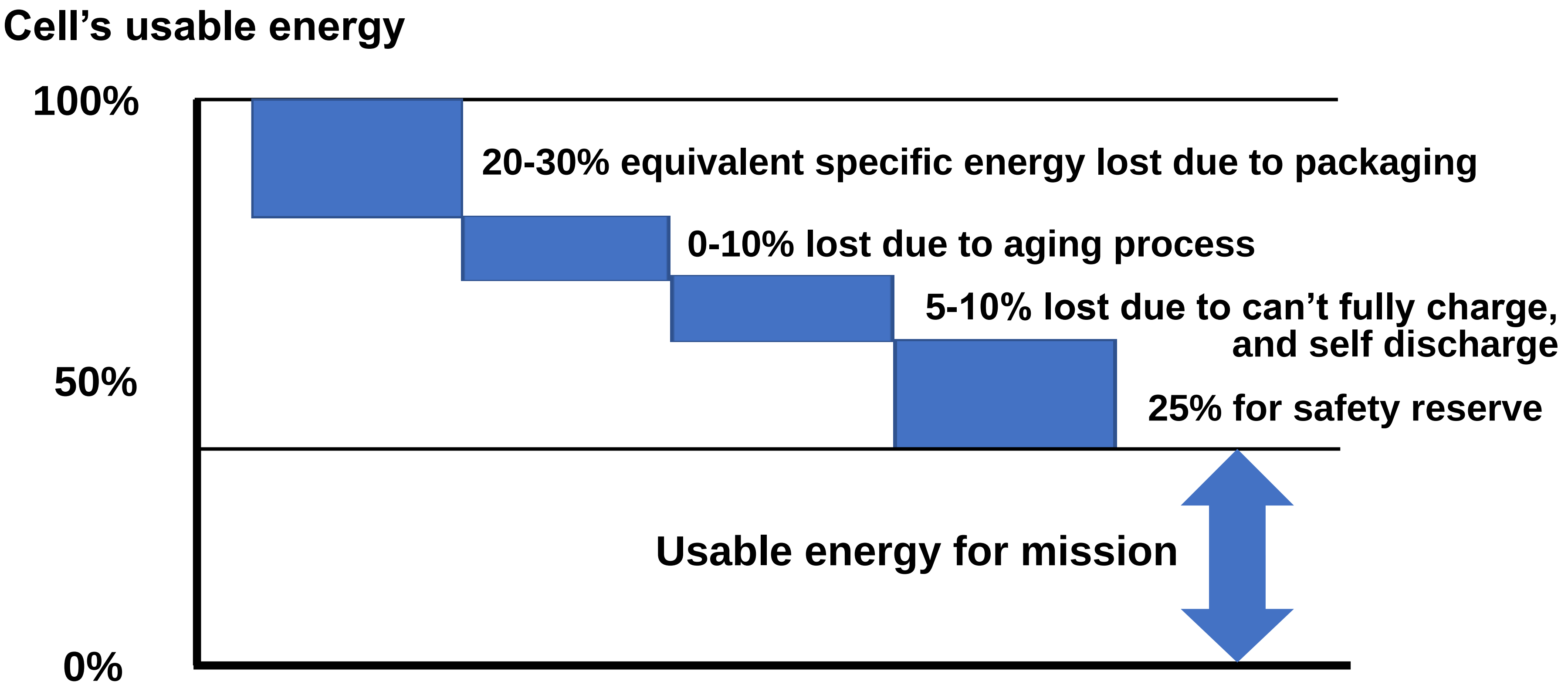


Cycle No.	25	35	45	55
50	-0.79%	-1.37%	-1.40%	-1.86%
100	-1.72%	-2.62%	-3.05%	-4.07%
150	-0.26%	-3.93%	-5.01%	-7.29%
200	-3.29%	-5.55%	-6.70%	-10.48%
250	-4.22%	-6.57%	-8.74%	-13.24%

Q_m is the initial maximum charge stored in lithium-ion cell, it's measured in amp-hours. Above shows at higher operating temperature, the cell will lose more capacity with charge cycles.

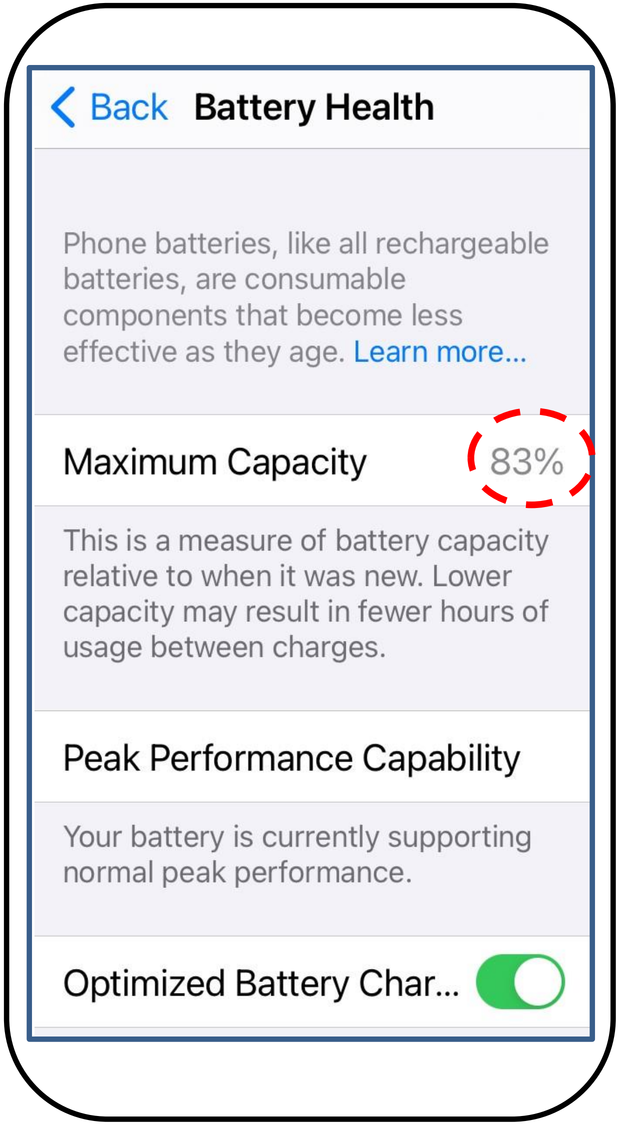
Source: Leng, F., Tan, C. & Pecht, M. Effect of Temperature on the Aging rate of Li Ion Battery Operating above Room Temperature. Sci Rep 5, 12967 (2015). https://doi.org/10.1038/srep12967

Real Usable Capacity From a Lithium Cell



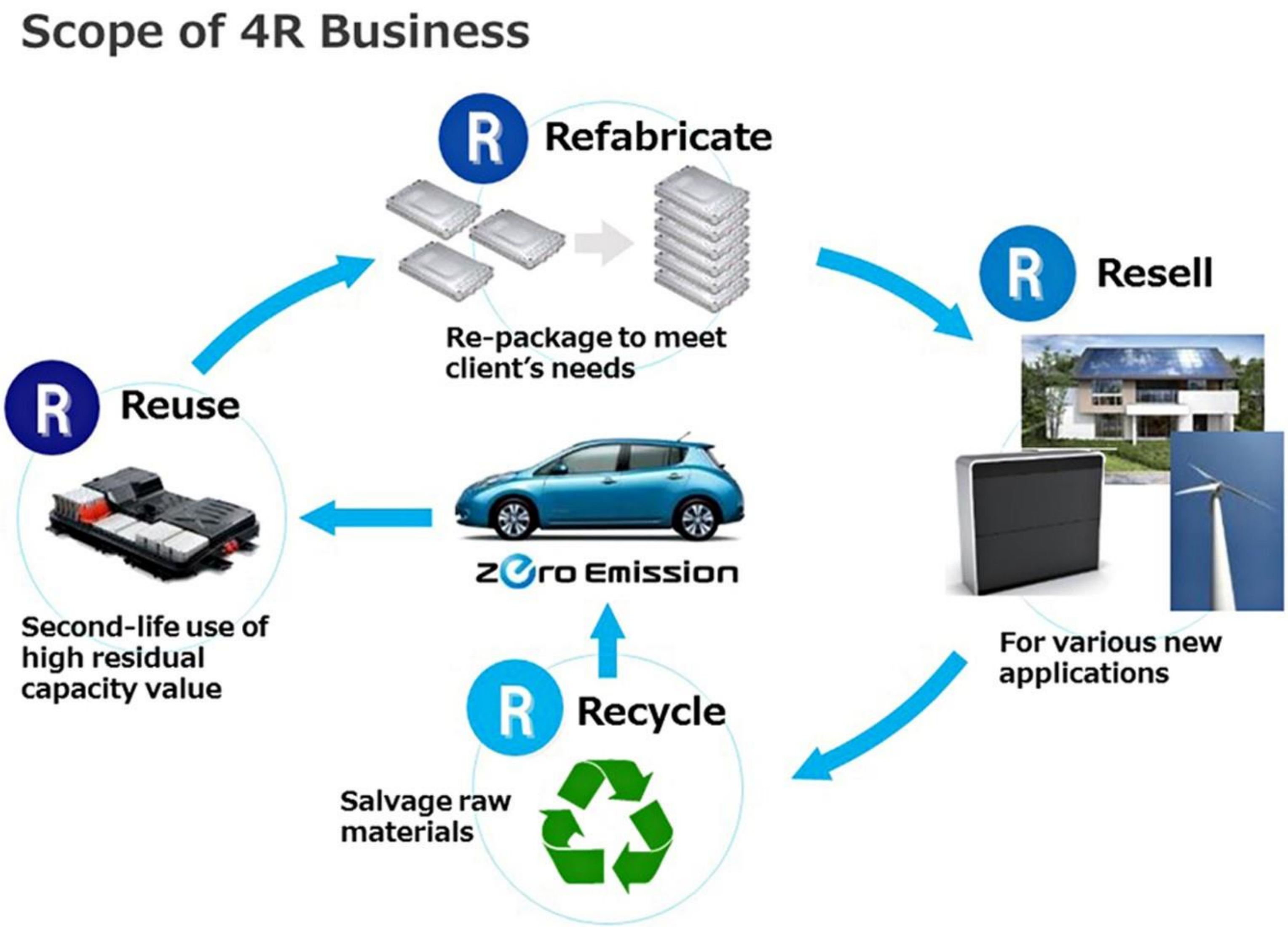
When a company goes for an aircraft endurance or speed record, they use good batteries !

When to Retire the Battery?



- As battery ages, its internal impedance goes up, hence, the ability to deliver peak power goes down, that can become dangerous,
- its maximum capacity will drop.
- In iPhones you can see the battery health. When it gets to 83%, the iPhone just does not last a day of use.
- For EV, the car is still drivable when battery health goes down to 75%
- For eVTOLs, should replace the battery when the health reaches 90%.

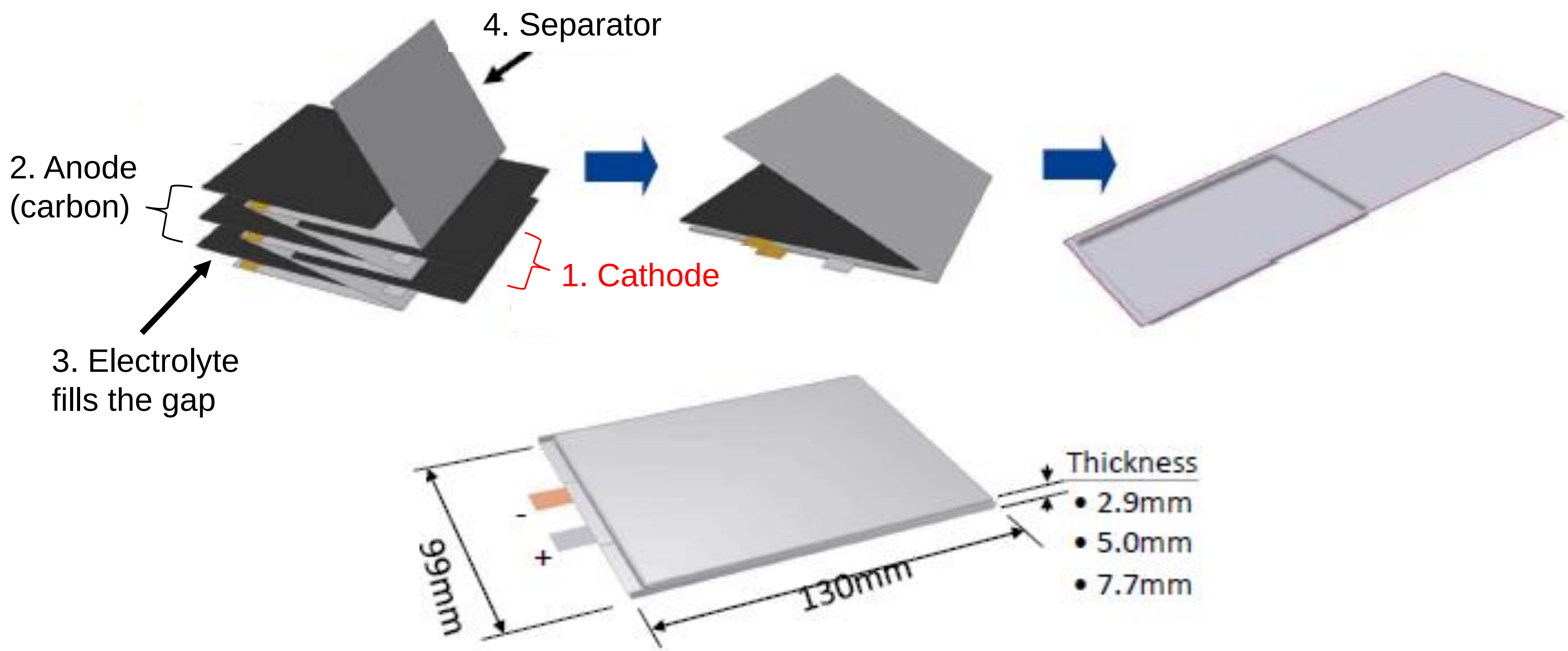
What to do with Retired Batteries?



Beta Technologies Uses Second Life Batteries for Vertiport

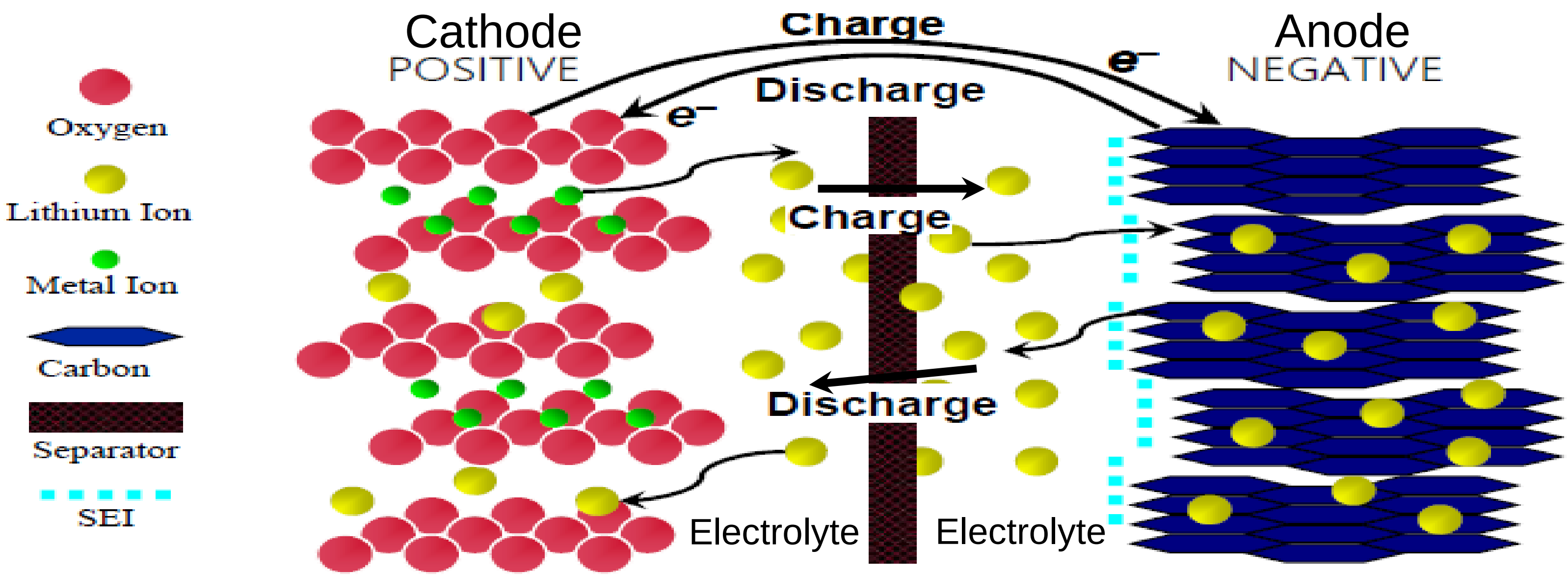
Battery Construction and Safety

Four Major Components of a Lithium Cell



1. Lithium oxide is used for the cathode as the active material.
2. When charged, lithium ions are moved to and stored in the anode.
3. The electrolyte is composed of salts, solvents and additives. Electrolyte has high ionic conductivity, is mainly used so that lithium ions can move back and forth easily.
4. Separator functions as a physical barrier keeping cathode and anode apart. It prevents the direct flow of electrons and it lets only ions pass through the microscopic hole. Separators are made from polyethylene (PE) and polypropylene (PP)

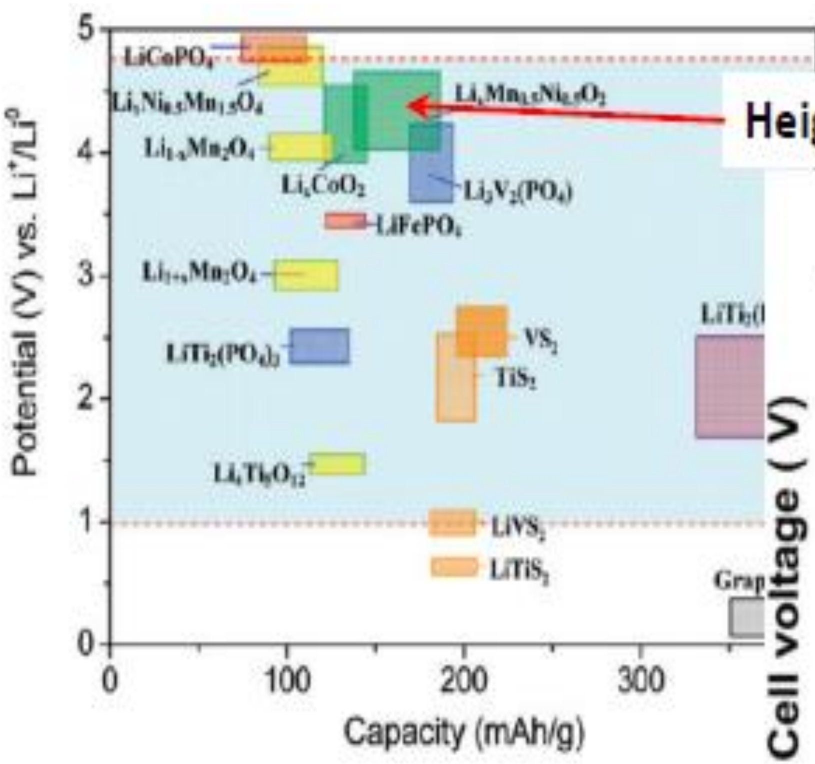
Internal Dynamics of a Lithium Cell



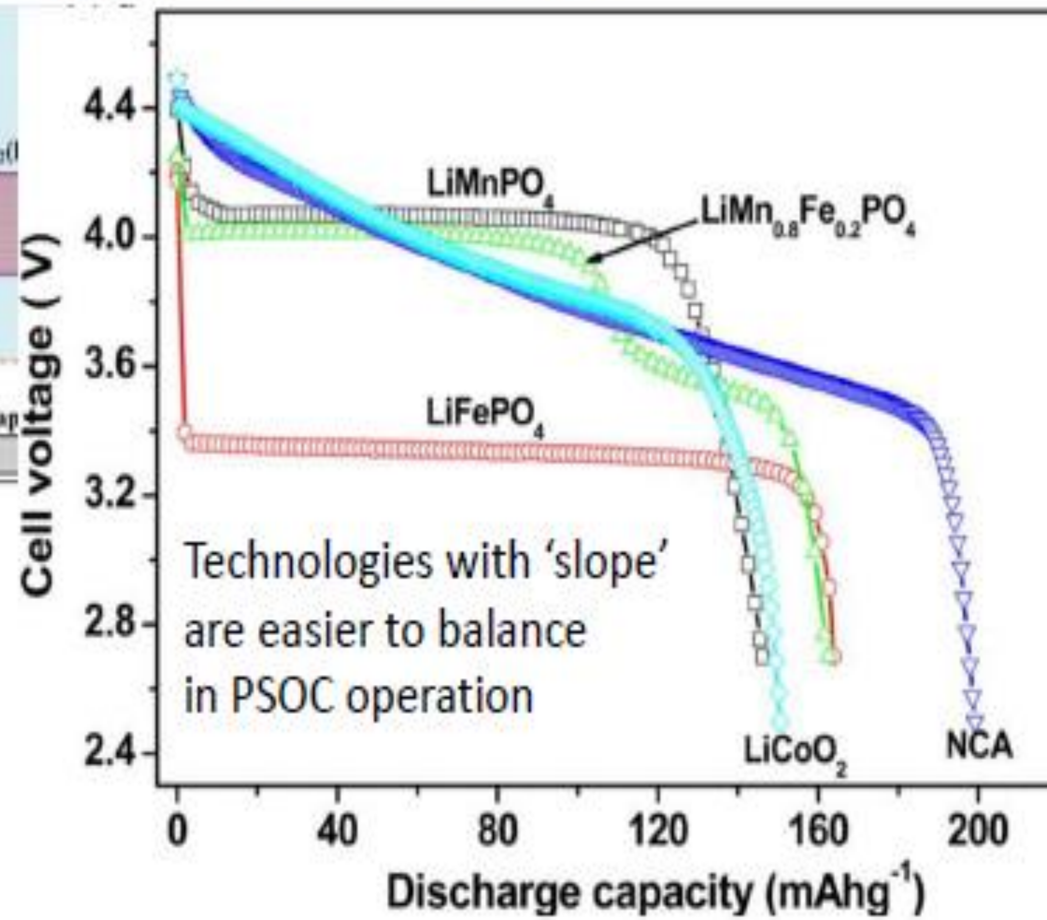
- A Lithium-ion battery generates electricity through chemical reactions of lithium.
- Lithium oxide (lithium + oxygen) is used for the cathode as the active material.
- When charged, lithium ions are moved to and stored in the anode.
- During discharge the lithium ions flow back to the cathode through the electrolyte and the negatively charged electrons e- flow through the wire.
- The electrolyte is composed of salts, solvents and additives. Electrolyte has high ionic conductivity, is mainly used so that lithium ions can move back and forth easily.
- Separator functions as a physical barrier keeping cathode and anode apart. It prevents the direct flow of electrons and it lets only ions pass through the microscopic hole.
- Cathode and anode determine the basic performance of a battery, electrolyte and separator determine the safety of a battery.

Sources: Jim Mocdowall and Samsung how lithium cell works:
https://www.samsungsdi.com/column/technology/detail/55272.html?pageIndex=1&idx=55272&brdCode=001&listType=list&searchKeyword=

Starting Voltage and Discharge Rate



Height of block indicates 'slope'

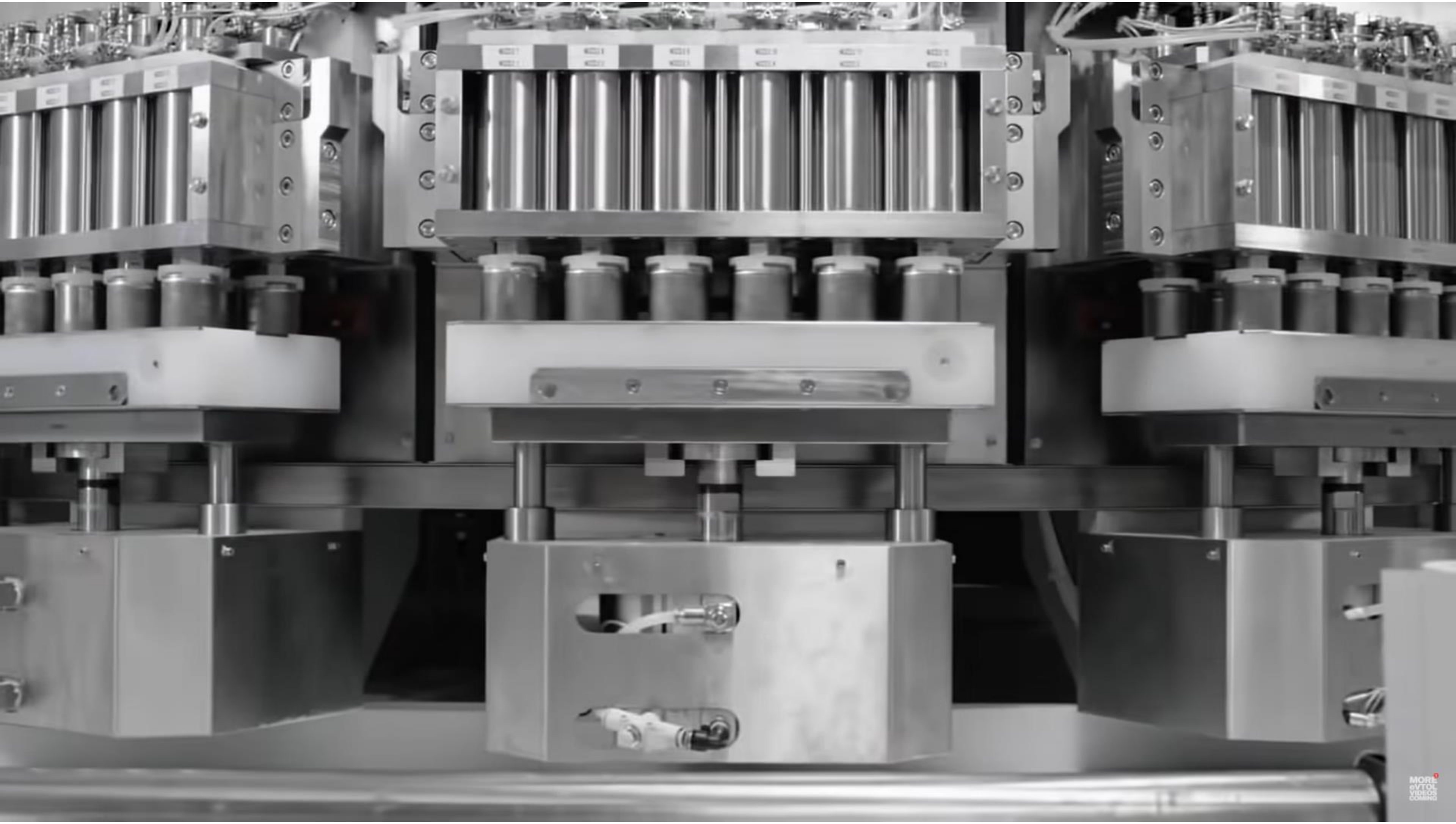


Technologies with 'slope' are easier to balance in PSOC operation

PSOC: Partial State of Charge

Source: Jim Mocdowall

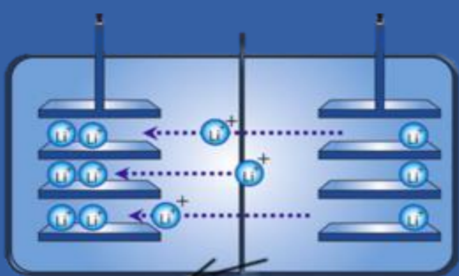
Cylindrical Lithium Cell Manufacturing

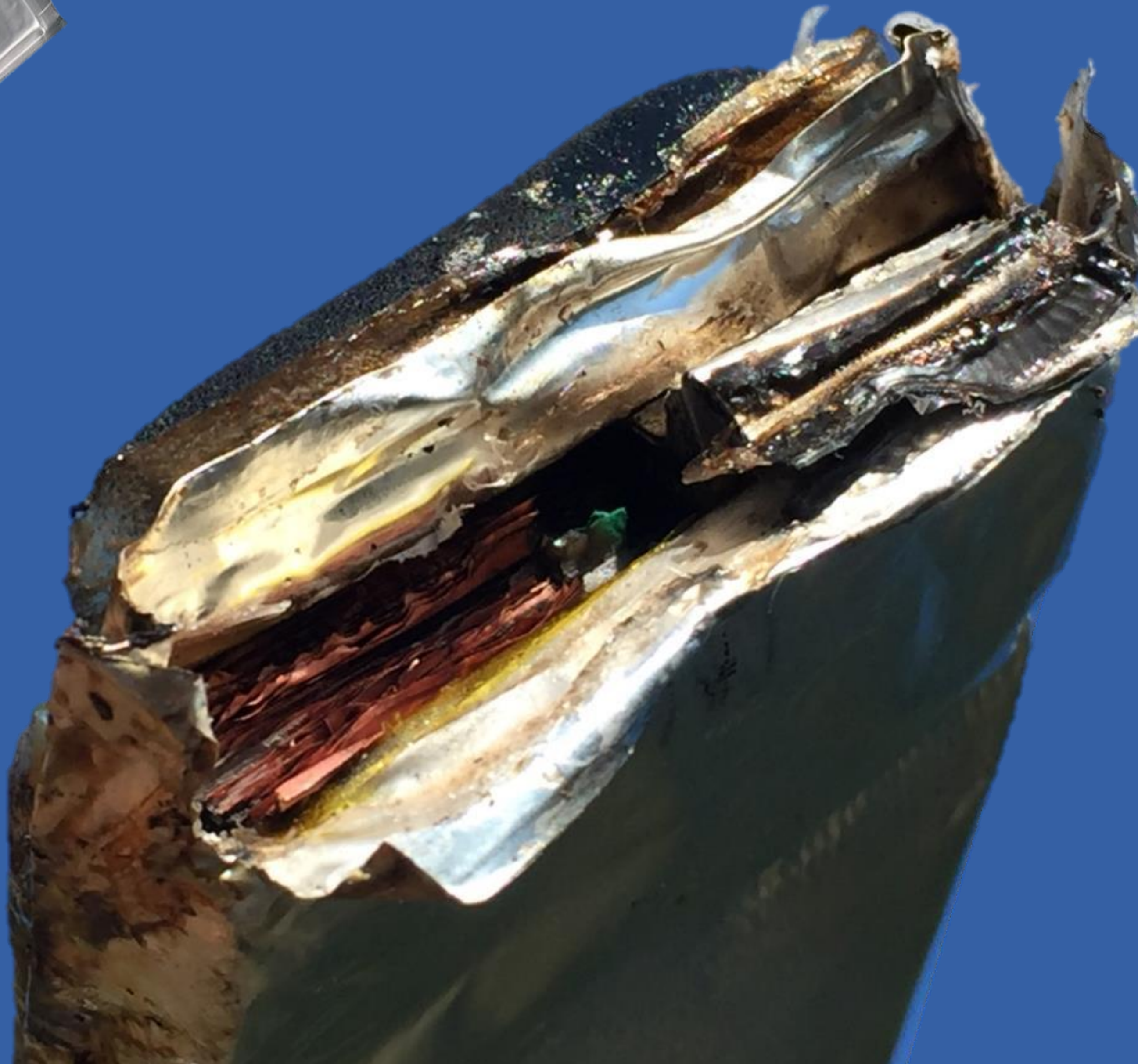


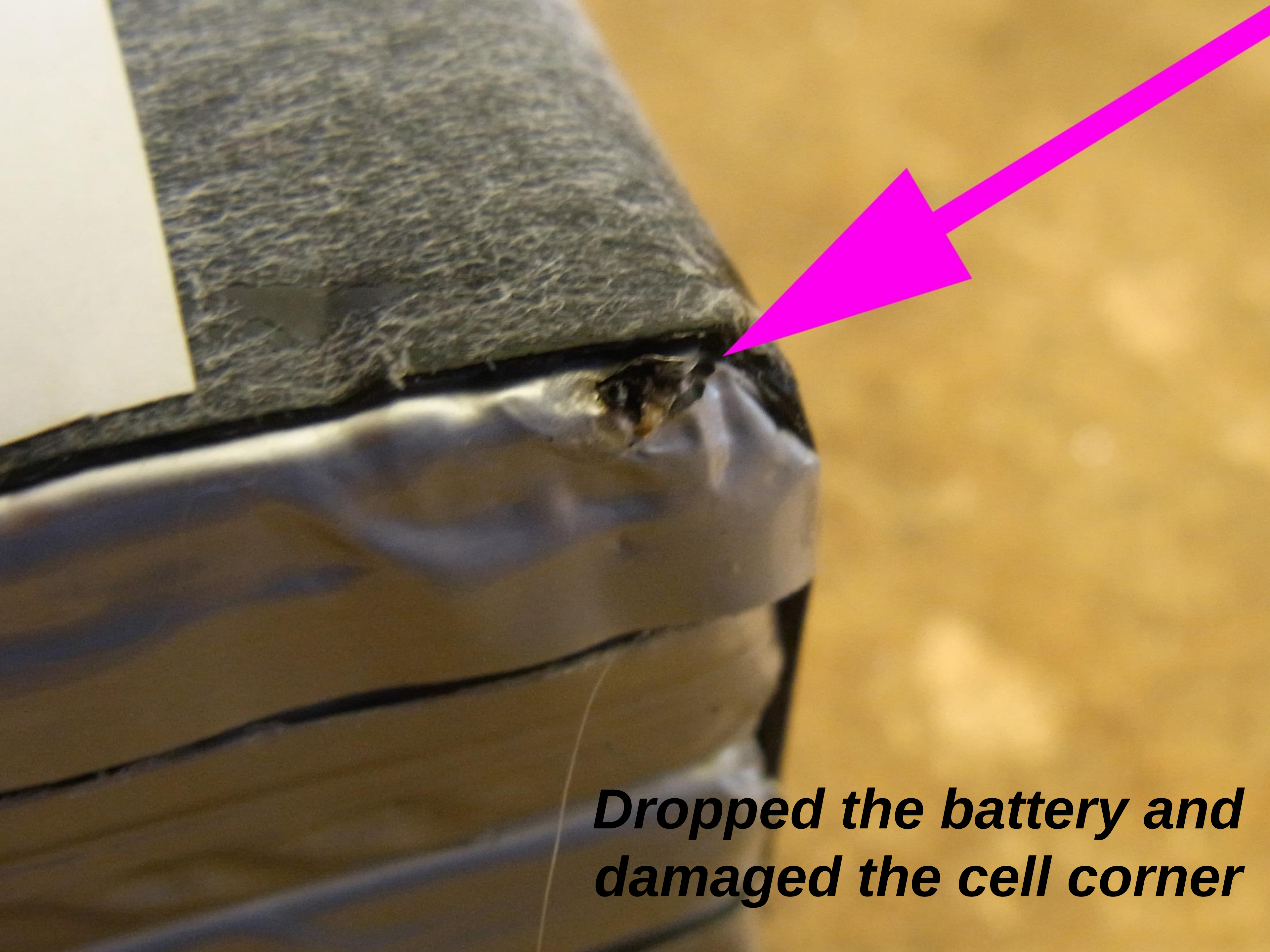
Cylindrical Lithium Cell Manufacturing

Example of a
good 5S pack

Example of a damaged 6S pack

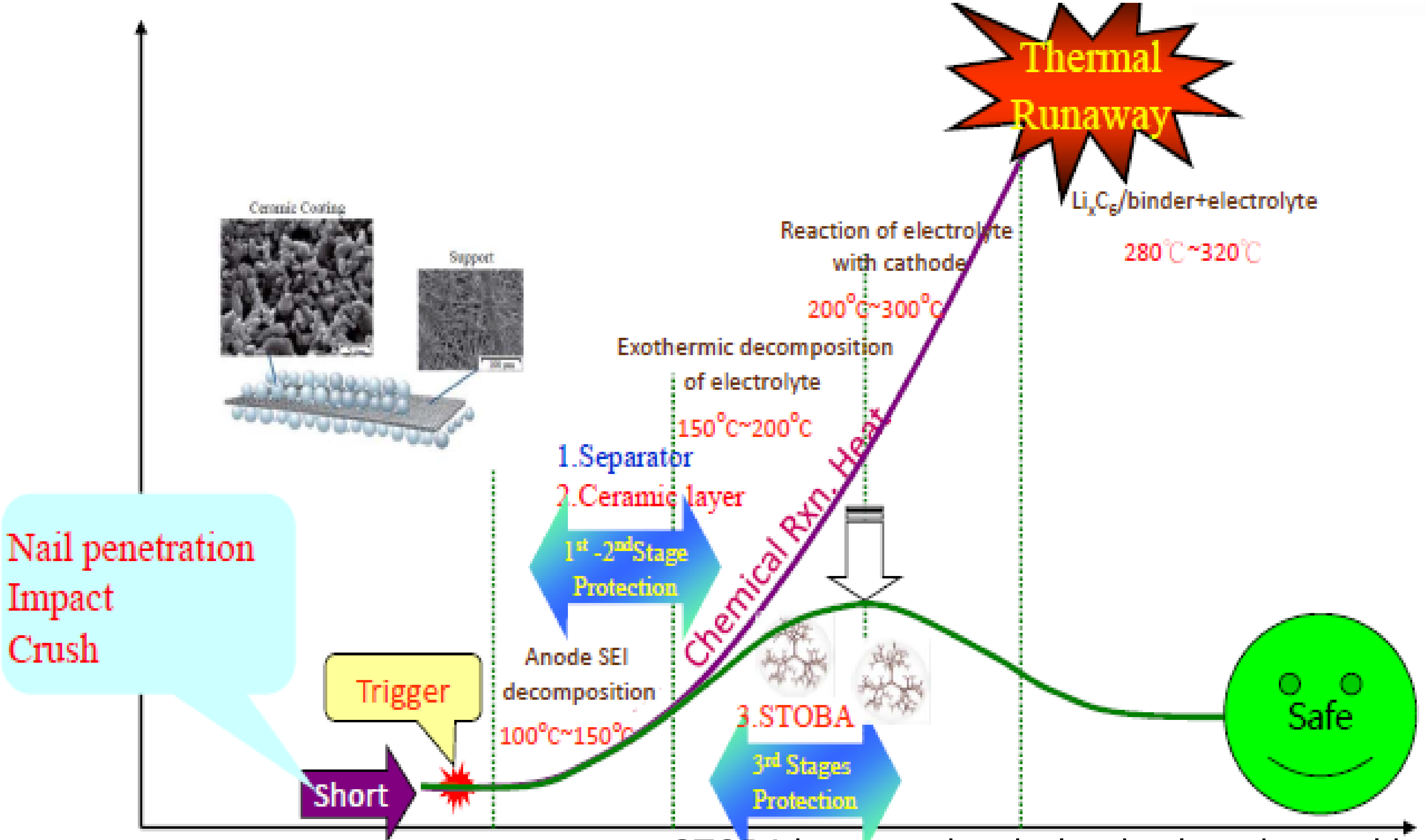





Dropped the battery and
damaged the cell corner

Torn Open and Charred Cell

Thermo Runaway is When the Internal Temperature of a Lithium Cell > 150ºC



STOBA is a new chemical technology that could help prevent thermal runaway

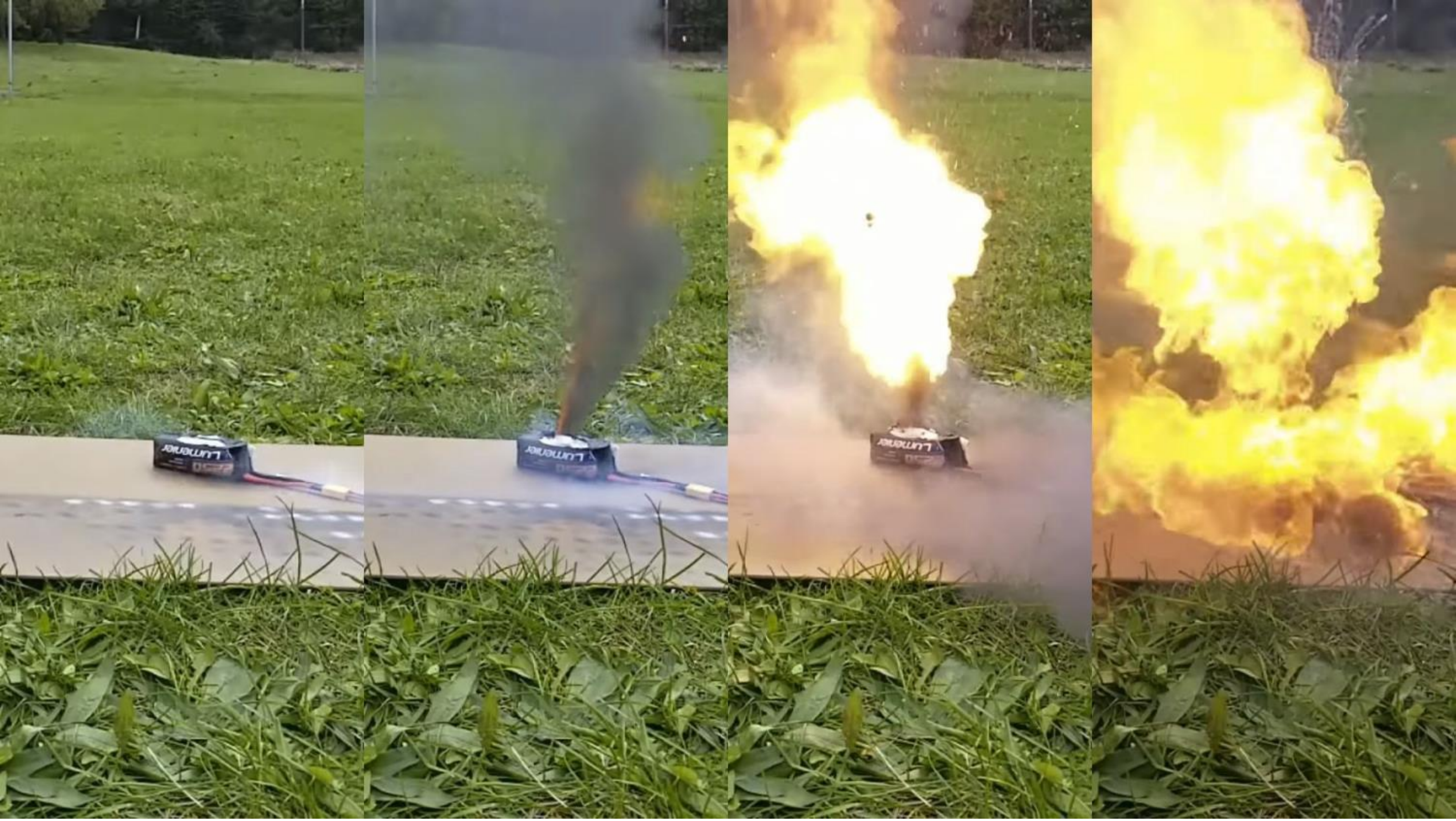
Example of a damaged pack due to sustained high current drain. Internal heat caused a single cell burst but did not reach thermo runaway to cause a fire.

Lithium Fires Are Almost Impossible to Stop


A Crash Can Cause Battery to Ignite

Fire Can Happen During Charging

Spontaneous Fire Destroyed Buses in 20 Min



There are manufacturers making lithium pouch for fire containment, but they are too heavy for flight. They are useful for charging and putting out fire.

Fire Protection Bags and Covers

Common Tests for Lithium Batteries

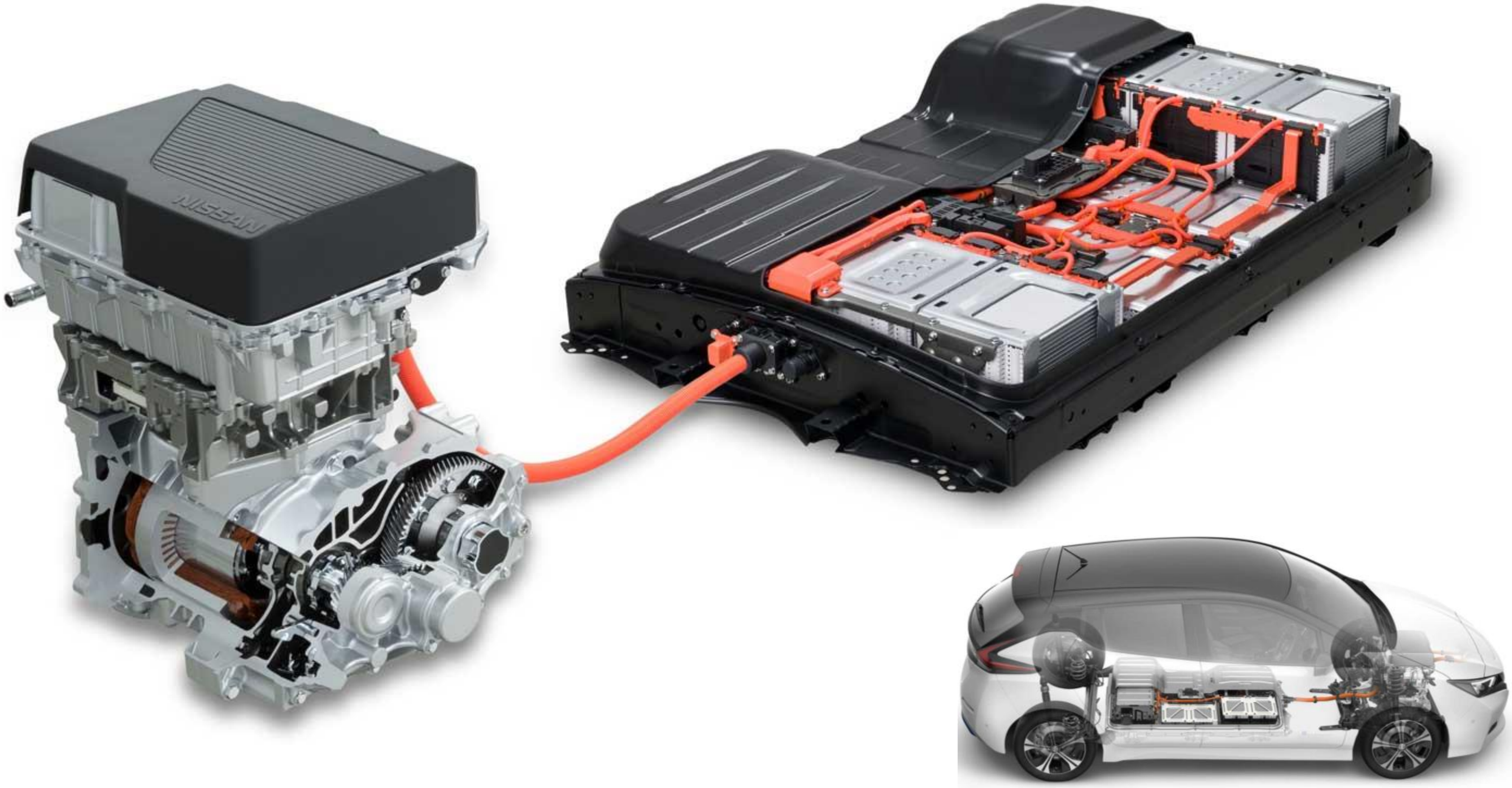
- **Heating**
- **Cold temperture**
- **Impact**
- **Crush**
- **Short circuit**
- **Nail penetration**
- **Corner cut**
- **Abnormal charging and discharging**
- **Extremely high current draw**
- **Deep discharge**

JW Rule of Thumb for Using Lithium Battery

1. Higher C capable cells are heavier.
2. If you need to discharge at 5C then buy 10C cells.
3. Not all manufacturers are equal !!
4. Discharging at higher C reduces cell life.
5. Do not discharge to below 20% of capacity.
6. Charging at higher C reduces battery life. <2C is best now
7. Best store the cells at around only 50% fully charged.
8. Always balance the cells while charging.
9. Cell capacity and voltage will degrade with use.
10. Do not physically damage the cell.
11. Do not use the cells if they are damaged or impaired.
12. Always prepare a way to put out battery fire in emergency.

Battery for Electric Cars

Battery Pack in Nissan Electric Car

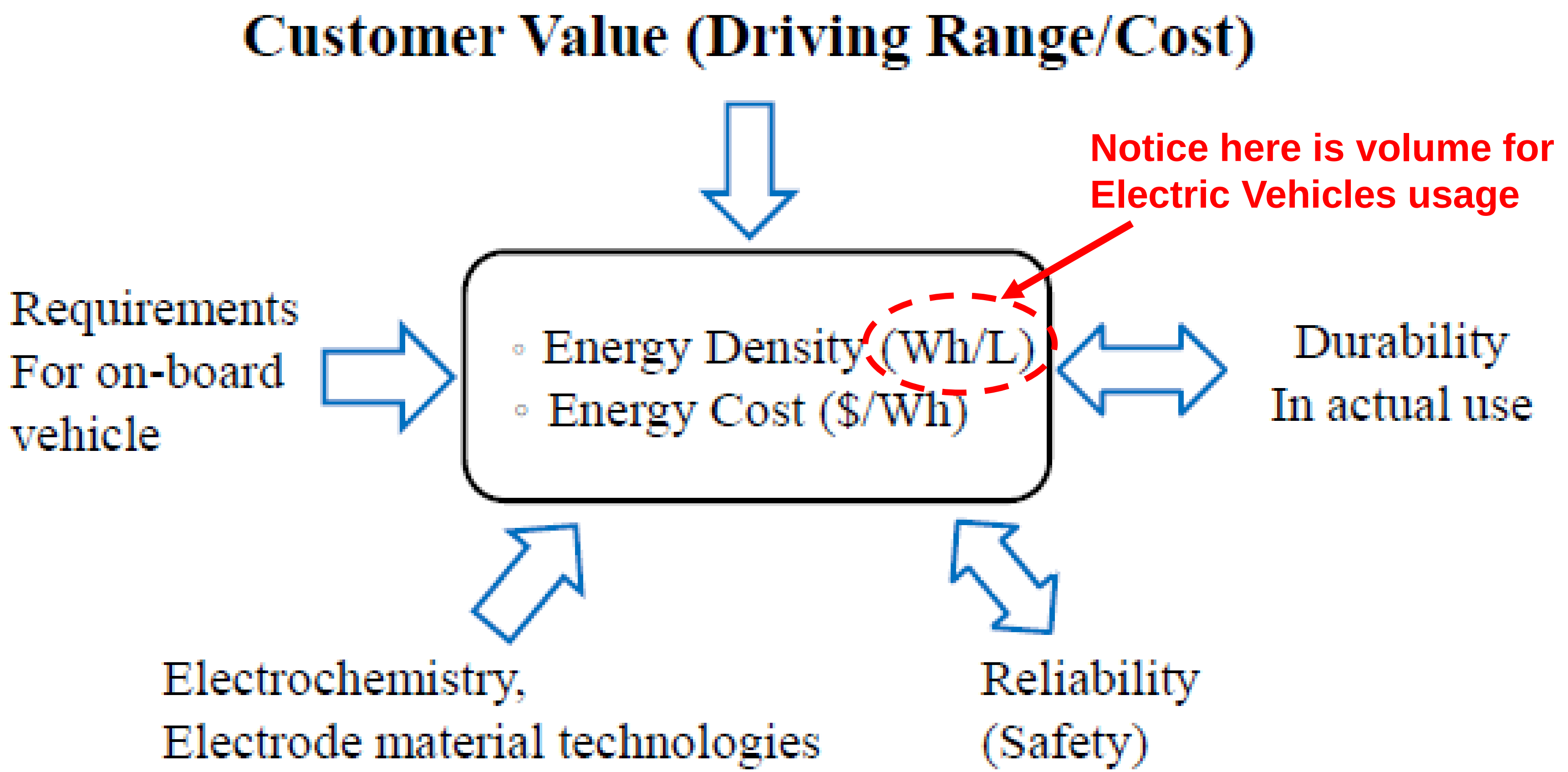


Nissan 3.Zero e+ features a 62kWh battery (with 288 cells), capable of delivering 217ps and 340Nm of torque, and resulting in a claimed driving range of 239 miles (385km) from a single charge. 97 mph top speed.

Requirements for Hybrid-Electric Vehicle Use

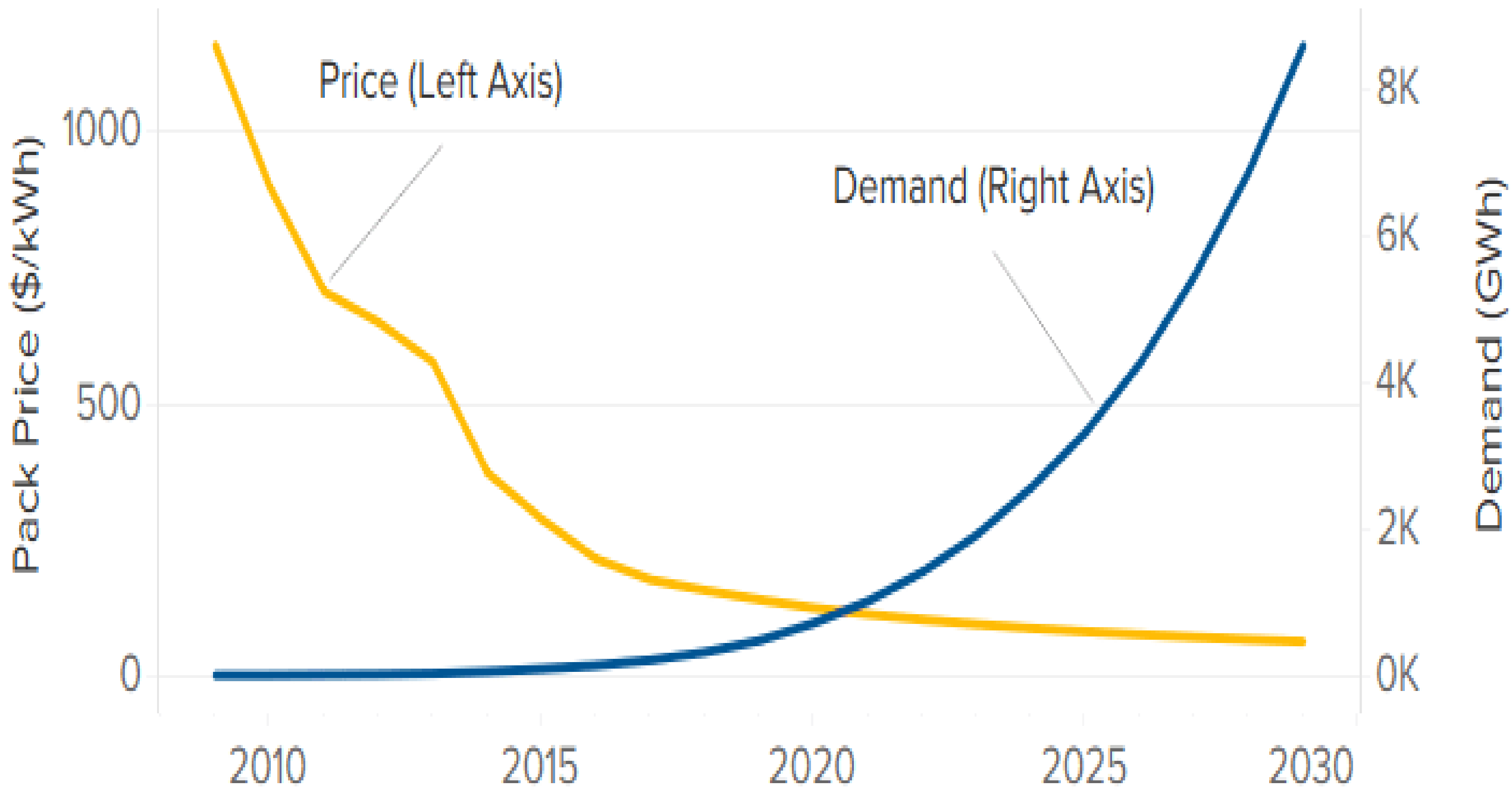
- Long service life – 10-~15 years
- Wide temperature range performance -30℃ to 60 ℃
  - High temperature degradation
  - Low temperature degradation
- Higher power and energy density Large current
  ⇨ input and out put power at low temperature
- Higher reliability
- Lower cost
- Recycle (reuse)

Requirements for Hybrid-Electric EV Use



Nissan's EV Battery Requirements to AESC

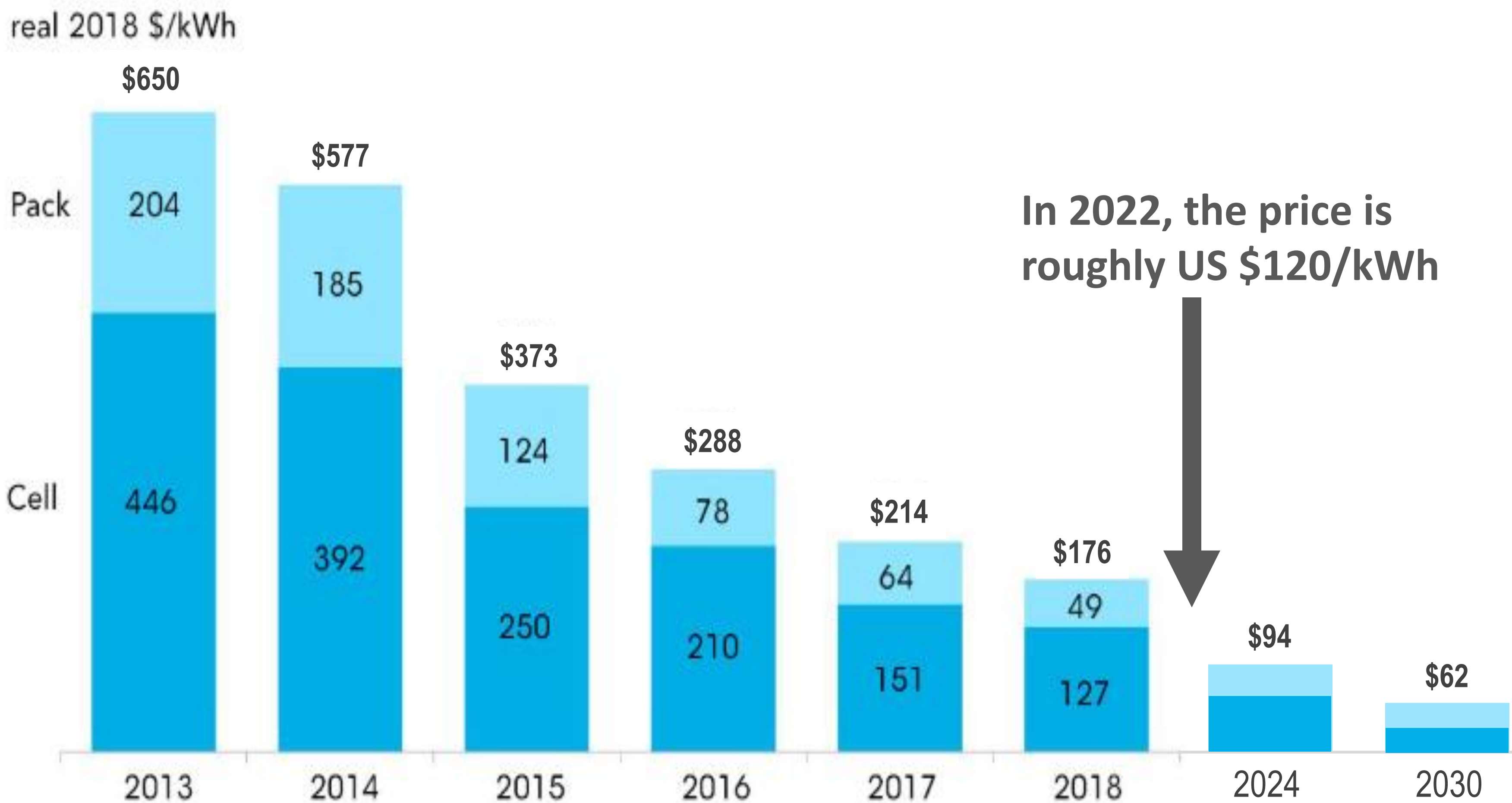
Li-ion Battery Market for EVs



SOURCE: Rocky Mountain Institute/BloombergNEF. Data is projected starting with 2020.

Battery Affects Purchasing Price and Operating Cost

Battery makes up 1/3 the price of electric car, and 50% of the operating cost for eVTOL aircraft.

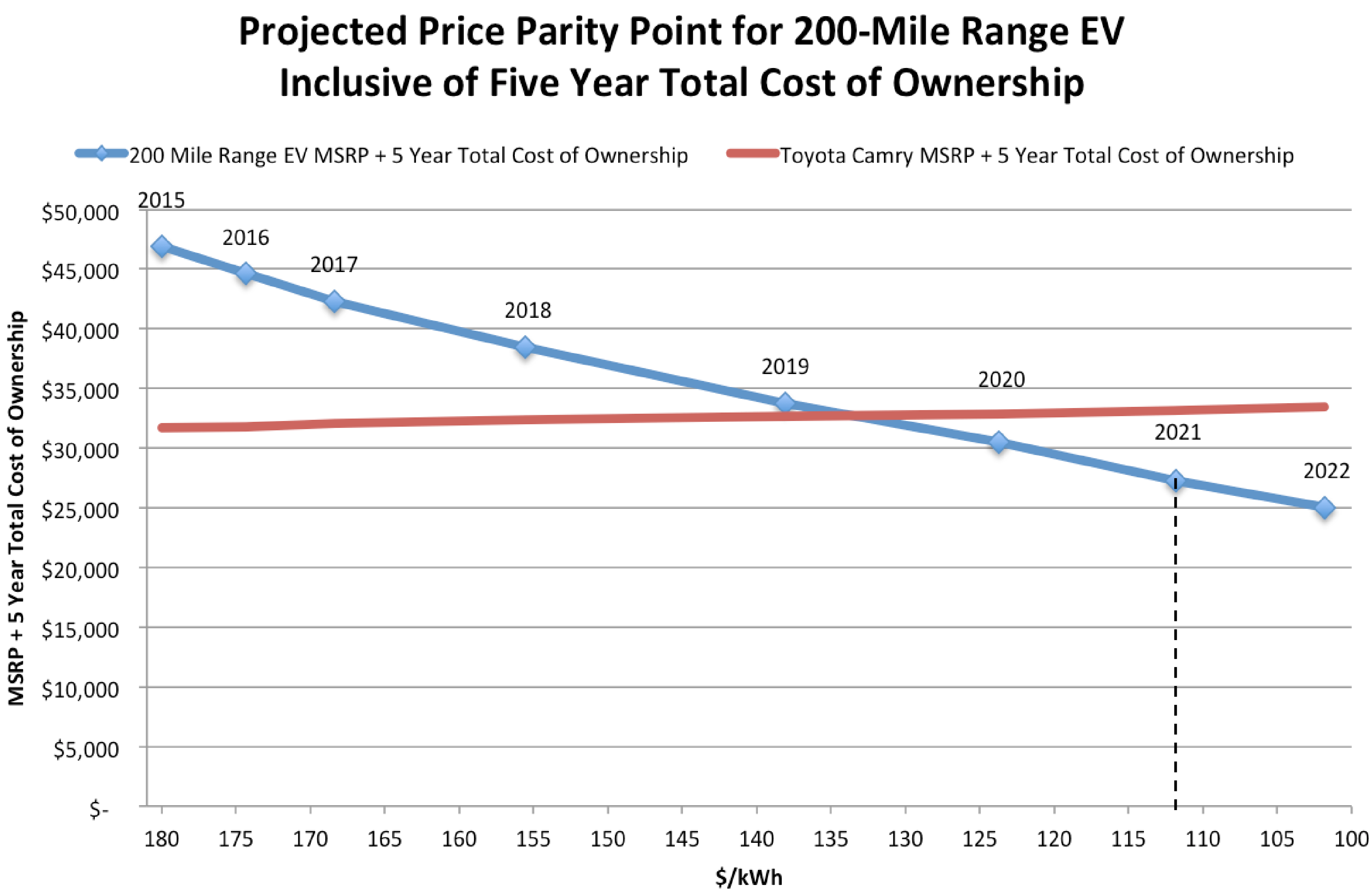


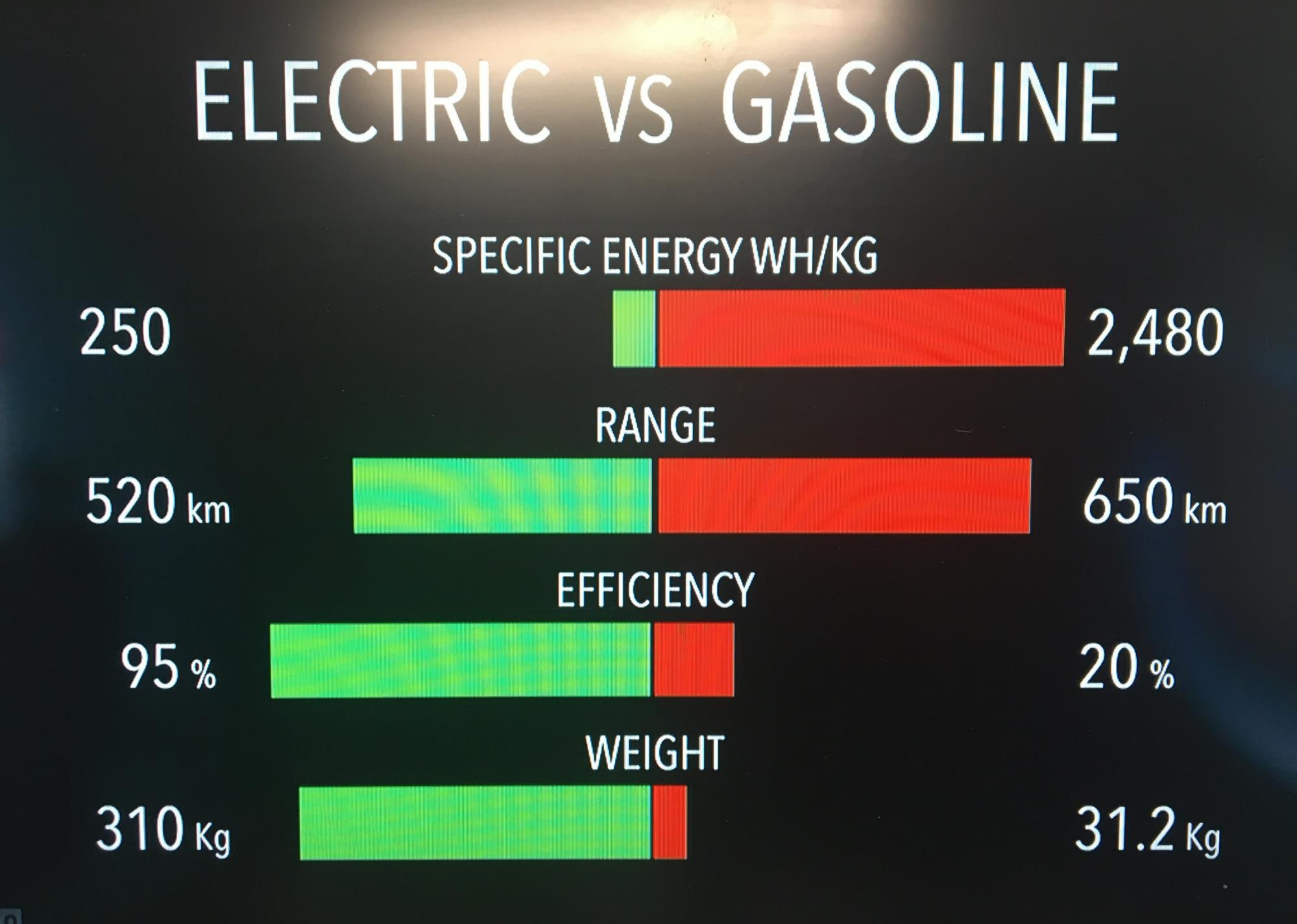
Source: BloombergNEF

Note, lithium cell price has been dropping because it has become a commodity, and 73% are made in China.

However, expect lithium battery price to be more expensive for aviation use

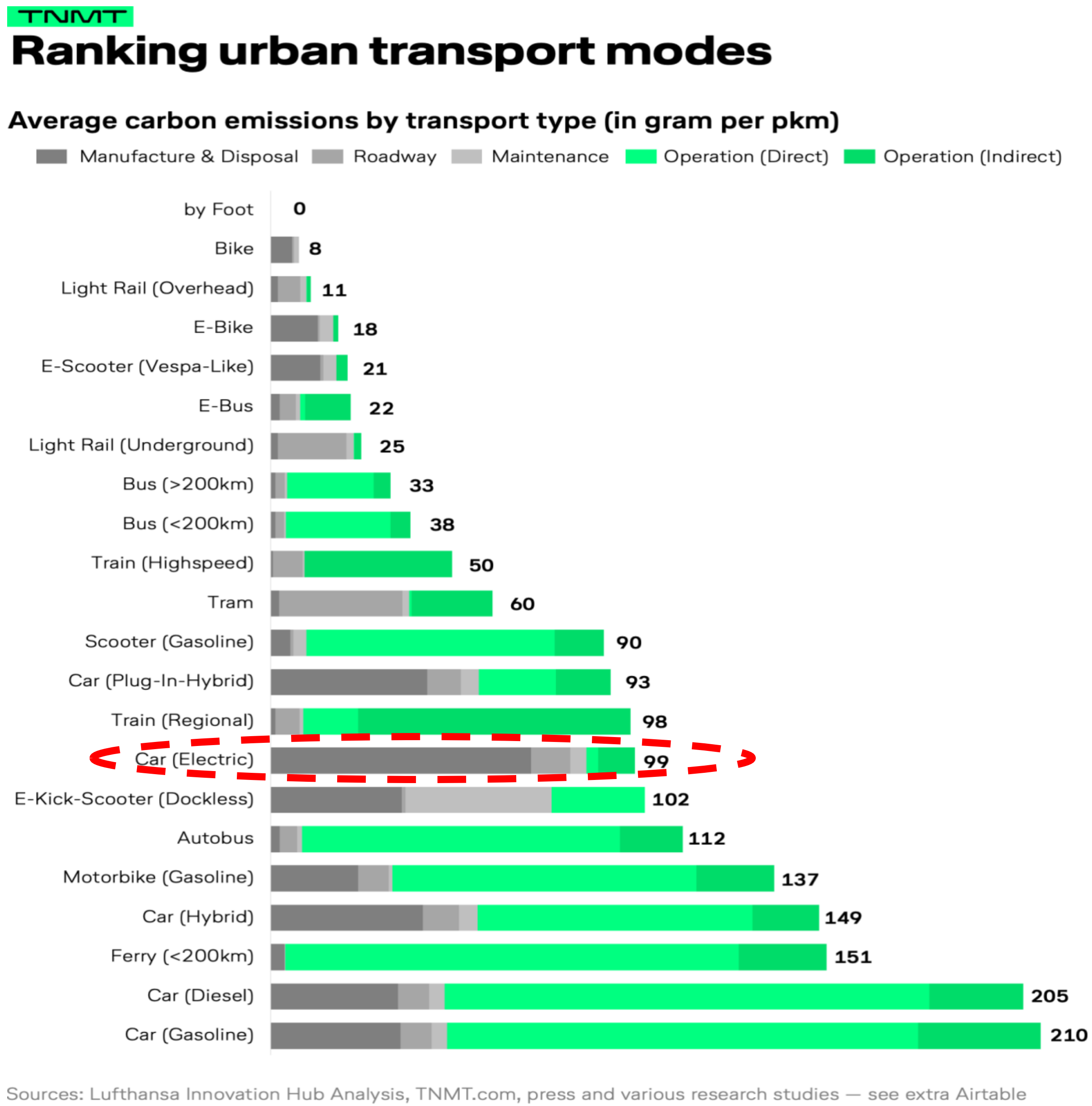
Today it's Cheaper to Own Electric Vehicle





Source: video from Subject Zero Laboratories

Ranking Urban Transportation Modes

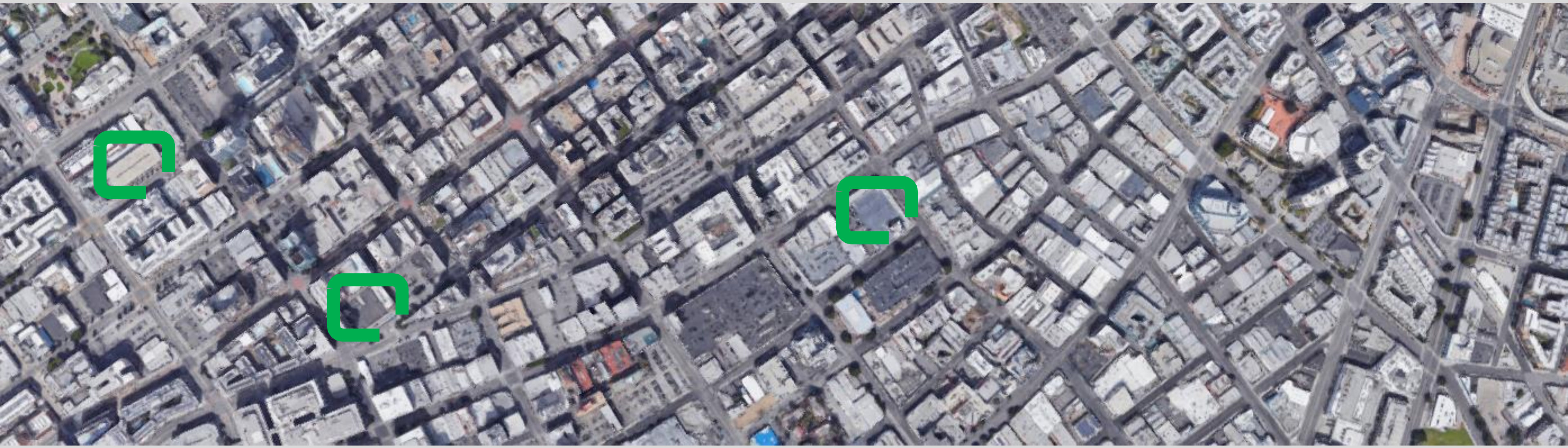


Source: Lufthansa Hub Report 2021
https://tnmt.com/wp-content/uploads/2021/04/CO2-by-transport-type-visual_LIH.png

Electric Flight for Urban Air Mobility

Infrastructure Required at a Vertiport

Vertiport Requirements



There are several location and site considerations in the development of a vertiport. Skyports undertake extensive site analysis and work with the landlord to assess each site for suitability

BUILDING & ENVIRONMENT

- Available footprint
- Loading capacity
- Approach and departure paths
- Multi-modal connectivity
- Weather conditions

SERVICES

- Power grid access and capacity
- Passenger access

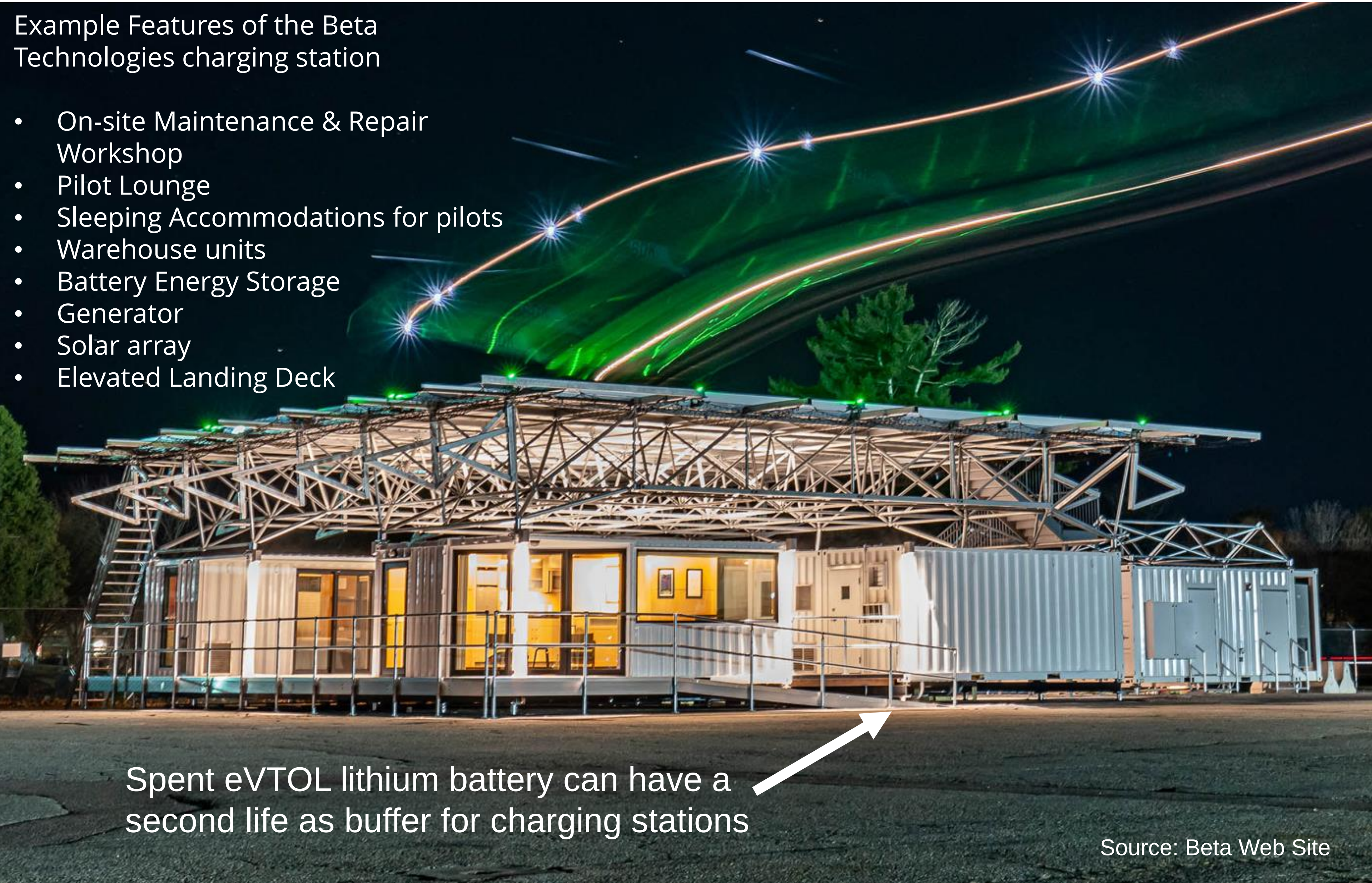
PLANNING & REGULATION

- Planning permission
- Aviation regulation approval
- Emergency services approval

COMMERCIAL VIABILITY

- Route & network analysis
- Passenger throughput & cash flow analysis

Vertiport and Charging Deck for Single eVTOL



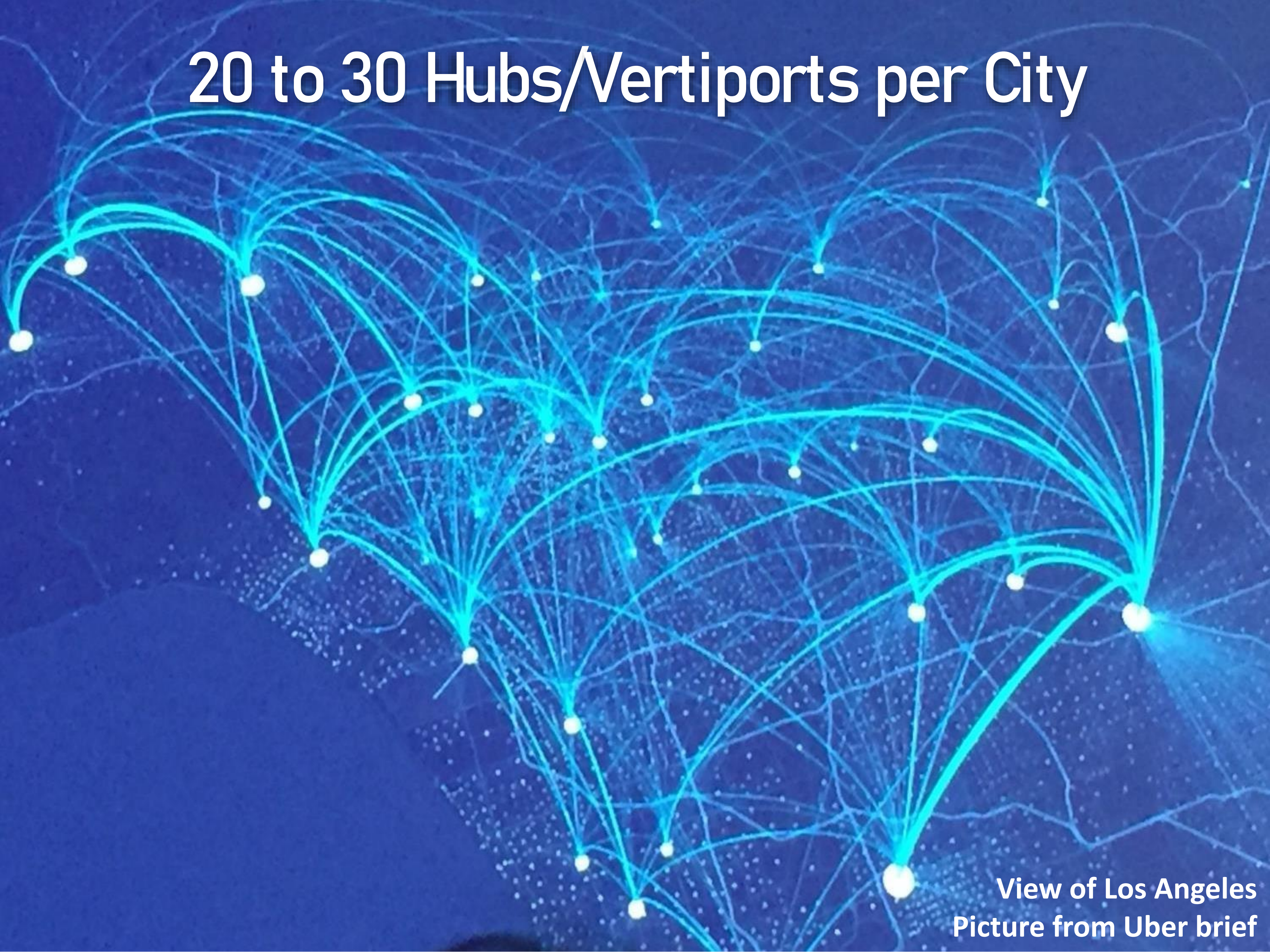
Example Features of the Beta Technologies charging station

- On-site Maintenance & Repair Workshop
- Pilot Lounge
- Sleeping Accommodations for pilots
- Warehouse units
- Battery Energy Storage
- Generator
- Solar array
- Elevated Landing Deck

Spent eVTOL lithium battery can have a second life as buffer for charging stations

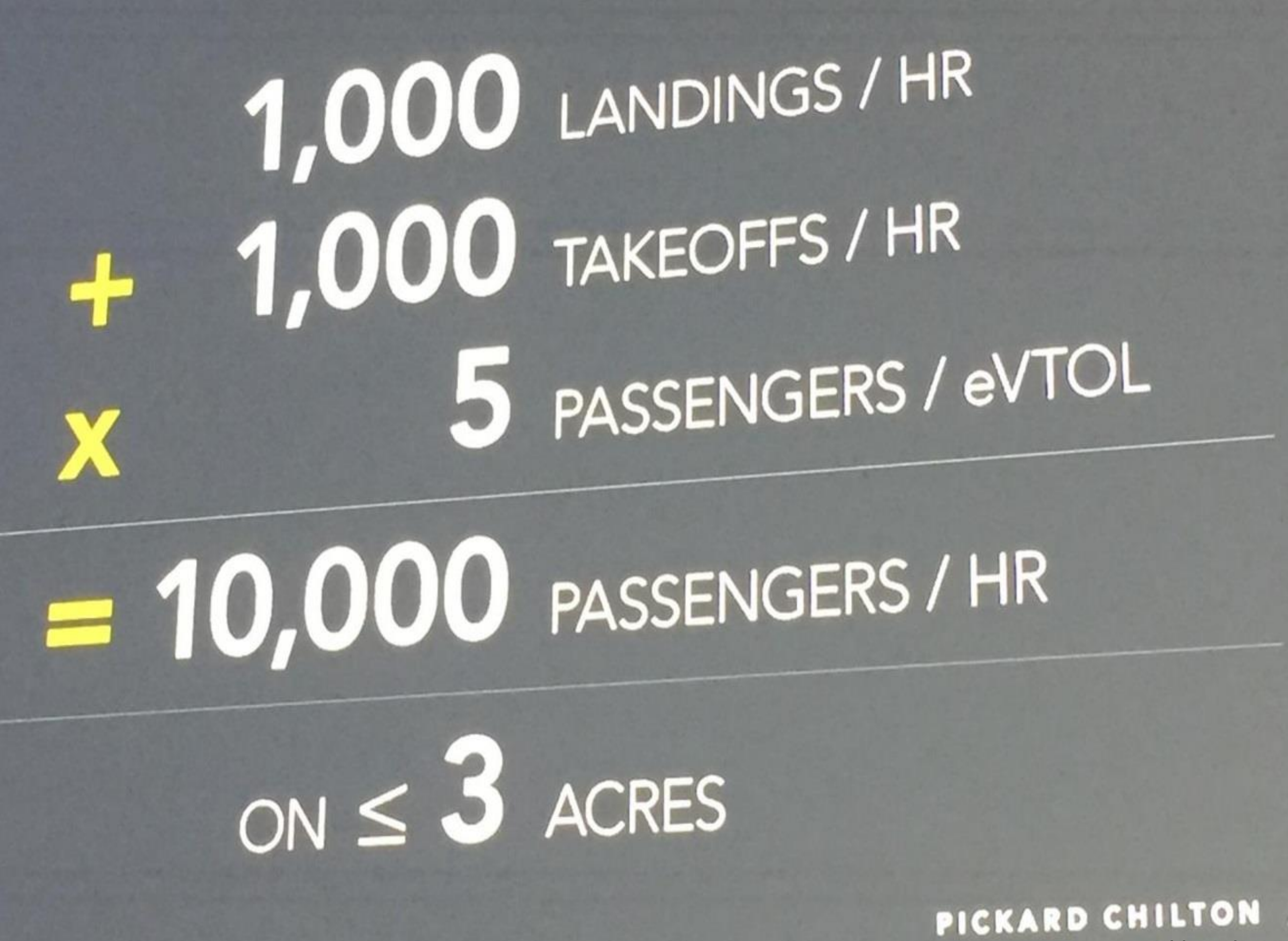
Source: Beta Web Site

20 to 30 Hubs/Vertiports per City



View of Los Angeles
Picture from Uber brief

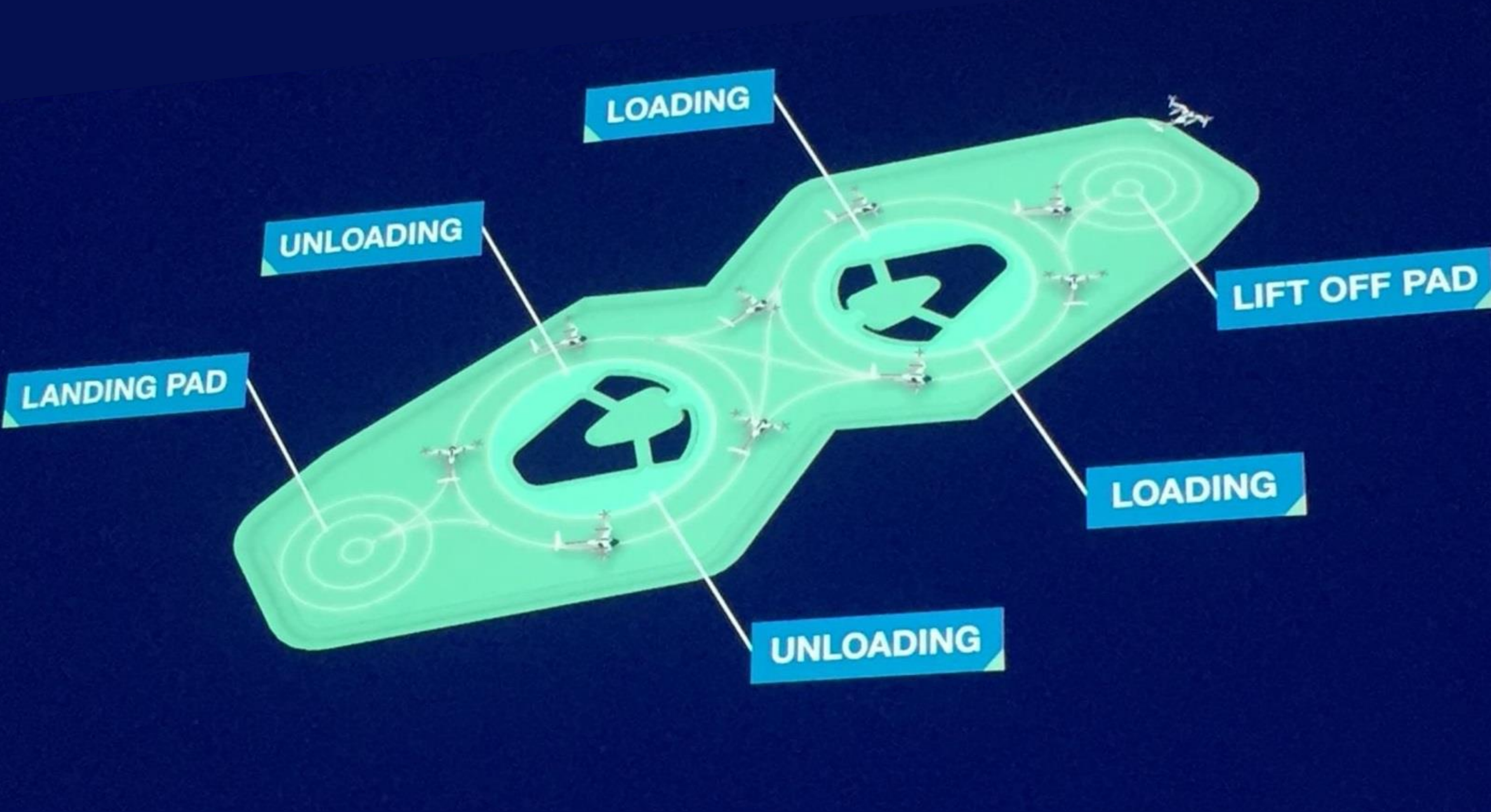
Example of a Mega Vertiport



Source: proposal by Uber

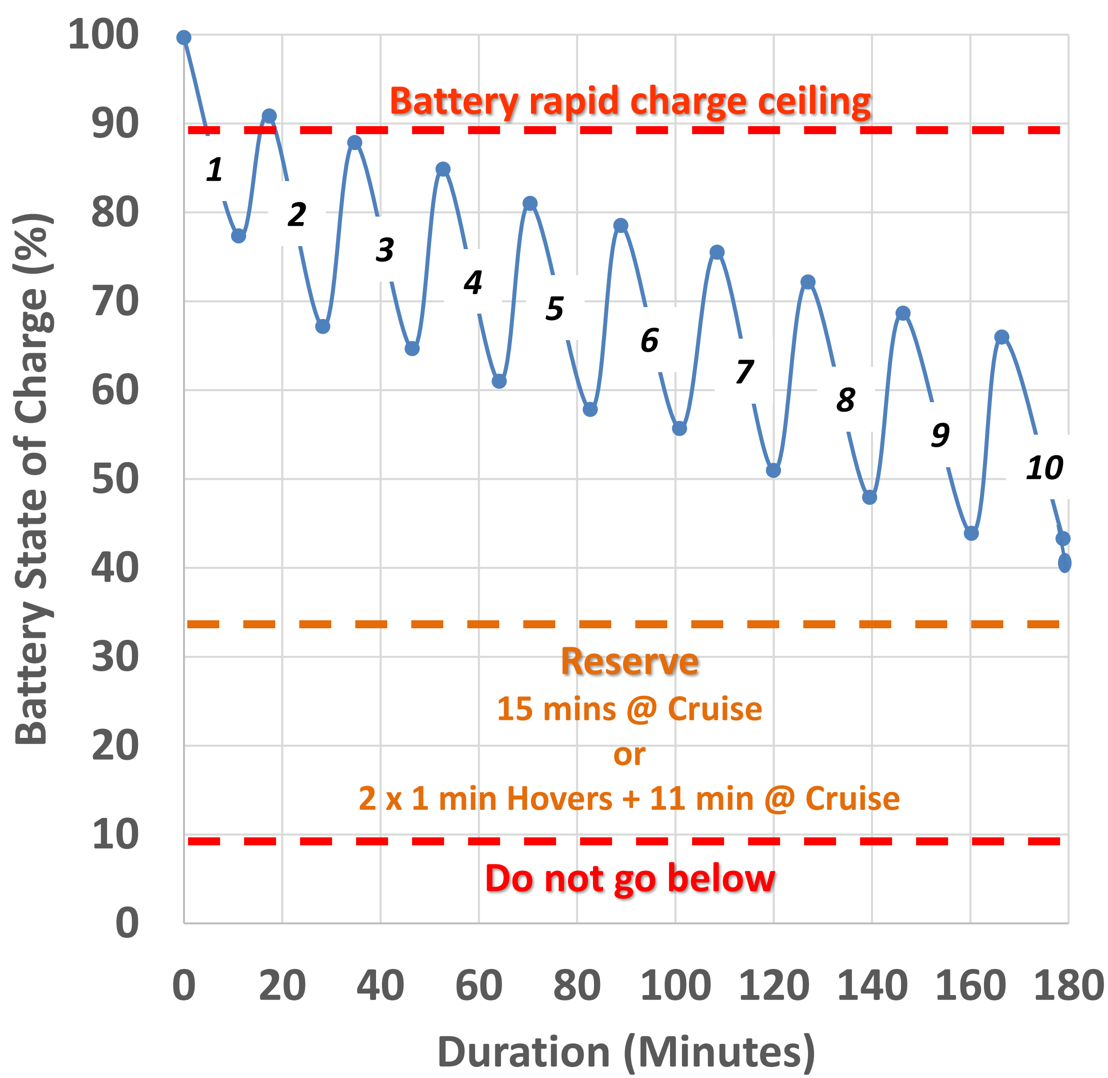
(Concept by Corgan)

6 Minutes between unloading and loading passengers This also permits a quick charge to top off battery



(Vertiport Concept by Corgan)

Ten Missions in 3-Hour Continuous Operation



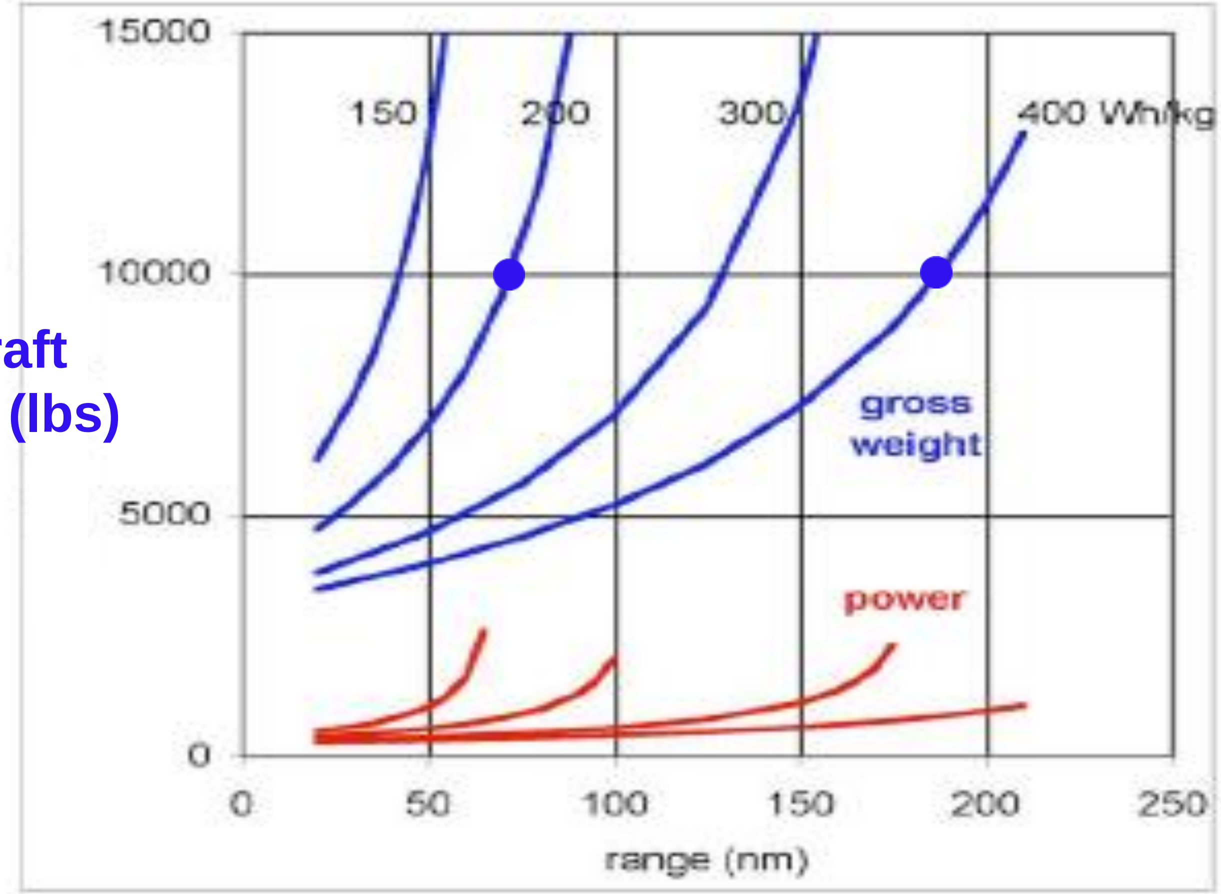
Action	Time
Takeoff	1 min
Cruise	10 min
Landing	1 min
Position/Plug	½ min
Ground Charge	6 min
Unplug/Position	½ min

Average mission 19 minutes
Ten x 25 mile missions

Feasibility of Concept

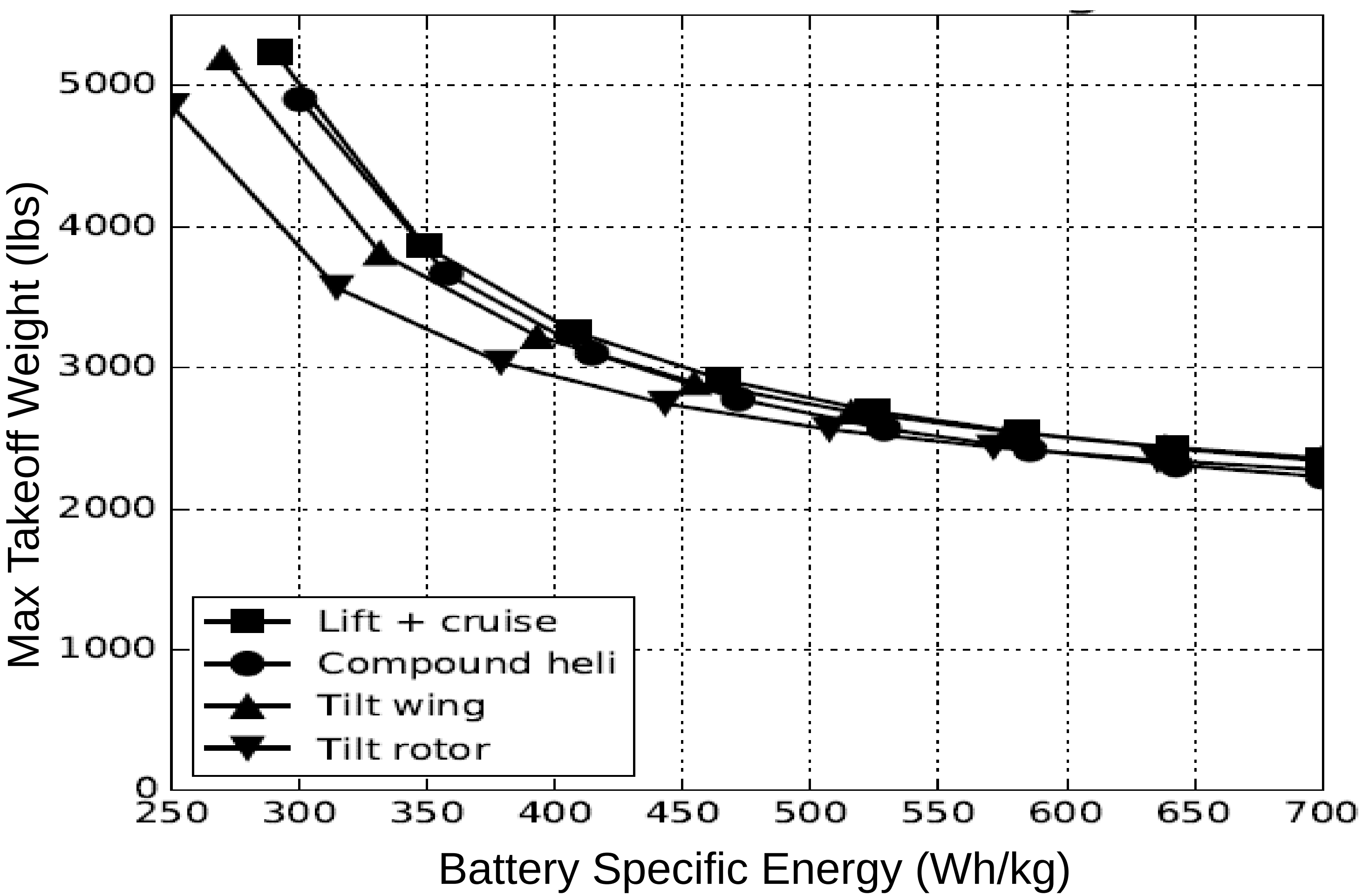
Electric, side-by-side, 6 passengers

Aircraft weight (lbs)



Effect of Specific Energy on eVTOL Weight

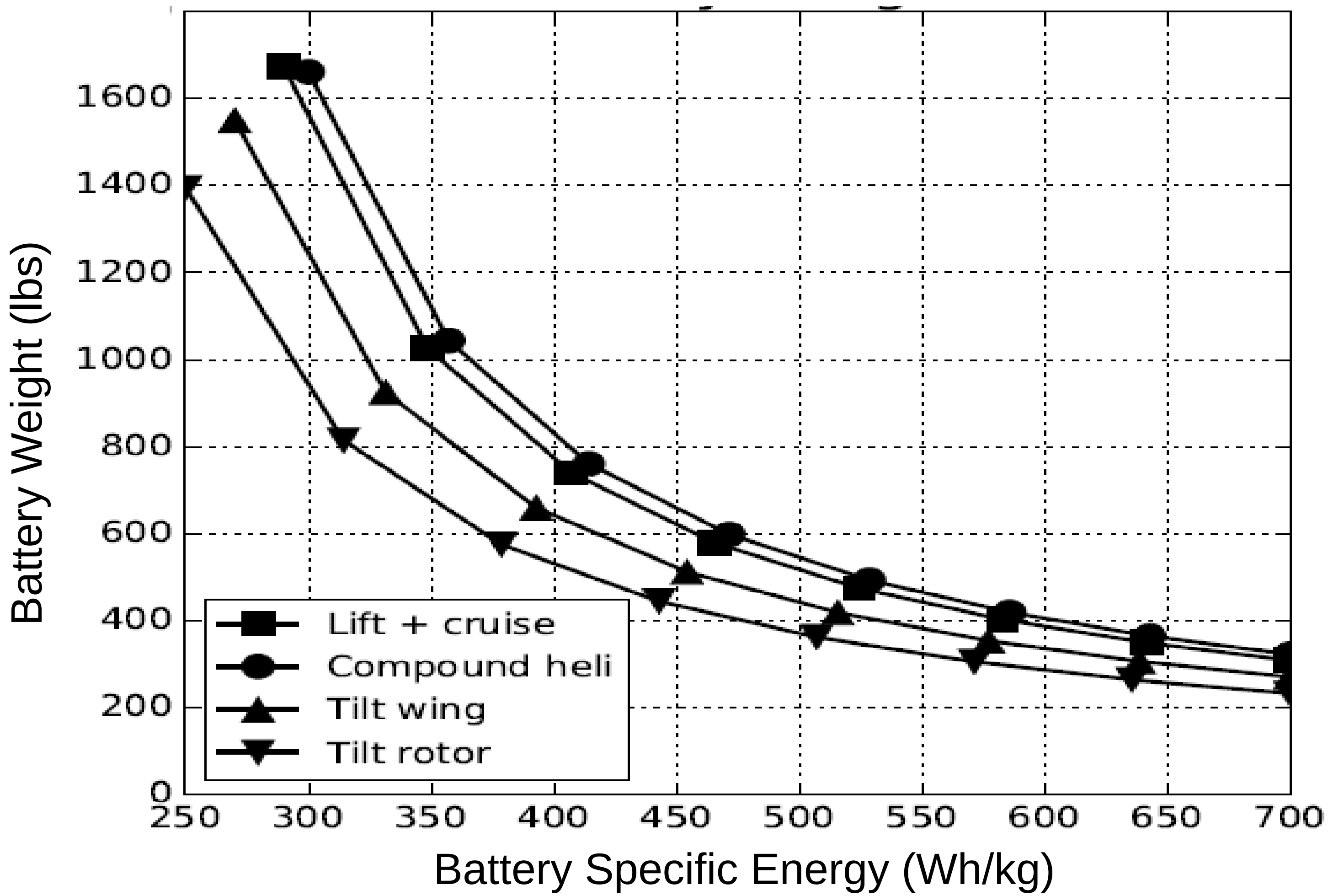
For a prescribed range, increasing specific energy helps reduce aircraft weight



Source: https://convex.mit.edu/publications/arthur_ondemand.pdf

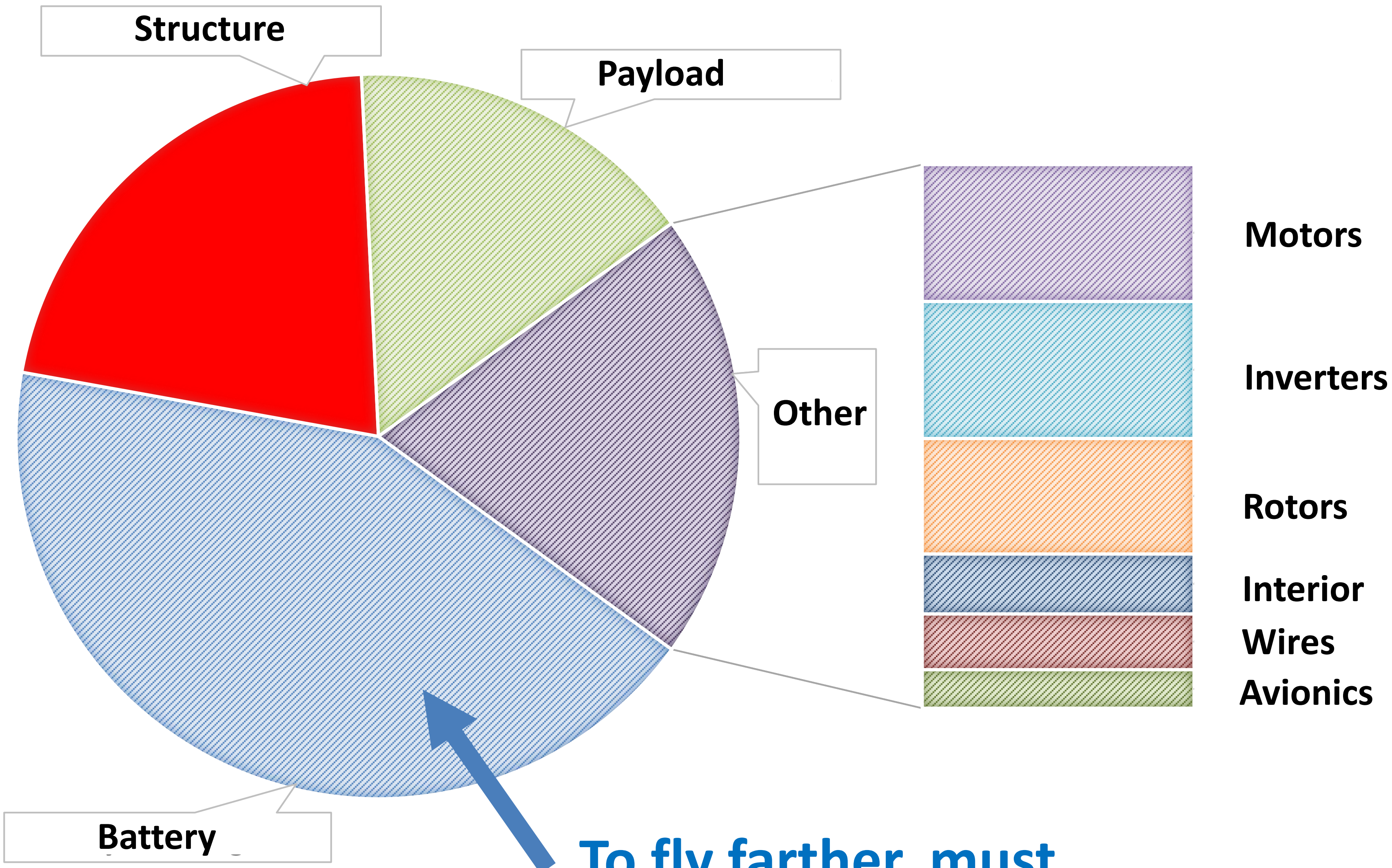
Effect of Specific Energy on eVTOL Weight

For a prescribed range, increasing specific energy helps reduce battery weight



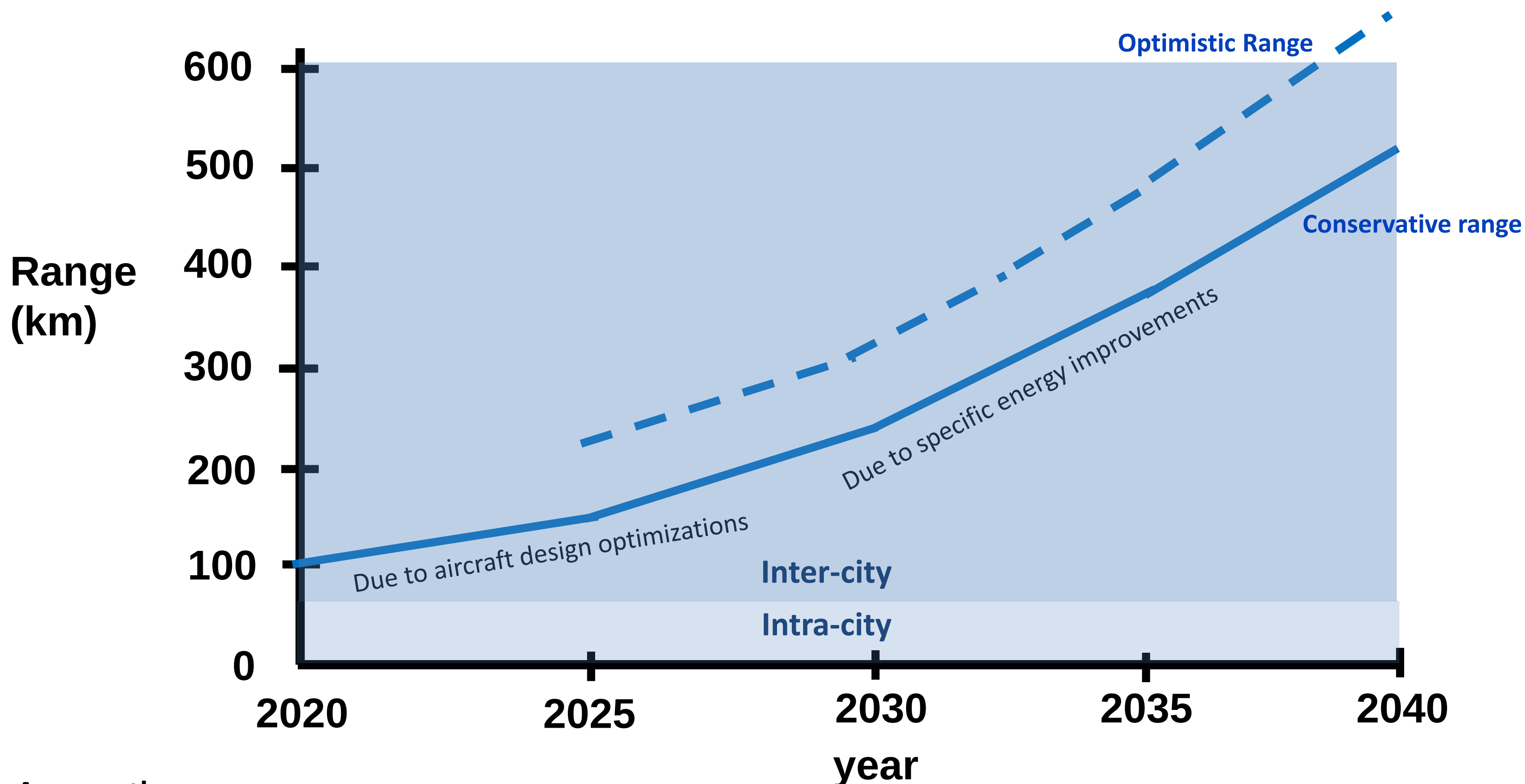
Source: https://convex.mit.edu/publications/arthur_ondemand.pdf

Weight Breakdown for an eVTOL Aircraft



To fly farther, must increase the specific energy of the battery !

Predicted Range versus Year for Generic eVTOL



Assume these specific energies at Pack Level for energy source* | **160 Wh/kg** | **200 Wh/kg** | **330 Wh/kg** | **500 Wh/kg** | **750 Wh/kg**

*If using cells, assumed a lost of about 35% in specific energy from cell level to pack level

Predicted by James Wang

2. Battery and Energy Source

by Dr. James Wang

SNUevtolclass@gmail.com