Cedric Weiss, PhD
A2Mac1, EV/Hybrid Department

Electric Vehicle Battery Chemistry and Pack Architecture

Charles Hatchett Seminar
High Energy and High Power Batteries for e-Mobility
Opportunities for Niobium
London, England
July 4, 2018

Outline

1) **Global Presentation of A2Mac1**
   By Fabrice Robert, European Sales Engineer

2) **History and types of EVs**
   Hybrids, full electric…

3) **Battery Pack Architecture**
   Battery pack components (housing, cooling, modules, BMS…)

4) **Focus on Battery Cells**
   Battery chemistry and materials

5) **Future of Electric Vehicle Battery**
   What's beyond Lithium-Ion for tomorrow's cars?

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6 benchmarking centres worldwide

600+ full teardowns

600 000 parts in storage

28 Mio photos

170+ customers

2.8 Mio pages viewed/month

- Trusted partner to all major OEMs worldwide and suppliers, including steel makers and material producers
- Key reference for competitive analysis in the automotive industry
- Industry leading data management software solution
- Best in class processes for effective data capture


FRANCE - Hary

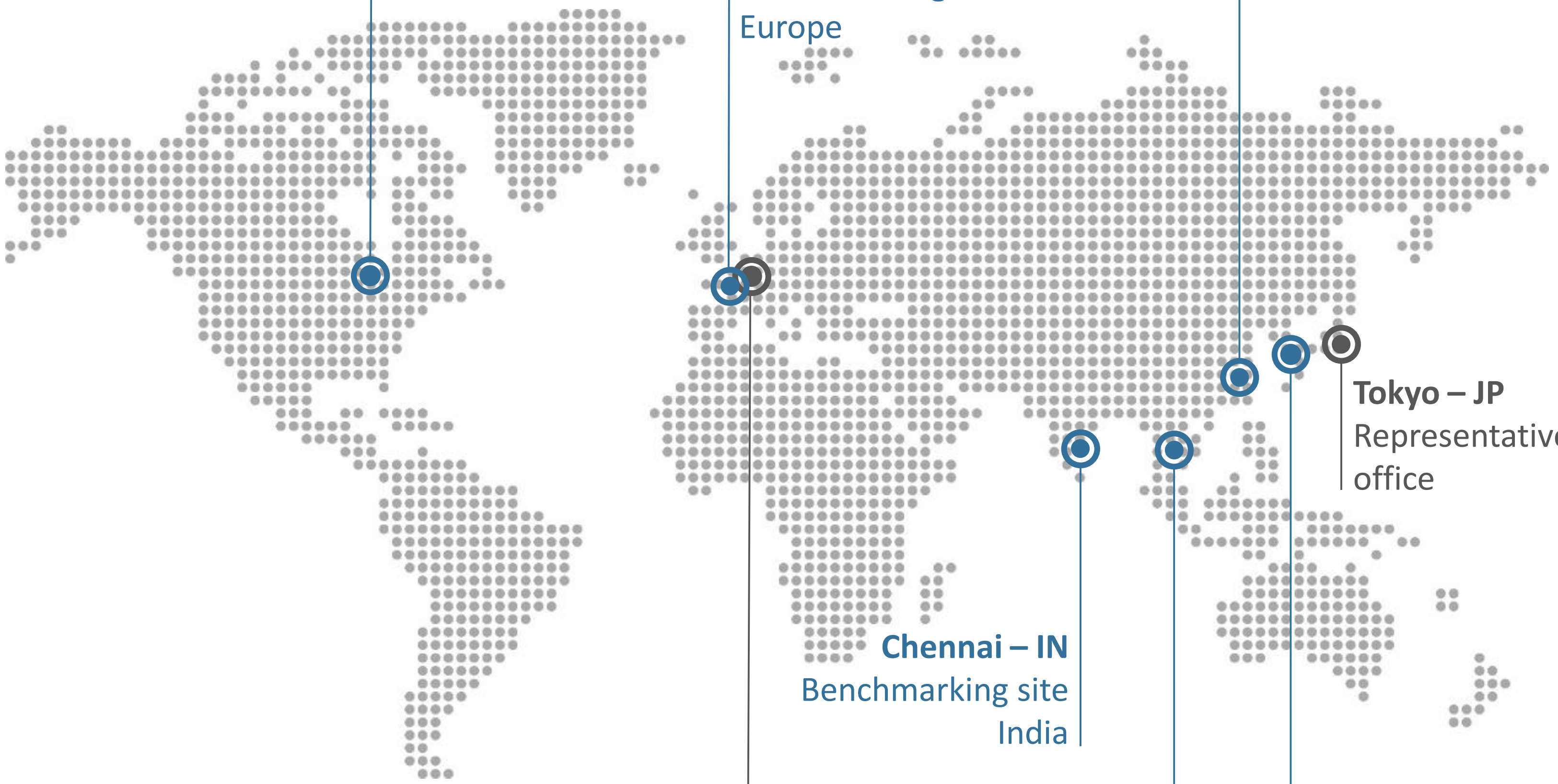

USA - Belleville

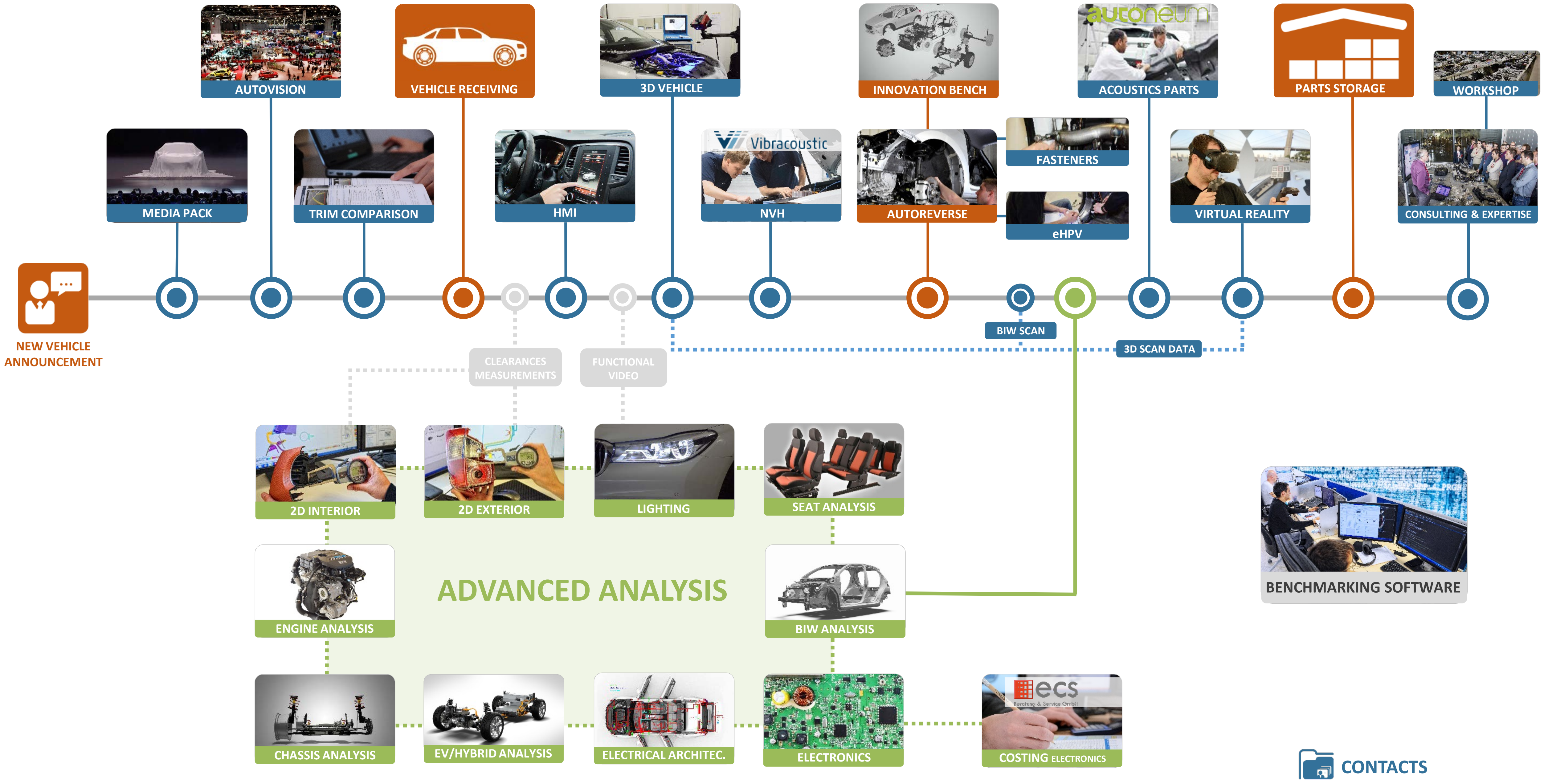

CHINA - Shanghai


THAILAND - Bangkok


INDIA - Chennai


KOREA - Hwaseong-si

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ELECTRICAL ARCHITEC.
ELECTRONICS
ecs
COSTING ELECTRONICS
BENCHMARKING SOFTWARE
CONTACTS

Video

EV/Hybrid at A2Mac1

EV/Hybrid perimeter Teardown & properties

- High Voltage Battery Pack
- Power electronic: Inverter / Charger
- High voltage cables
- HVAC and Cooling system
- E Machine: EV Drive and Transmission
- ECU System management

Cell Analysis Report

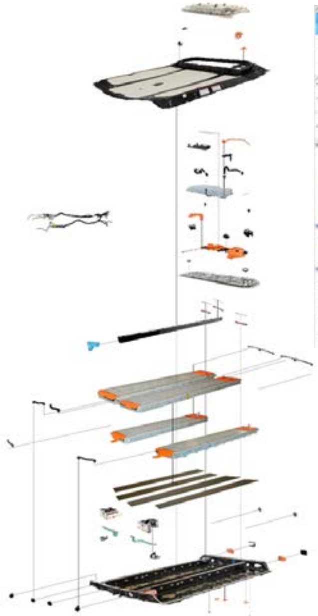
- Performance testing
- Structural analysis
- Chemical analysis
    - Electrolyte analysis
    - Separator analysis
    - Electrodes analysis

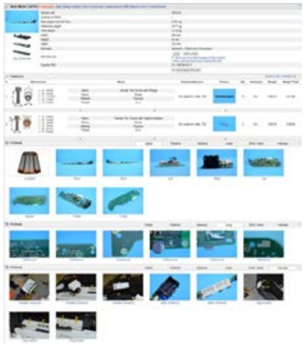
BMS Report

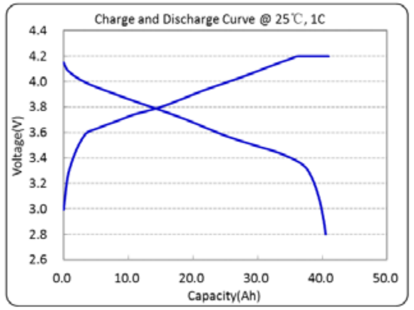
- Bill of materials
- Functional Layout detail
- Block Diagram
- Battery Architecture Observations

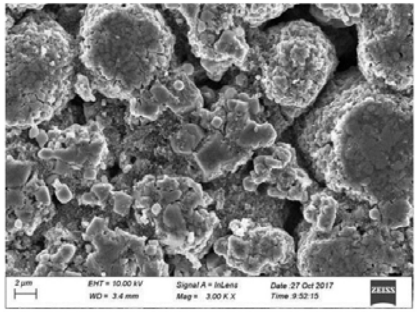
Functional Schematics

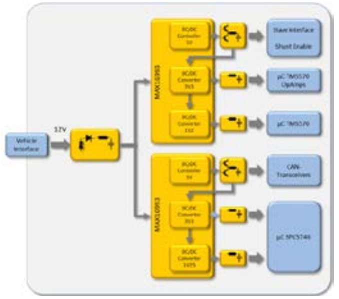
- Cabin Heat/Engine Thermal
- HV components Heat exchanger
- HV components & cabling systems
- Battery external cooling
- Battery thermal
- Battery pack electrical

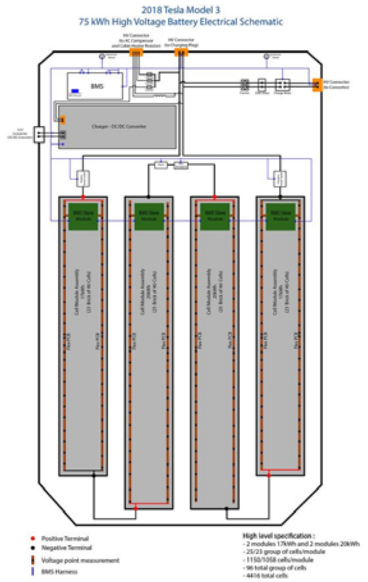












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   Battery pack components (housing, cooling, modules, BMS…)

4) **Focus on Battery Cells**
   Battery chemistry and materials

5) **Future of Electric Vehicle Battery**
   What's beyond Lithium-Ion for tomorrow's cars?

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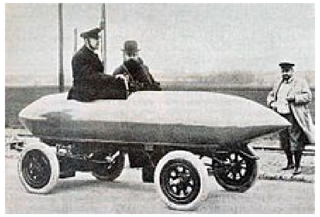
A look back in history

1960s-1970s: Renewed interest in electric cars by several manufacturers (1st oil crisis, growing environmental concerns…)

1859: invention of the lead–acid battery (1st rechargeable battery) by French physicist *Gaston Planté*



1899: The *Jamais Contente* sets first speed record over 100 km/h

1902: 1st "mass-produced" electric car (Studebaker Electric)

1910s-1920s: Gasoline powered cars take over the market

- Better road infrastructure: longer distances to travel
- ICE prices went down with Ford's mass production
- More petroleum discovered, ICE with less noise, smell, vibrations…

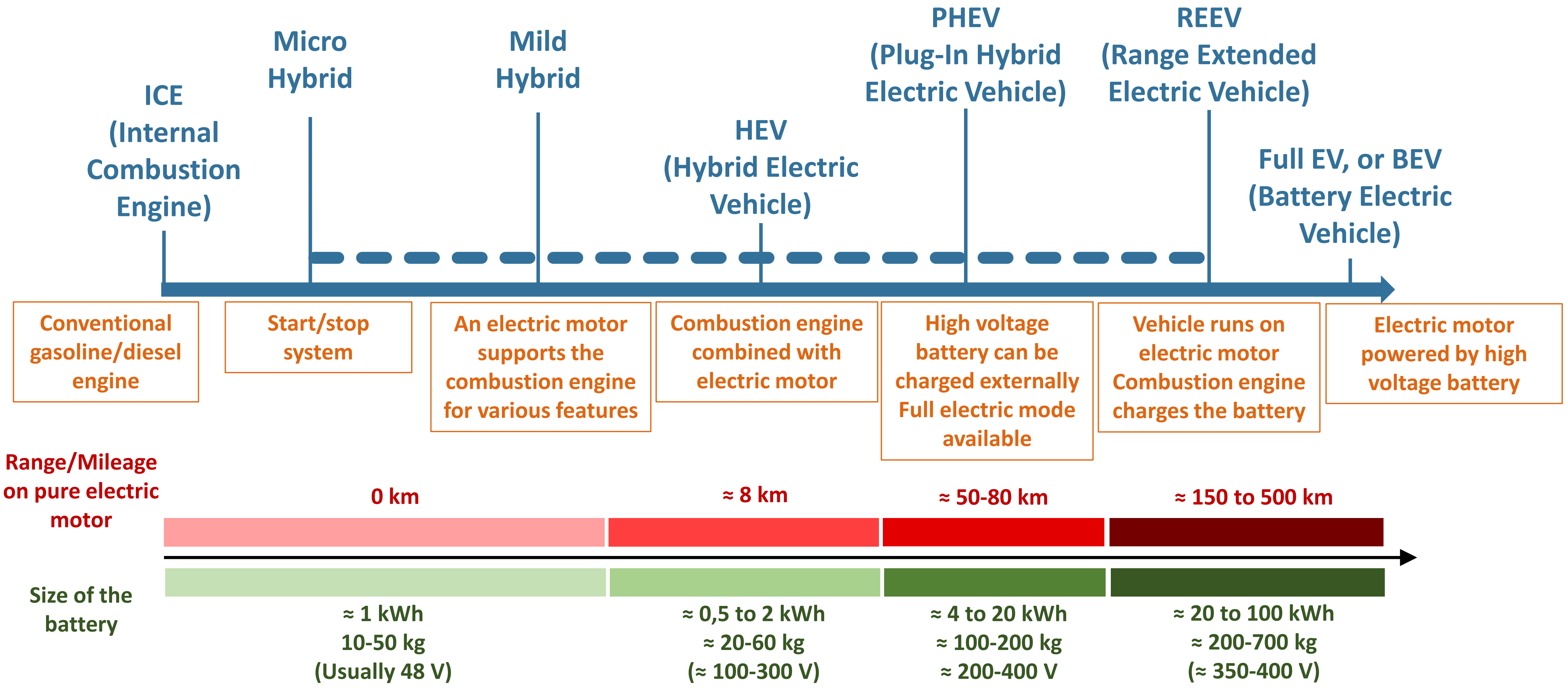
1997: The Toyota Prius I launch is the beginning of a new era for hybrid and electric vehicles

Today

Today, the EV/Hybrid car market is growing thanks to:

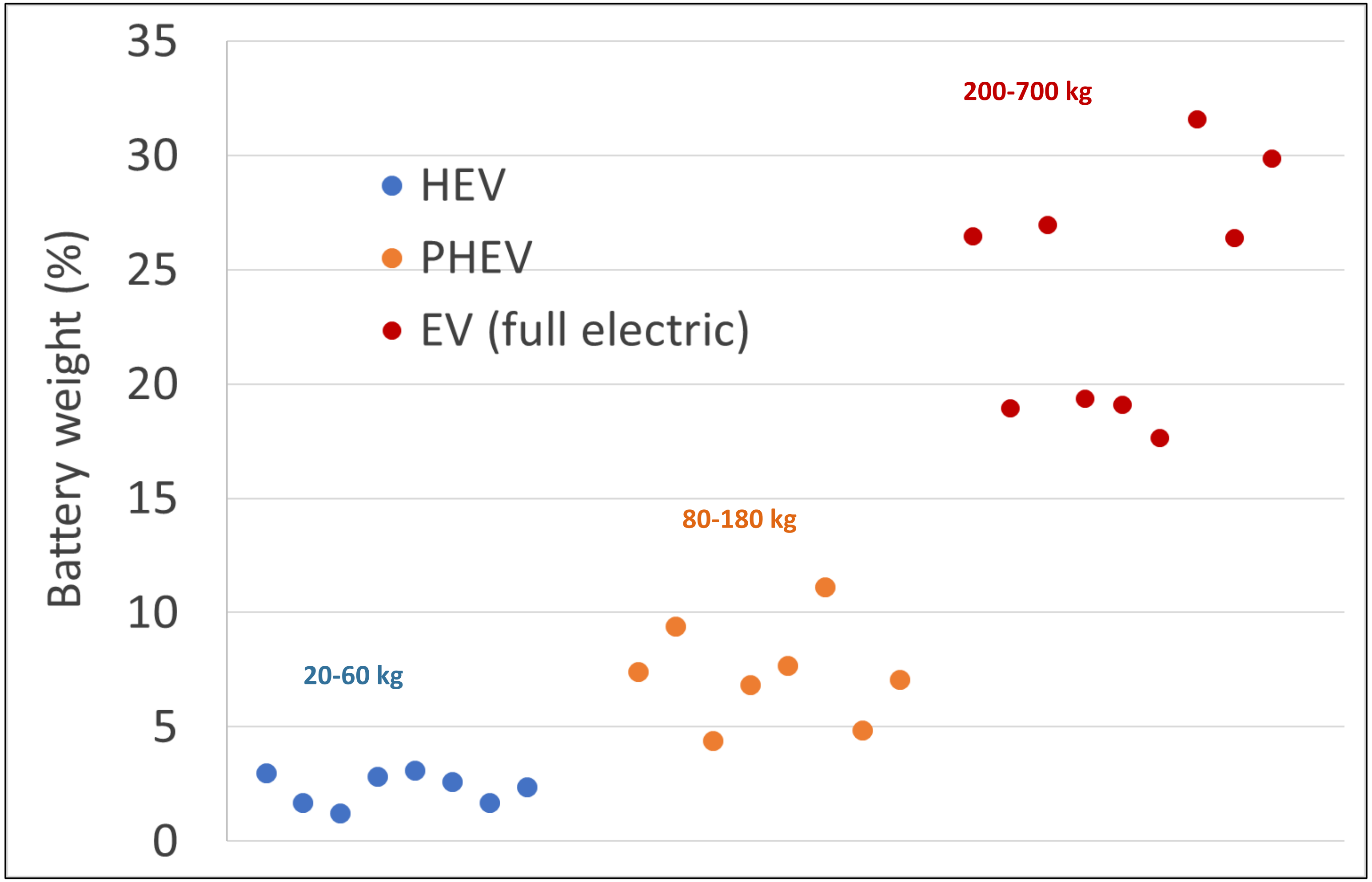
- Emissions regulations
- Battery chemistry/performance improving
- New players like Tesla challenging traditional carmakers

Types of Electric Vehicles



Weight of the Battery Pack

Contribution to the total weight



Battery weight fraction in the vehicle:

1 to 3 % for HEV (Hybrid Electric Vehicle)
4 to 12 % for PHEV (Plug-in Electric Vehicle)
17 to 32 % for EV (full Electric Vehicle)

Source: A2Mac1 database

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The Battery Pack Architecture

Tesla Model 3

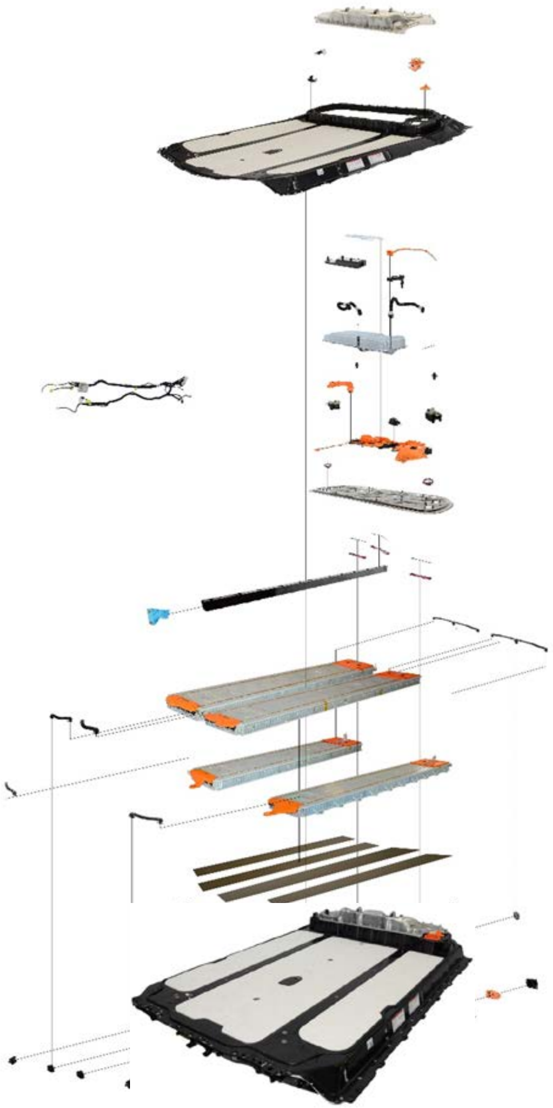
Weight = 460 kg (26 % of 1766 kg)

Length = 2.15 m
Width = 1.47 m

4 modules, 4416 battery cells
Nominal Voltage = 355 V
Capacity = 217 Ah
Energy = 75 kWh

The Battery Pack Architecture

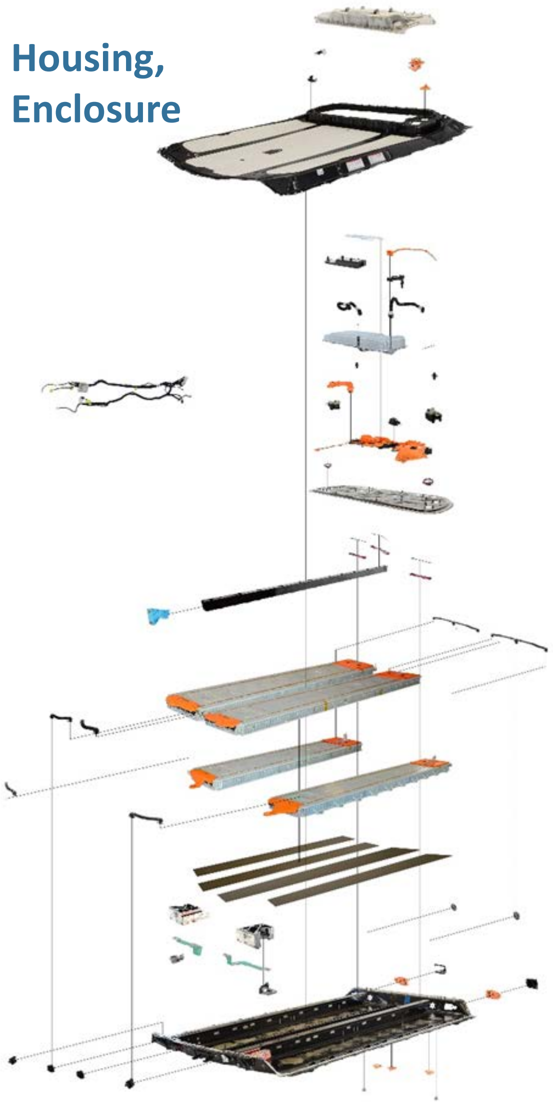
What's inside the Battery Pack ?



The Battery Pack Architecture

Enclosures

Housing,
Enclosure

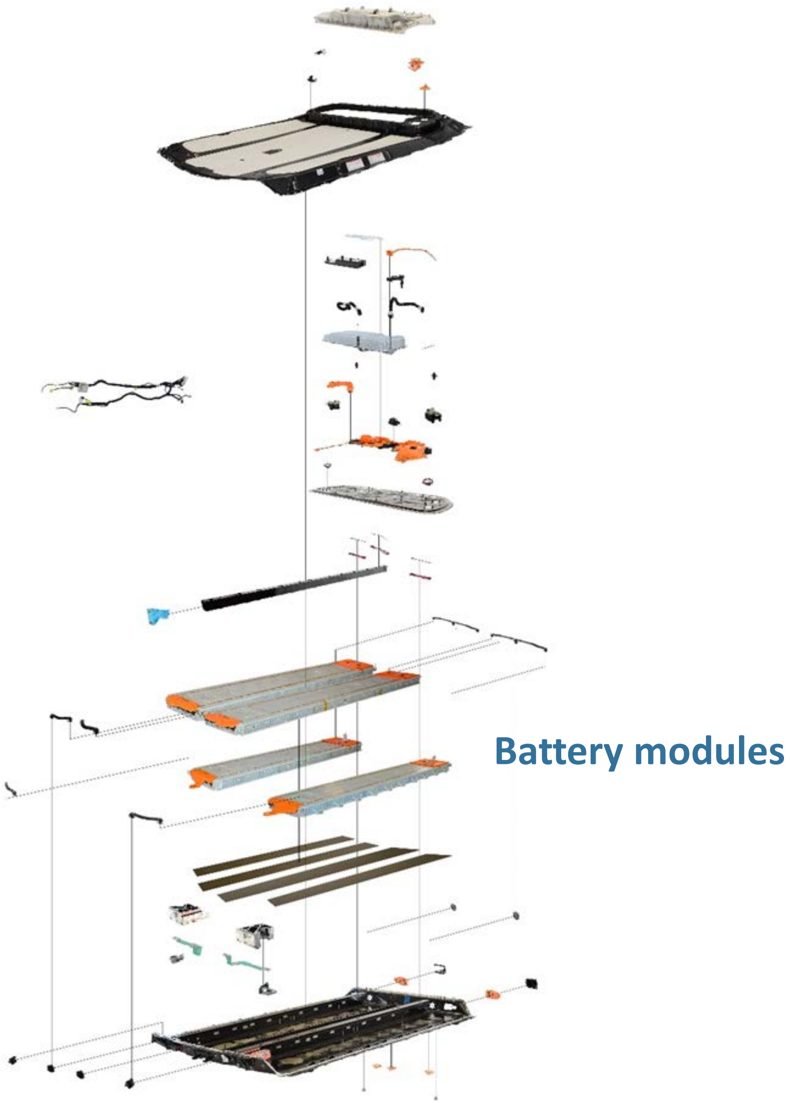


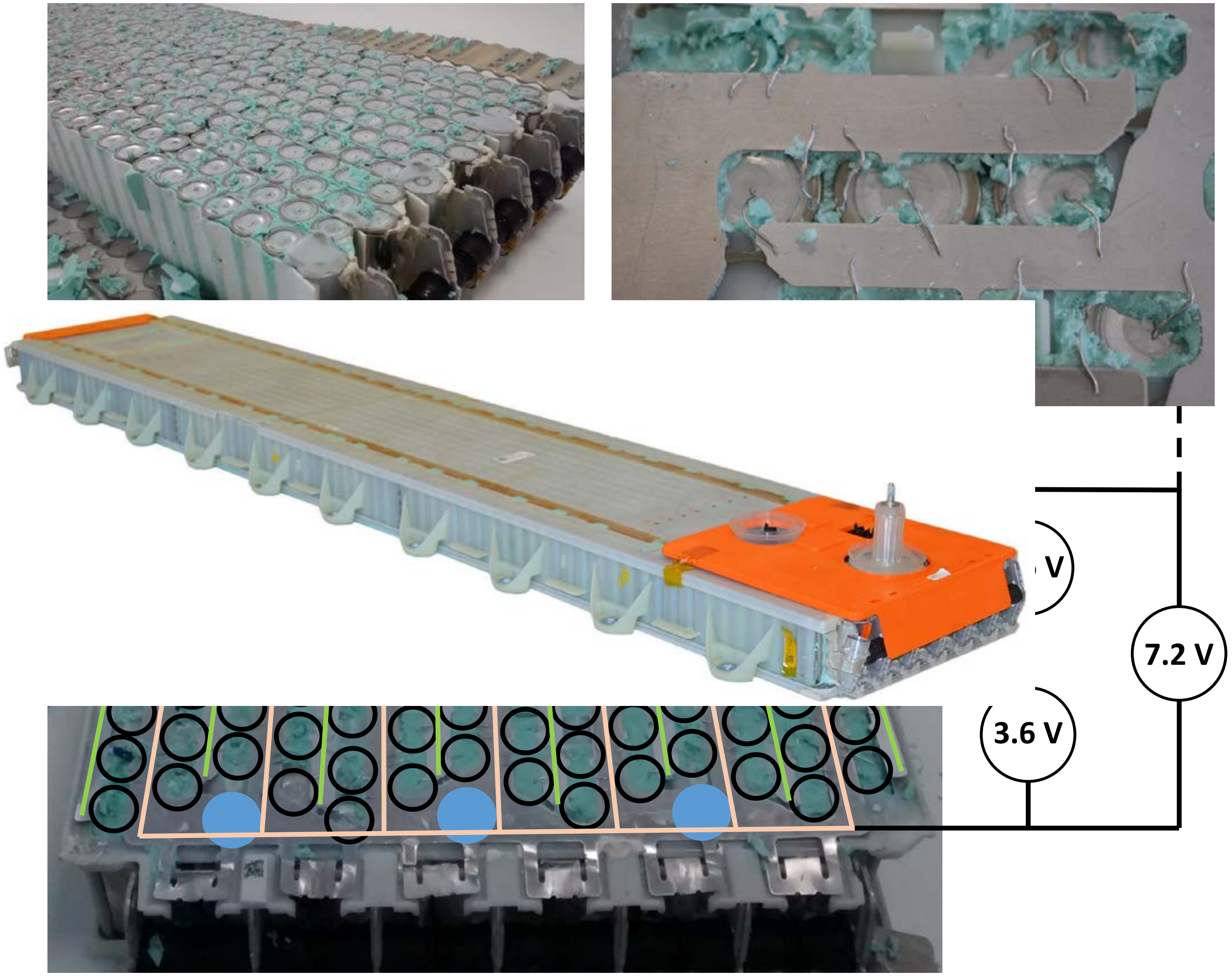
Housing,
Enclosure

Metal or plastic "box"
Can be reinforced against impact crash

The Battery Pack Architecture

Battery Modules

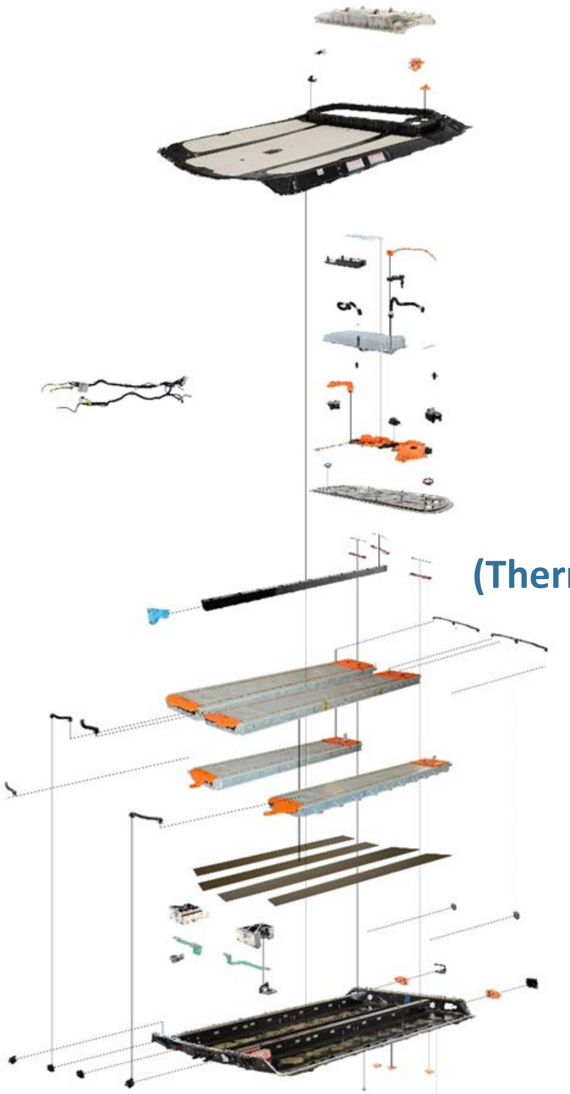




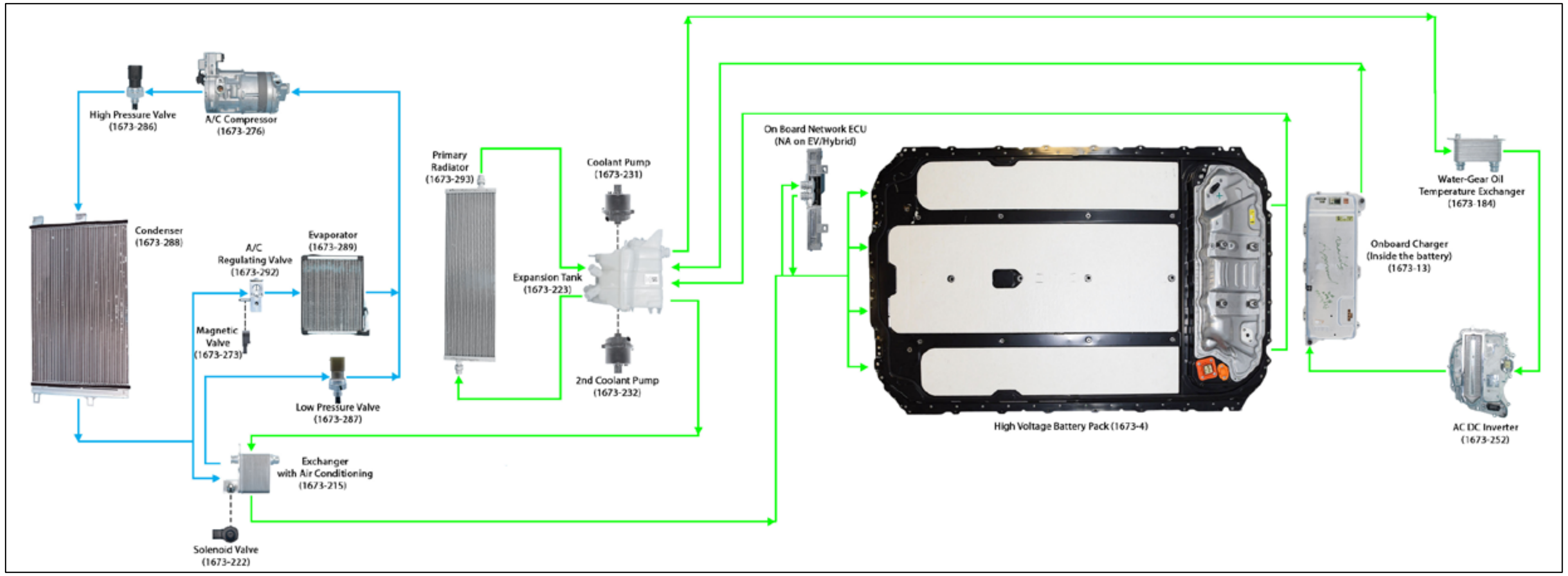
46 cells/brick in parallel, 96 bricks in series
(96 S 46 P)

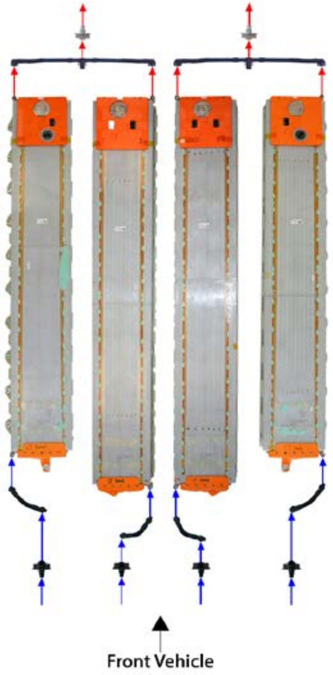
The Battery Pack Architecture

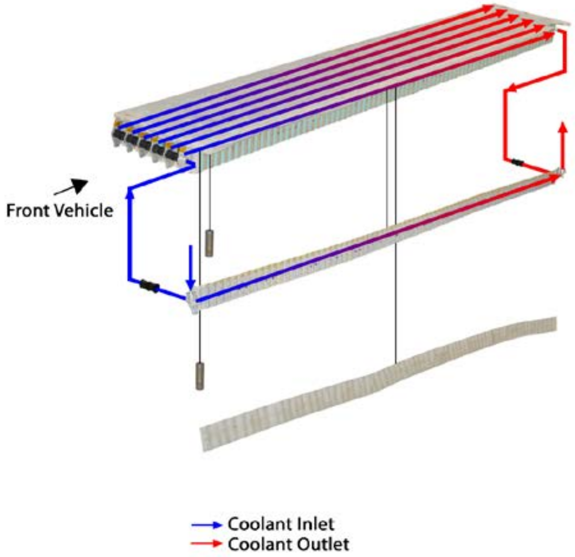
Thermal Management System (TMS)



TMS
(Thermal Management System)

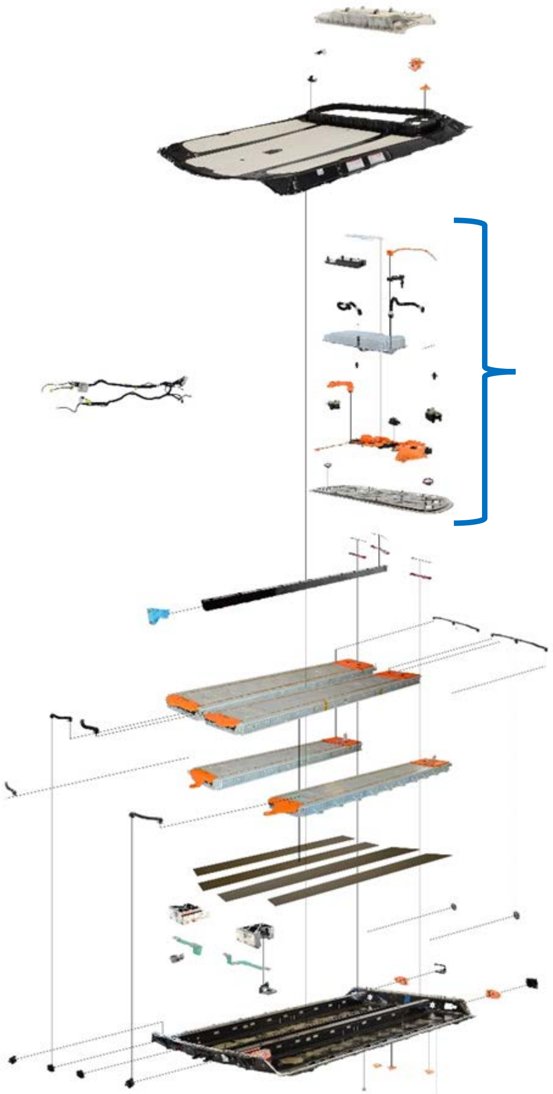




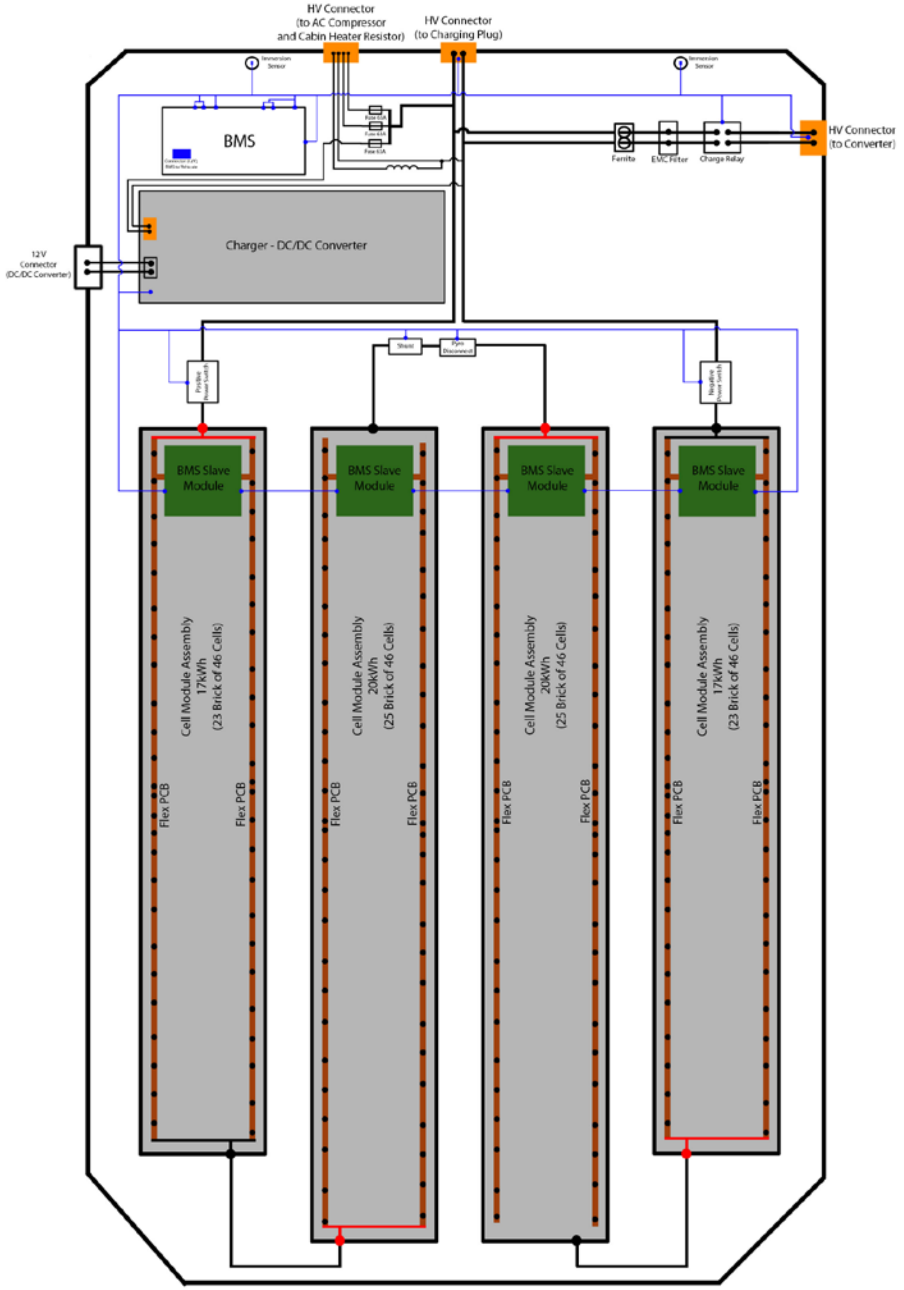


The Battery Pack Architecture

Electrics/Electronics



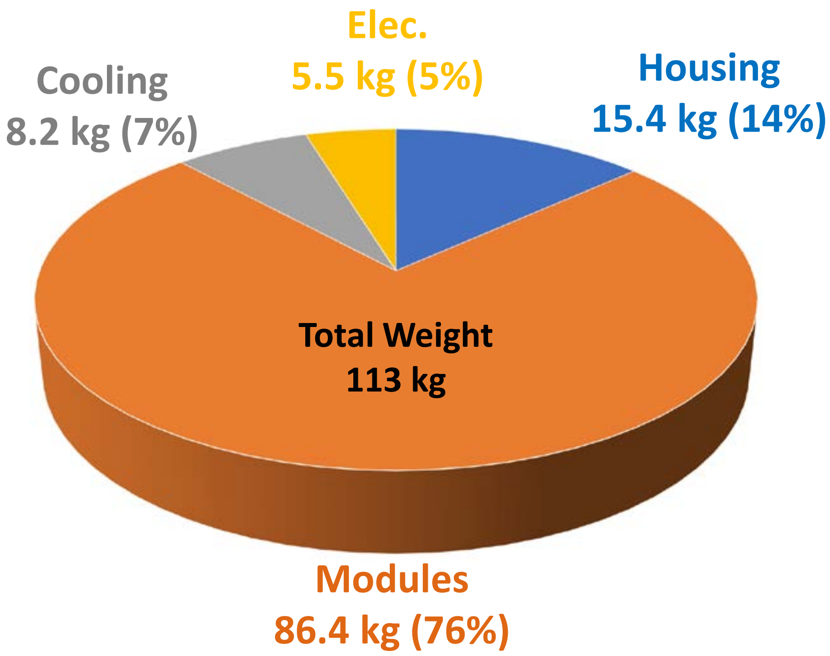
Electronics



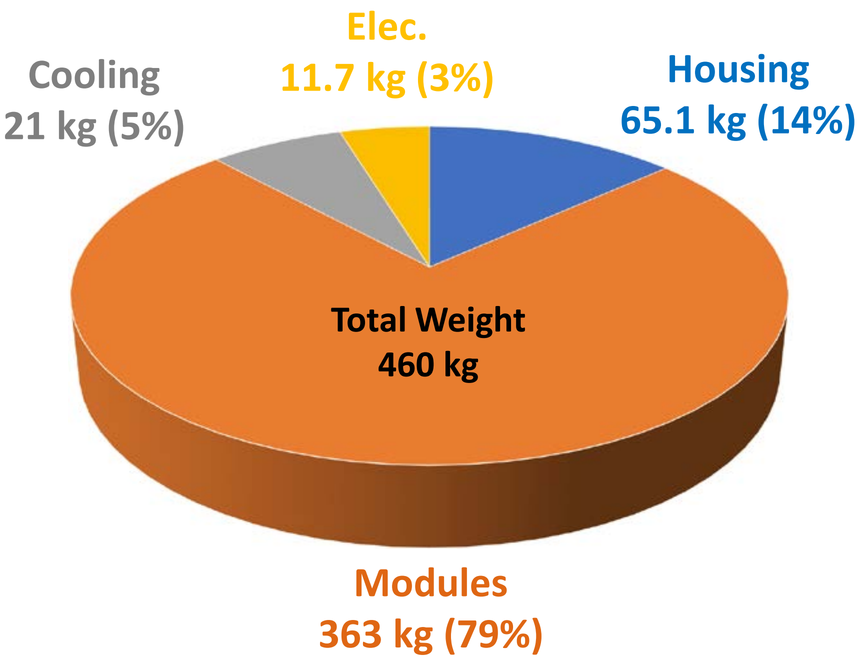
The Battery Pack Architecture

Weight Distribution

Mercedes GLE 550e (PHEV)



Tesla Model 3 (EV)



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Battery Cells Form Factors

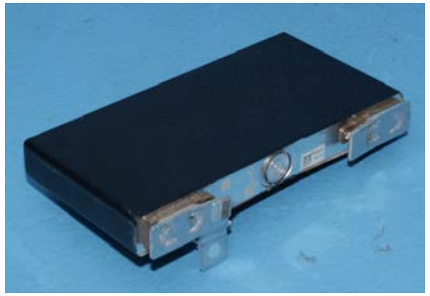
Cylindrical cell

- Standard sizes: 18650, D, AA…
- Steel casing
- Low manufacturing cost
- High specific energy (Wh/kg)
- Good mechanical stability

Pouch Cell

- No standard size, each manufacturer designs its own
- Laminated bag
- High energy density (Wh/L)
- Requires stacking pressure
- Sensitive to moisture and high pressure

Prismatic Cell



- No standard size, each manufacturer designs its own
- Aluminum or steel casing
- Good energy density (Wh/L)
- Commonly used in electric vehicles

Battery Cells (Li-ion): Chemistry and Materials

Anode Materials

Carbon (graphite, hard carbon) → Most common anode material

Graphite with ≈ 1-3 % silicon : C + Si → Silicon brings better specific energy

LTO (Lithium Titanate Oxide) : $Li_4Ti_5O_{12}$ → High power, high cycle life, safe
Low voltage, low specific energy

Major battery cells manufacturers:

Panasonic (Tesla)
Samsung SDI (BMW, VW…)
A123 (GM, Mercedes…)
LG Chem (Renault, GM, Volvo…)
Sanyo, Hitachi, Lithium Energy Japan, Toshiba, CATL…

Cathode Materials

LCO: $LiCoO_2$ → High specific energy but expensive because of the cobalt (mostly used in portable electronics)

LMO: $LiMn_2O_4$ → No cobalt but low specific energy and cycle life. Usually blended with NMC (Nissan Leaf, Chevy Volt…)

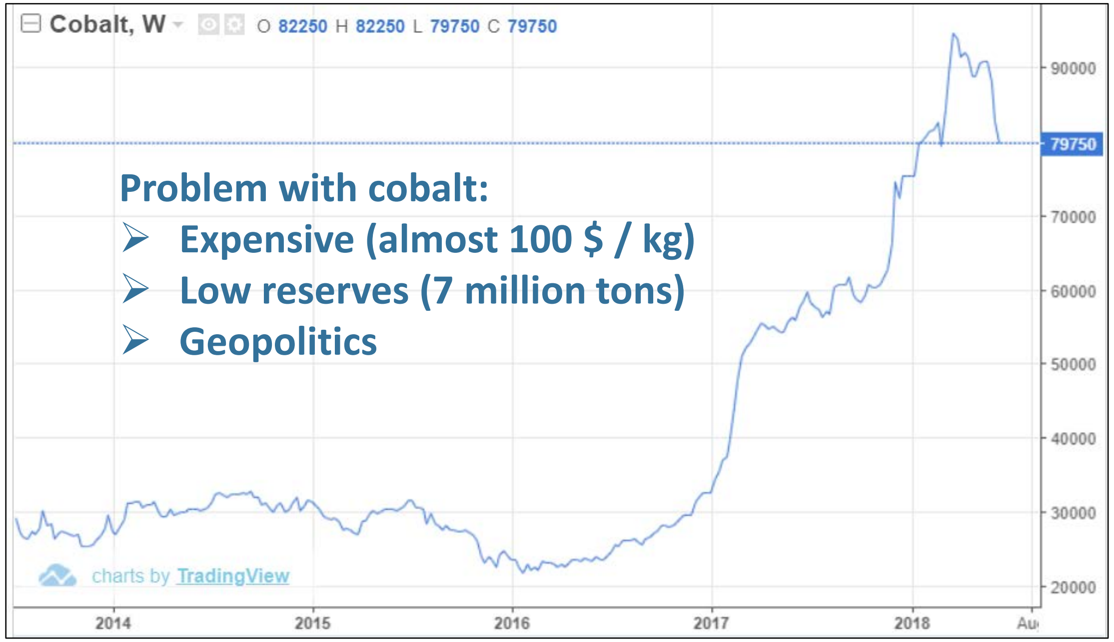
NMC : $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ → High specific energy but high cobalt content. Most common cathode material in EVs

NCA : $LiNi_{0,8}Co_{0,15}Al_{0,05}O_2$ → Highest specific energy, high specific power. Lower cobalt content than NMC but less safe. NCA has Tesla's preference (reduced cobalt content in Model 3)

LFP : $LiFePO_4$ → Long cycle life, high power, very safe but low specific energy

Battery Cells (Li-ion):

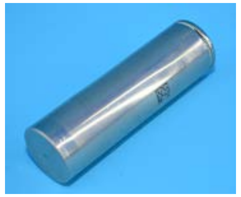
The Cobalt Issue



Problem with cobalt:

- Expensive (almost 100 $ / kg)
- Low reserves (7 million tons)
- Geopolitics

Tesla Model 3



69 g
17 Wh
4416 Cells/vehicle

In previous models, cathode material (NCA) was: $LiNi_{0,8}Co_{0,15}Al_{0,05}O_2$

$LiNi_{0,9}Co_{0,05}Al_{0,05}O_2$

8 kg Li/vehicle (0.1 g/Wh)

≈ 3.5 kg Co/vehicle (0.04 g/Wh)

(As compared to ≈ 10 kg with: $LiNi_{0,8}Co_{0,15}Al_{0,05}O_2$)

Today's trend is to reduce amount of cobalt in EV batteries (NCA and from NMC 111 to NMC 811)

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Battery Cells for Electric Vehicles: Beyond Li-ion and/or better Li-ion

Several new battery chemistries are being studied and developed in laboratories worldwide

Solid-state Li-ion	→	Replaces highly flammable liquid electrolyte by solid electrolyte Higher energy density and safer Could be the next generation of EV battery: Among the major players working on this technology are *Toyota*, *BMW*, *Saft* in partnership with *Solvay, Siemens*…
Titanium Niobiate (TNO)	→	TNO is being developed by *Toshiba* to replace LTO as the anode in Li-ion Higher energy density, fast charging
Lithium Sulfur	→	Uses sulfur as the cathode Higher specific energy Main issues: cycle life, sulfur has low conductivity and expands during discharge Companies like *Oxis energy* or *Sion Power* try to commercialize Li-S batteries
Lithium air	→	Uses air (oxygen) as the cathode Highest specific energy Main issues: cycle life, low power, water and nitrogen filtering *Samsung* and many research labs work on this technology
Other	→	Na-ion, Mg-ion… Other improvements in Li-ion: use of graphene, high capacity cathodes, high voltage cathodes…

Thank you very much for your attention !

Any question ?

Please don’t hesitate to contact us:

Cedric Weiss

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