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Tesla Model 3 Teardown: The Battery Pack

Sept 5, 2019

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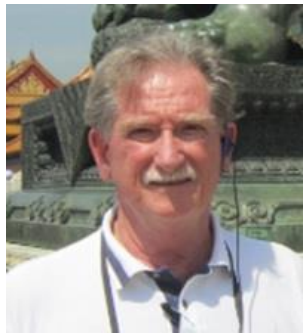
Today's Presenter



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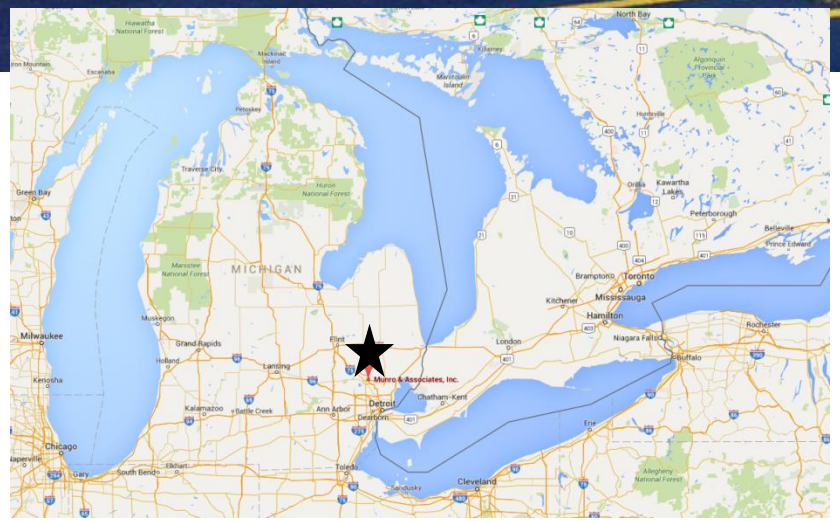

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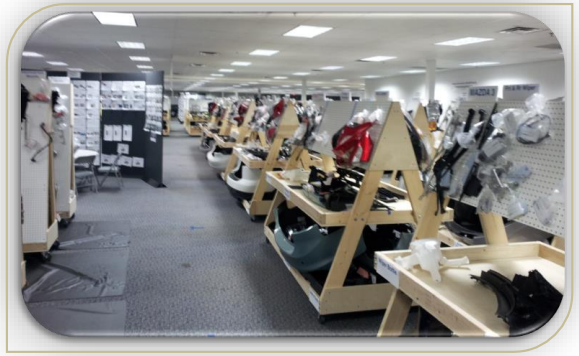

Exterior

Components are examined for technology, cost, weight, labor and quality

Seats

Powertrain (Engines, Trans, Diff, Etc.)

Munro & Associates, Inc.

Your Innovation Partner for:

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- Product Tear-Down
- Reverse Engineering
- Cost & Weight Management
- Lean Product & Manufacturing Process Improvement
- Quality Enhancement
- New Product Development
- Technology Transfer

Mission

Helping Customers consistently maximize product Value, Quality & Profit

Powertrain Summary

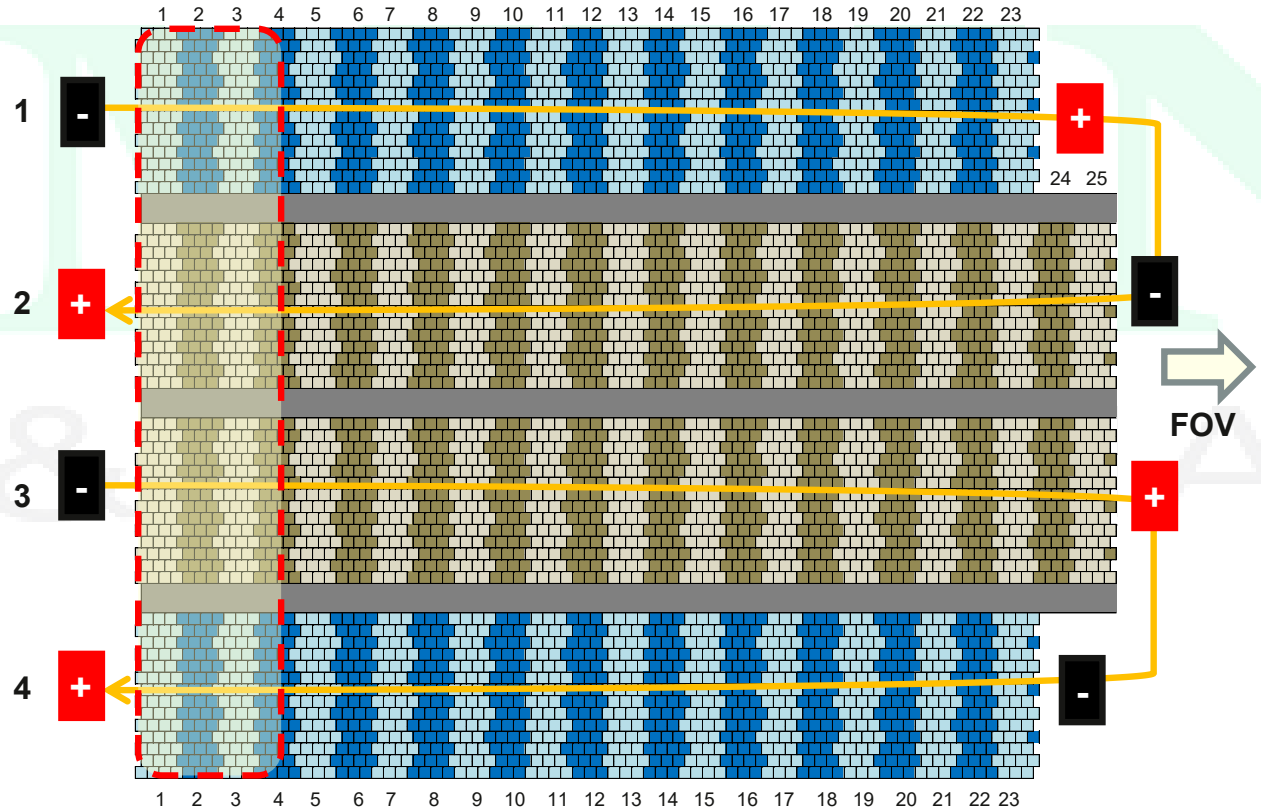
Despite the slow ramp-up it can hardly be disputed that Tesla has developed a sophisticated powertrain. Our analysis of the powertrain has been a journey of discovery and engineering delight from the battery to the gearbox, the high voltage electronics, and supporting battery management systems. Each of these systems exhibits a step beyond the Model S and demonstrates Tesla's continuous aggressive approach to push technology boundaries.

The Model 3 75kWh long range battery pack is a non-serviceable assembly constructed of an upper and lower steel enclosure. It is glued and screwed together then secured to the floor structure with 48 bolts, some of which can only be accessed from the inside of the vehicle under trim components. On the top of battery pack cover, where the battery pack meets the floor pan, is an insulating fiber layer to provide noise isolation, thermal isolation, and vibration damping. The battery pack is positioned between the sills and spans the length of the vehicle from the front of dash to back the rear seat. All battery management components are contained in the rear of the battery pack that can be accessed under the rear seat cushion and steel access cover as illustrated below.

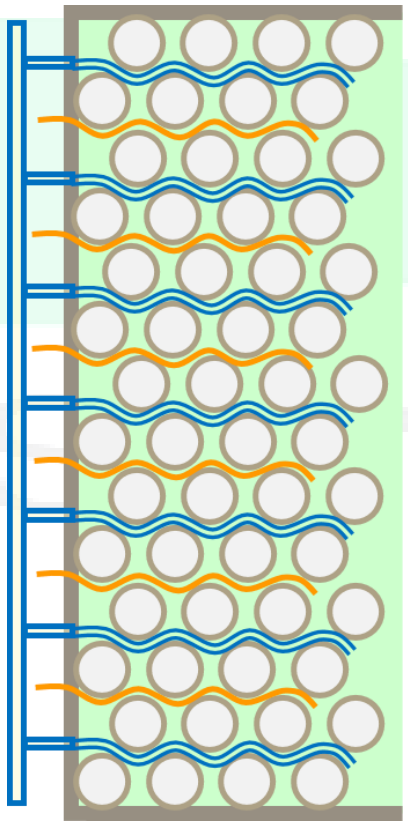
Weight as removed: 473.55 kg / 1,044 lbs.

Powertrain Summary

The battery pack contains 4416 cells housed in four modules. Two of the four modules have 23 bricks with 46 cells per brick and the other two have 25 bricks with 46 cells per brick. Within each brick the cells are in parallel, while the bricks are in series. Each brick in series holds a nominal 3.5 volts to deliver a total of 350 volts (~3.5*(23+25)*2). The measured variation of voltage between bricks is 2 to 3 mV. Within each brick are seven coated aluminum serpentine micro extrusion cooling channels running lengthwise between the cells to transport the ethylene-glycol through the bricks. The seven cooling channels alternate with six fiber spacers also running lengthwise through the module. These fiber spacers are constructed of a thermally insulating material.



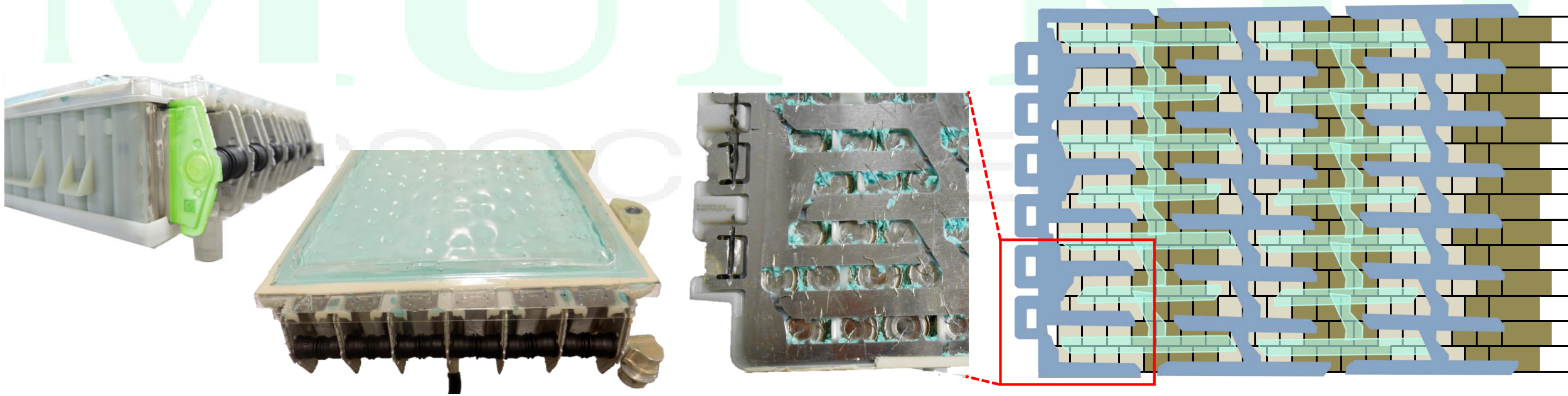
Approximate location of battery management system



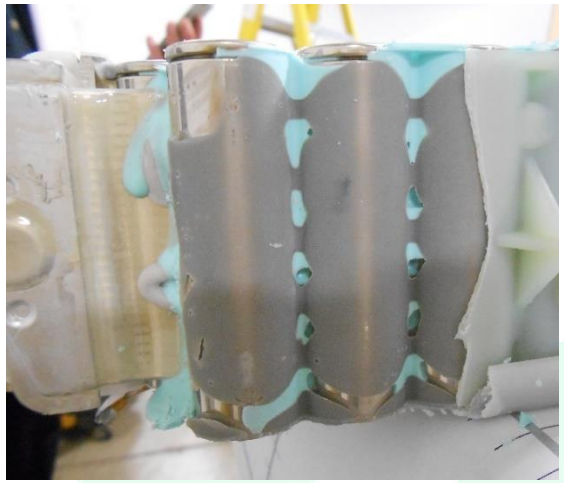
Powertrain Summary

The Model 3 battery module uses the latest generation of lithium ion battery cells called the 2170 manufactured by Panasonic at Tesla's Gigafactory 1 in Nevada. In Tesla's first quarter 2018 update it is stated that the Model 3 has *"the highest energy density cells used in any electric vehicle. We have achieved this by significantly reducing cobalt content per battery pack while increasing nickel content and still maintaining superior thermal stability. The cobalt content of our Nickel-Cobalt-Aluminum cathode chemistry is already lower than next-generation cathodes that will be made by other cell producers with a Nickel-Manganese-Cobalt ratio of 8:1:1."*

Each module has a 33% glass filled nylon upper and lower trays and two longitudinal sides. Within the module each battery is surrounded by glue then topped with the brick buses that are wire bonded to the cells. The assembly is then capped with the upper tray and a non-electrically conductive, thermally conductive foam that is injected into the assembly to fill the voids. The cooling channels, the fiber spacers, adhesive, and foam help to ensure the cells within the module remain in their designated positions and isolated from neighboring cells to minimize conductive heat transfer between the cells.



Eye Catching Features



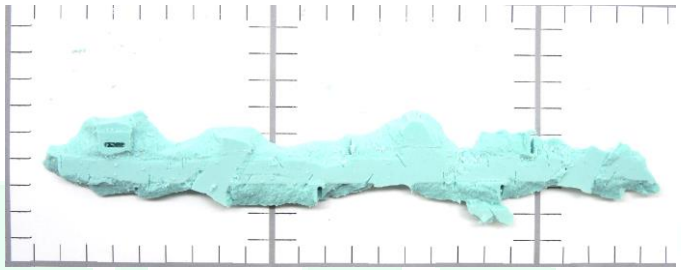
Description:

- Adhesive is used to attach the battery cells to the cooling channels and the covers of the battery module.

Advantages:

- The thermally conductive adhesive minimizes vibration between components.

Eye Catching Features



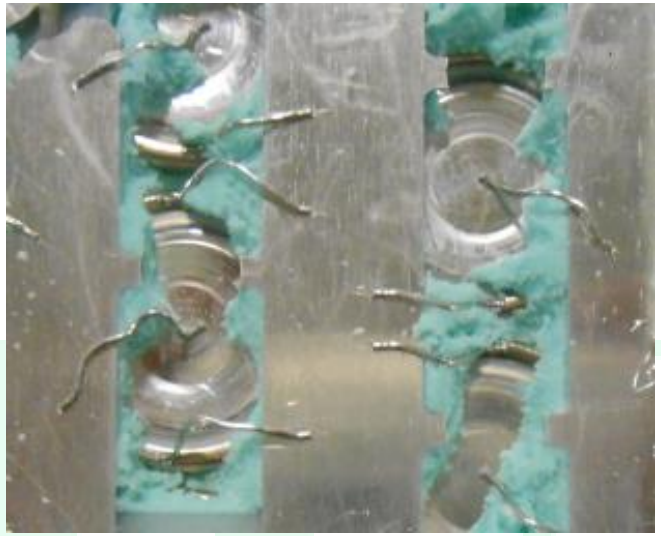
Description:

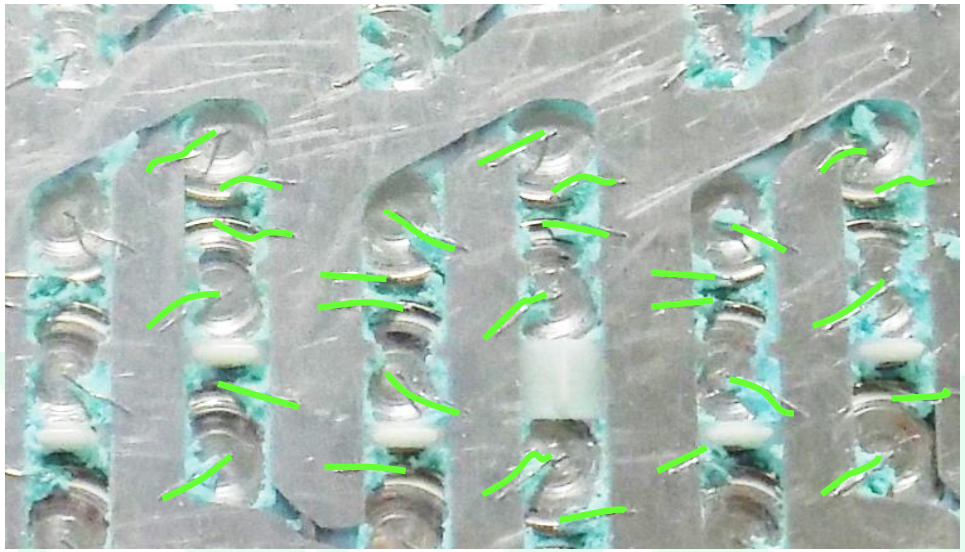
- The battery packs are filled with a non-electrically conductive, thermally conductive potting compound.

Advantages:

- The potting isolates the battery cells from vibration and further ensures the cells within the module remain in their designated positions.

Eye Catching Features





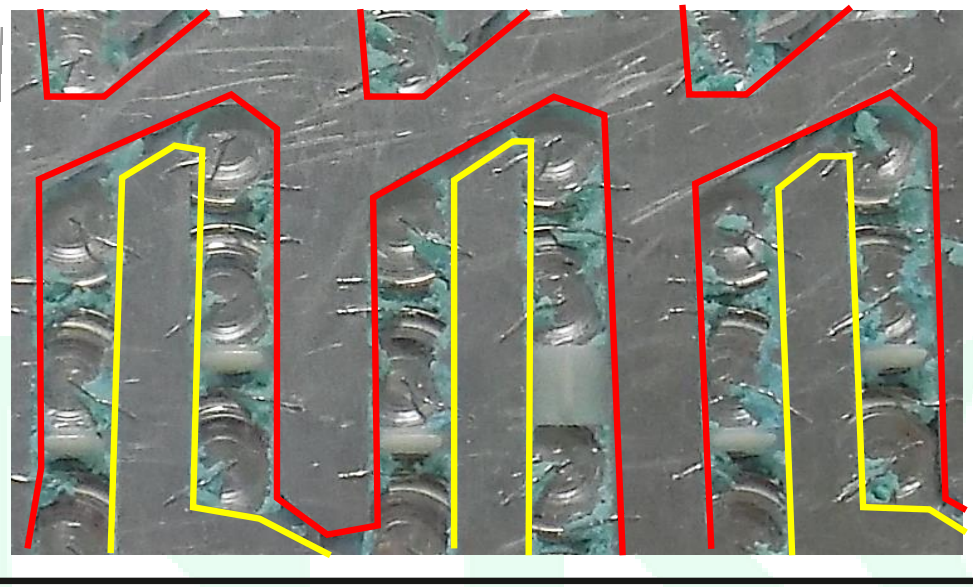
Description:

- The Model 3 uses a wire bonding technique to wire bond the batteries to the current collectors.

Advantages:

- In an overcurrent or short circuit condition, the wires will break to ensure no arcing occurs.

Eye Catching Features



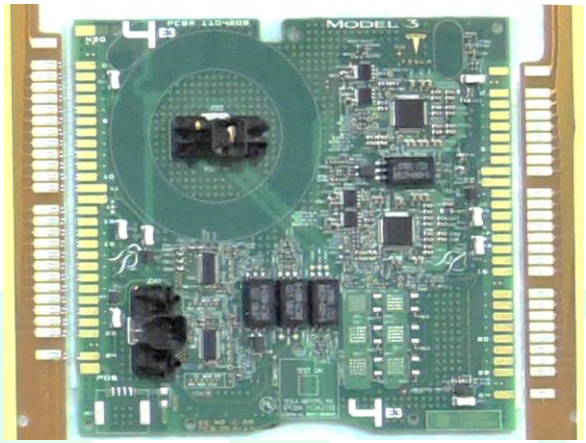
Description:

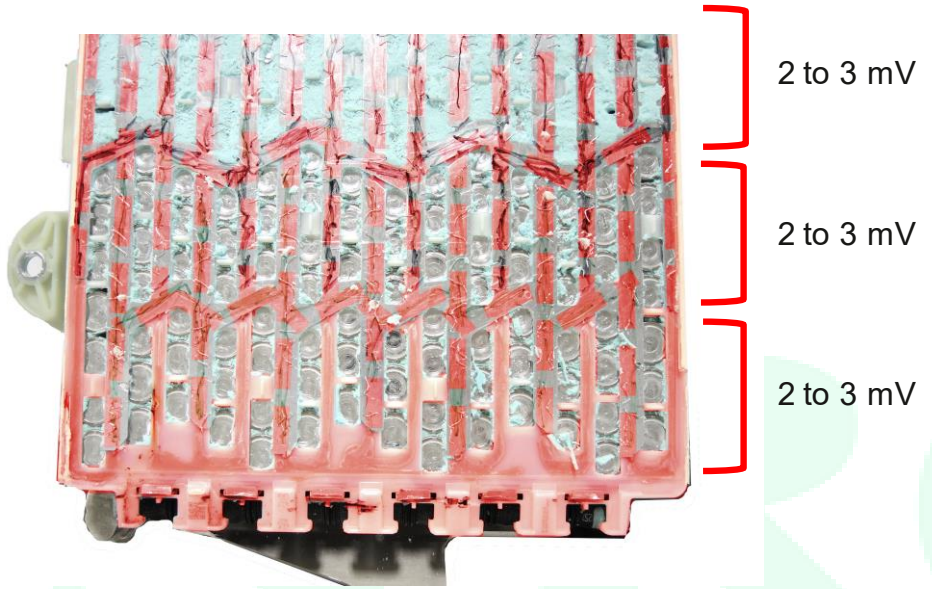
- The Model 3 battery pack has 96 total current collector plates or conductors located on top of the batteries. The cells are wire bonded to the conductors.

Advantages:

- The wire conductor connection to the battery cells and current collector plates creates a frangible disconnect system when the battery pack system and electric vehicle are exposed to a predetermined mechanical or thermal force or event.

Eye Catching Features





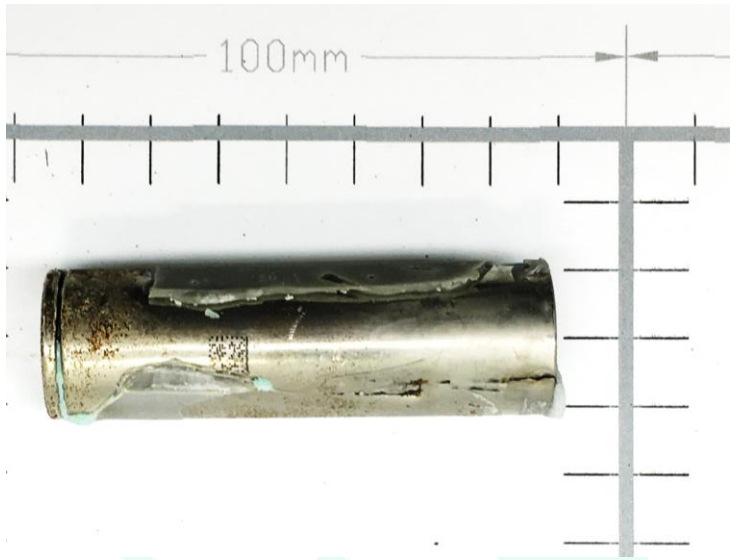
Description:

- The battery management system (BMS) controls the voltage of the 23 to 25 individual brick sections within 2 to 3 millivolts.

Advantages:

- This precise level of voltage variance demonstrates an improved methodology for balancing batteries and is closer than what is typically achieved in a standard battery pack.
- Reference patent US7602145B2 Method of Balancing Batteries

Eye Catching Features



Description:

- The Model 3 battery cell is the 2170 with new chemistry and lower cobalt.

Advantages:

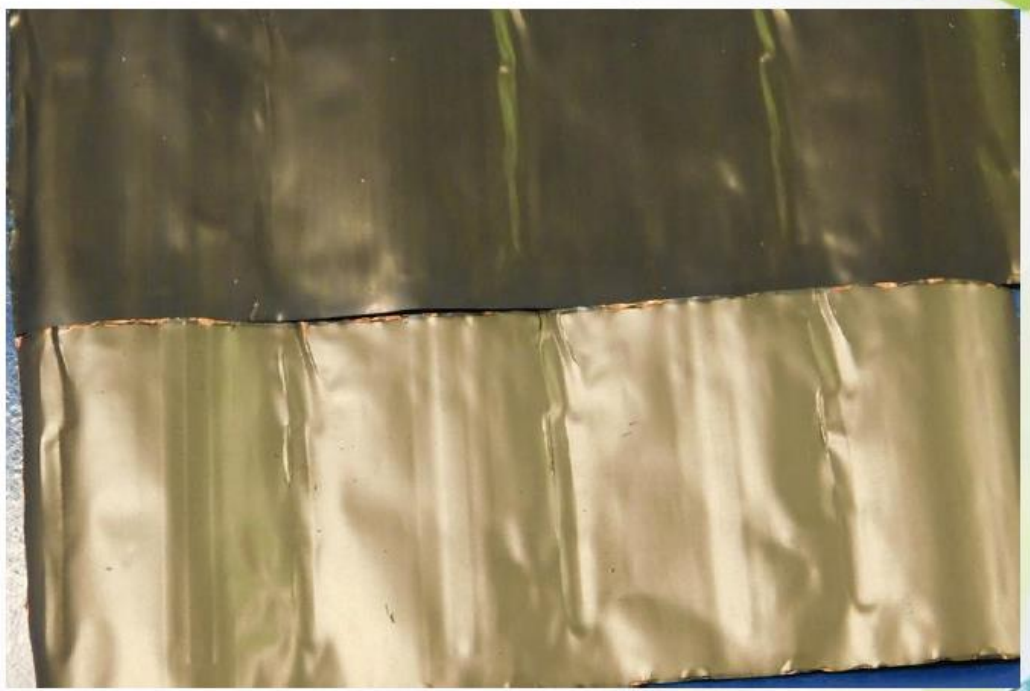
- According to Elon Musk, it's "the highest energy density cell in the world, and also the cheapest." The 2170 cell is around 50% larger by volume than the 18650, but it can deliver almost double the current (the 18650 delivers 3,000 mA, and the 2170 has been tested at 5,750-6,000 mA).

https://evannex.com/blogs/news/tesla-s-new-2170-cell-packs-more-power

Cell Components

Separator

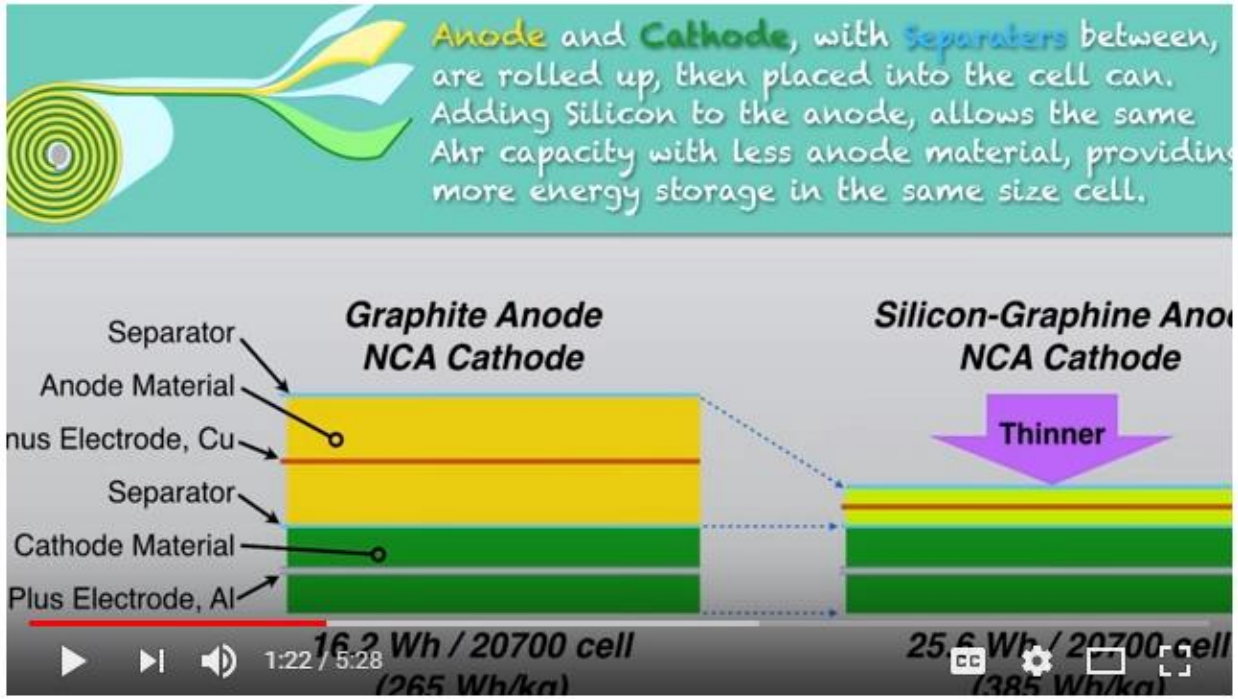
Coating Information	Cathode	Anode	Separator
Foil Thickness (µm)	13.9	7	~13
Loading (mg/cm^2)	24	13.5	N/A
Press Density (g/cm^3)	3.617	1.628	N/A

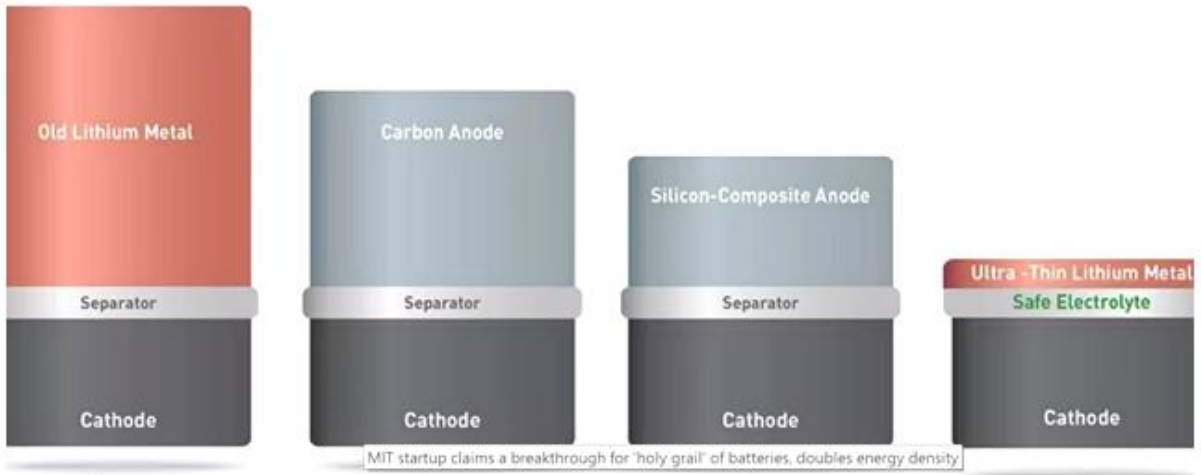


Cathode

Anode

Battery





Gen 0
Li-Metal
100-200 Wh/kg
200-300 Wh/L
Dangerous

Gen 1
Li-ion
200-250 Wh/kg
600 Wh/L
Safe

Gen 2
Li-ion
250-300 Wh/kg
700 Wh/L
Safe

Gen 3
Li-Metal
400-500 Wh/kg
1200 Wh/L
Safest

Tesla's 18650 cells vs 2170

MUNRO & ASSOCIATES, INC.

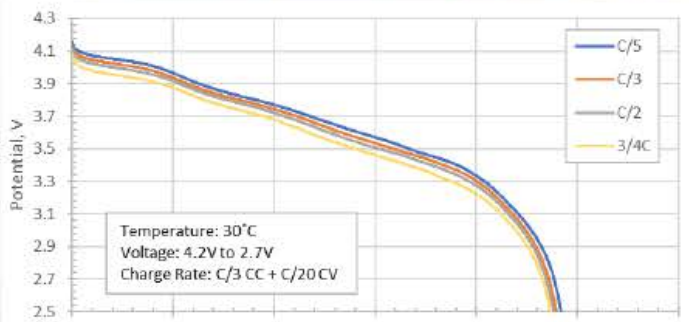
Basic Performance Metrics

Metric	Value	Unit
Nominal Capacity	5.0	Ah
Nominal Voltage	3.6	V
Weight	0.06857	g
Height	70	mm
Diameter	21	mm
Volume	24245.24	mm^2
	0.024245	L
Nominal Energy	18	Wh
Specific Energy	262.5	Wh/kg
Energy Density	742.4	Wh/L

B3 Report

	Prismatic	Pouch	Cylindrical
Supplier	SDI	LGC	Panasonic
BEV example	BMW i3 MC	ZOE Gen2/Bolt	Model 3
SOP	MY17	MY17	MY17
Cathode	LMO-NCA-NCM622	NCM622	NCA
Anode	Gr	Gr	Gr/Si
Capacity Ah	94	59	4.75
Voltage V	3.7	3.7	3.6
Wh	347.8	218.3	17.1
Cell size W mm	173	127.6	21.3
H mm	125	325	70.3
T mm	45	11.3	Cy
Cell volume Litter	0.973	0.469	0.025
Cell weight Gram	1,841.0	905.8	65.8
Volumetric Energy Density Wh/L	357	466	683
Gravimetric Energy Density Wh/kg	189	241	260

USABC Standard Capacity 30˚C, C/3 Charge, C/3 Discharge yields ***4.8Ah***

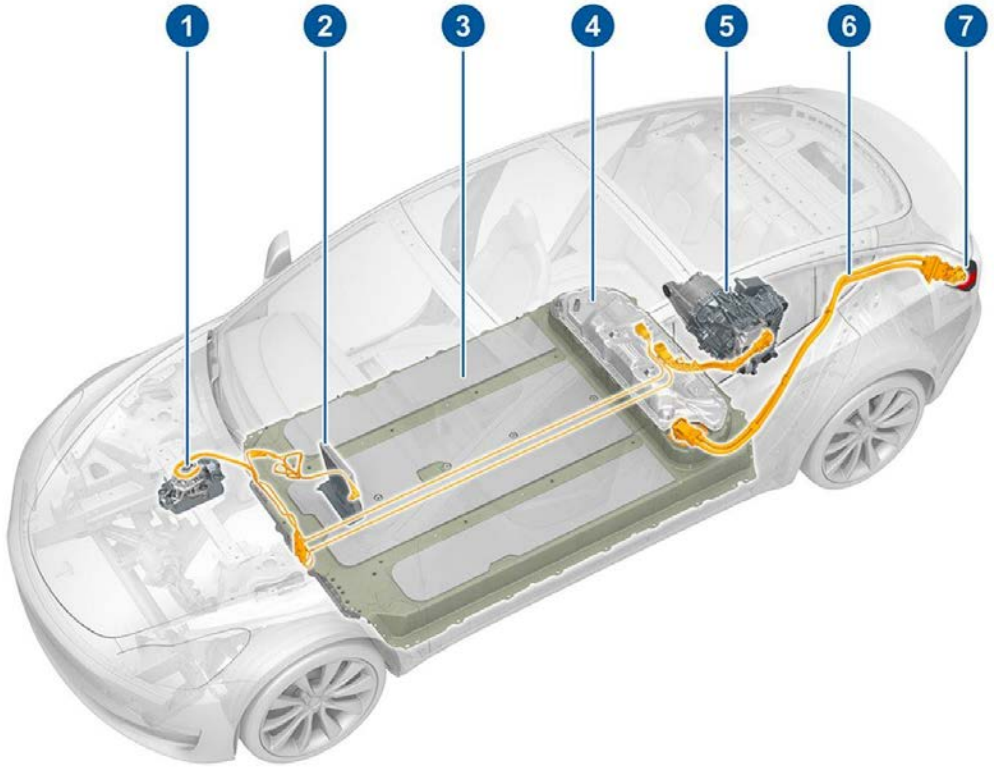


Battery

Element	Units	Tesla Model 3 Anode (Rinsed)	Tesla Model 3 Anode	Tesla Model 3 Cathode (Rinsed)	Tesla Model 3 Cathode
Ni	ppm per electrode active mass	41.2	53.6	589000	586000
Mn		0.136	0.319	2.56	2.57
Co		1.76	2.18	27700	27500
Li		9510	10900	65100	65400
Al		9.2	14.6	n/a	n/a
B		n.d.	n.d.	n.d.	n.d.
Ca		63.8	60	40.3	40.9
Cr		13.4	15.2	n.d.	n.d.
Fe		46	71	1240	1260
Mg		6.32	6.42	65.1	65.8
Na		336	498	14.3	89
P		6370	12700	808	3780
S		45	37	166	174
Ti		31	31.7	3.9	3.4
Zn		6.93	3.02	8.05	7.6
Zr		33.3	56.5	n.d.	n.d.

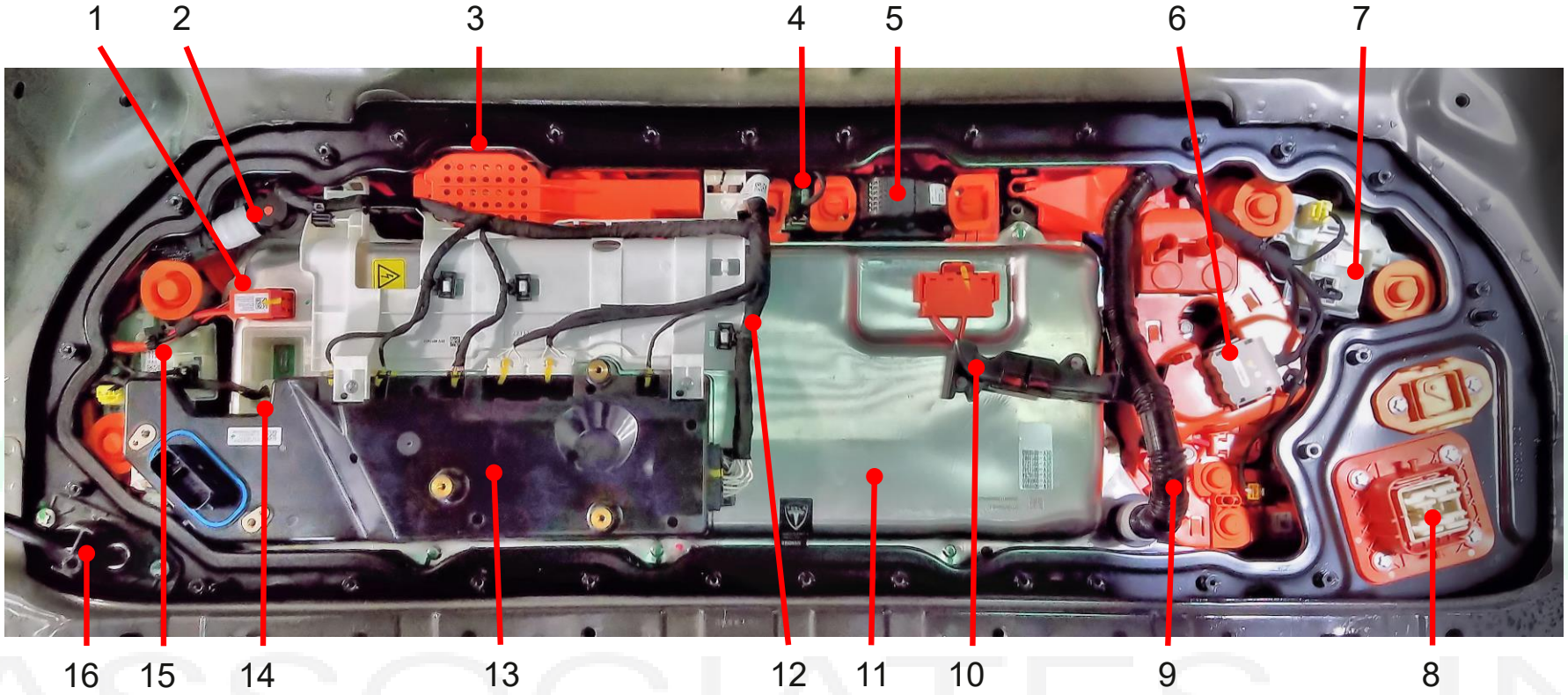
High concentrations of Fe, beyond impurity levels

HIGH VOLTAGE COMPONENTS



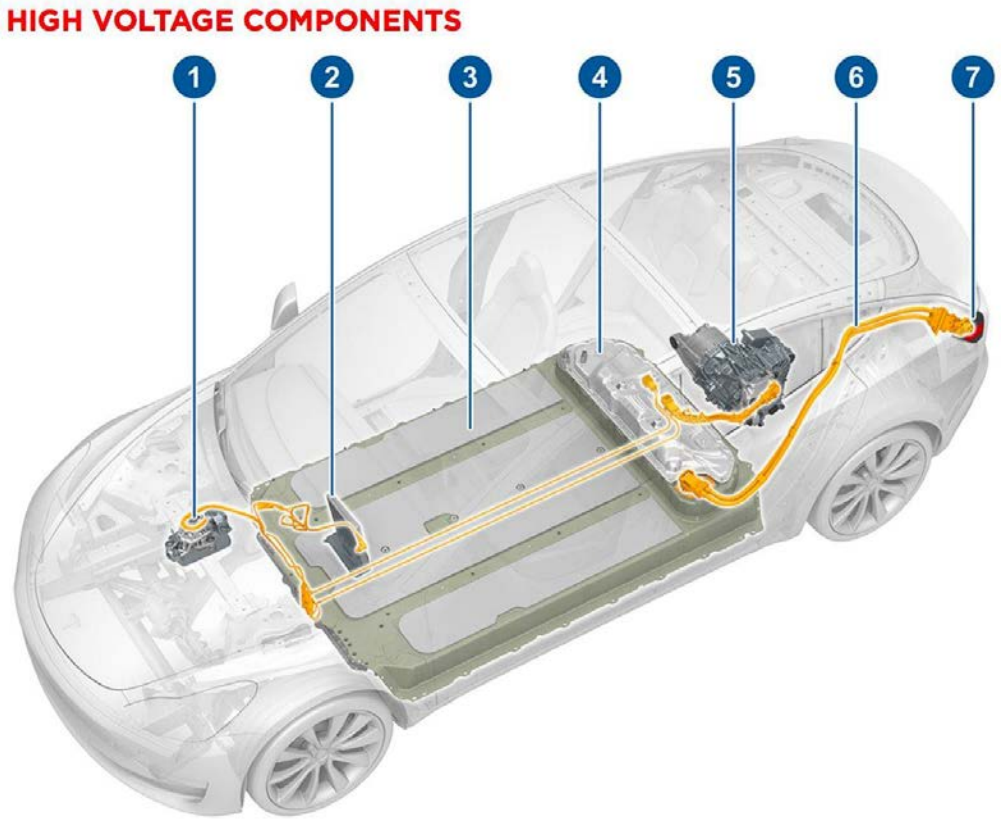
1. A/C Compressor
2. Cabin Heater
3. High Voltage Battery
4. High Voltage Battery Service Panel
5. Rear Drive Unit
6. High Voltage Cabling
7. Charge Port

Penthouse Component Identification



1. High Voltage (HV) Output to Battery Bus
2. Coolant Line for On Board Charger
3. High Voltage Fuses
4. HV Current Monitoring Shunt
5. HV Pyrotechnic Fuse
6. FC Contactor Connection
7. Negative HV Contactor
8. Charge Port Cable Connector
9. Coolant Line for On Board Charger
10. On Board Charger Input from Charge Port
11. Power Conversion System (PCS)
12. Battery Control System Harness
13. High Voltage System Controller
14. Control System Connection to OBC
15. Positive HV Contactor
16. 12V Output to Vehicle from OBC

Charging Cable



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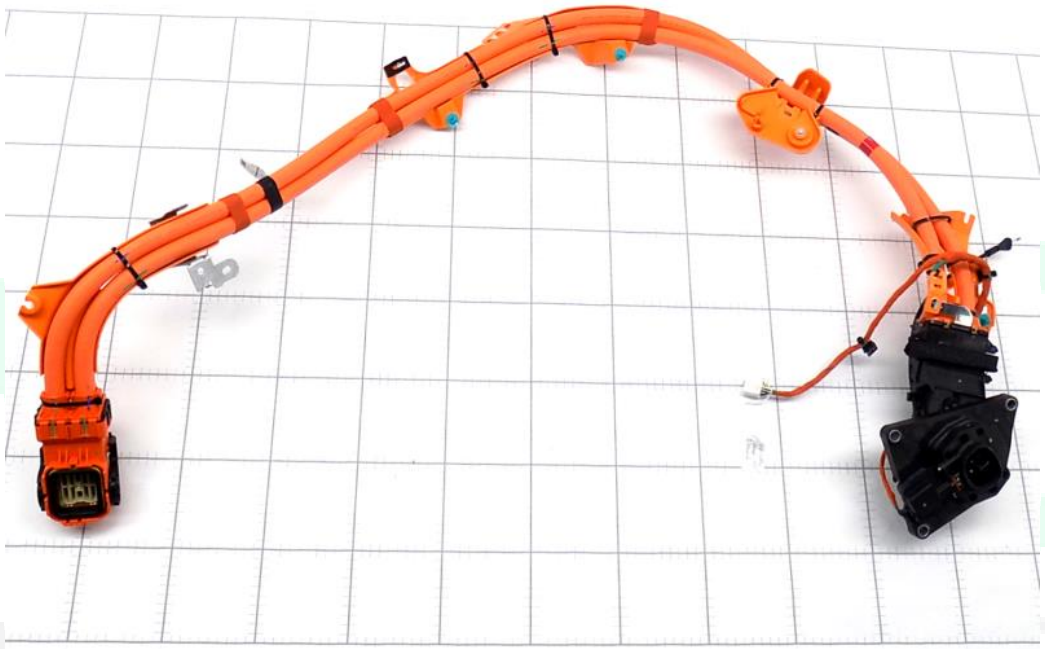
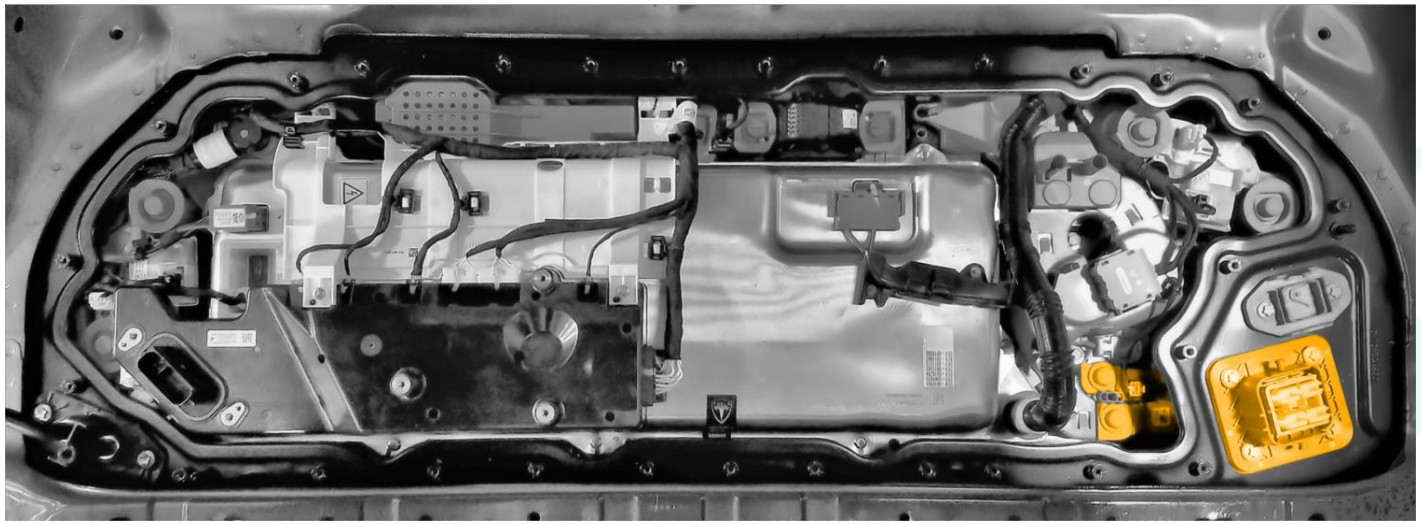
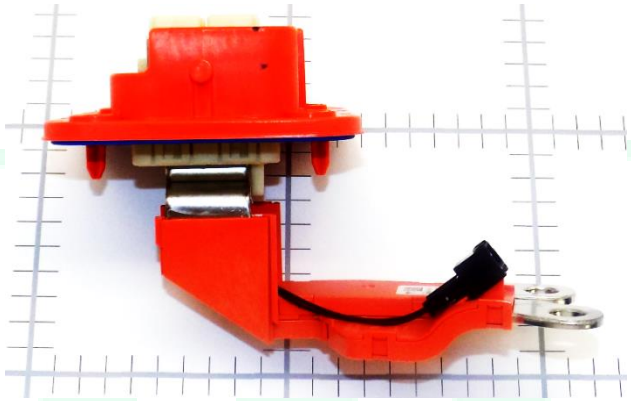
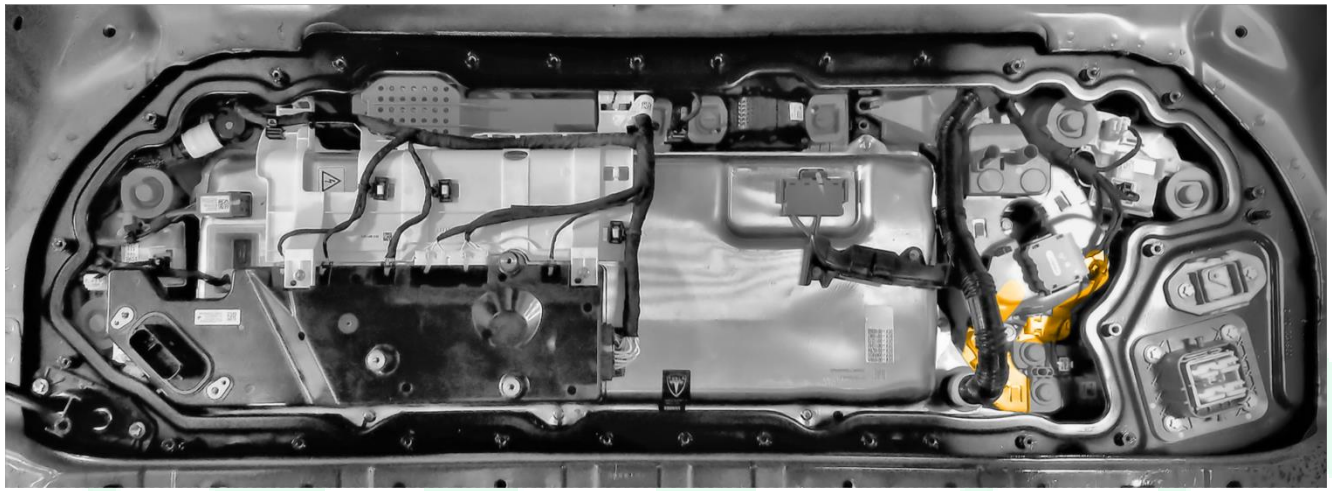


Charging Cable Connector

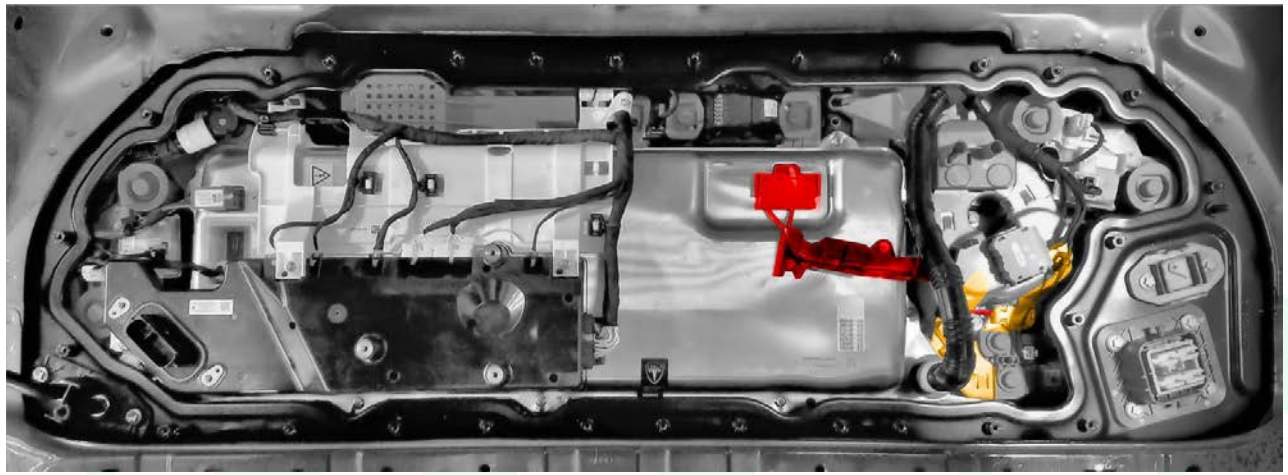




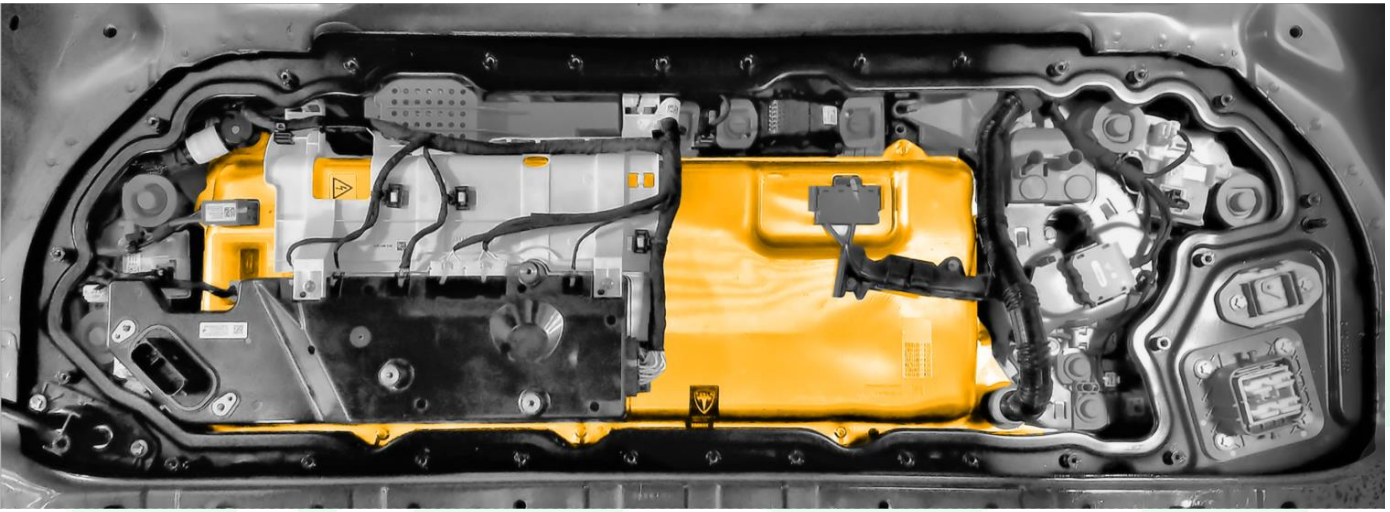
Flexible Busbars



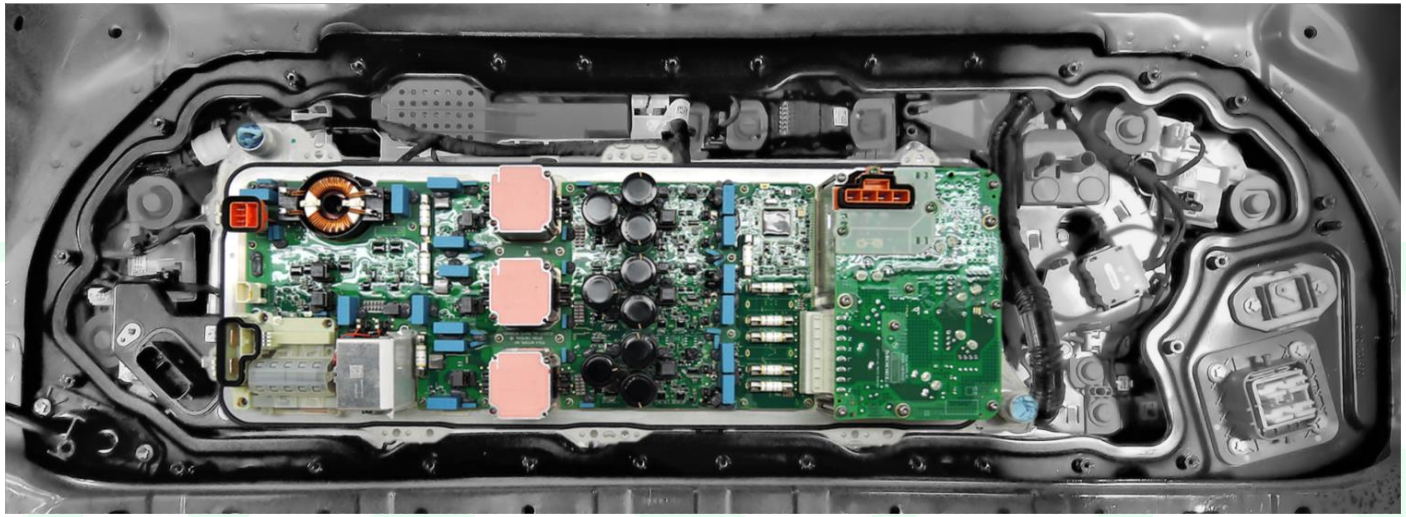
AC Filter Harness

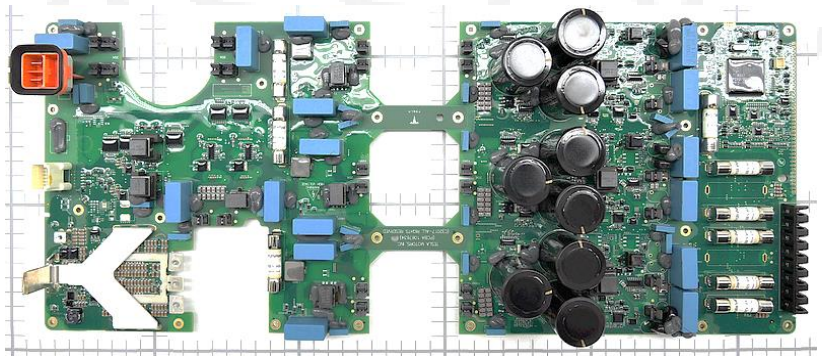


Power Conversion System (PCS)

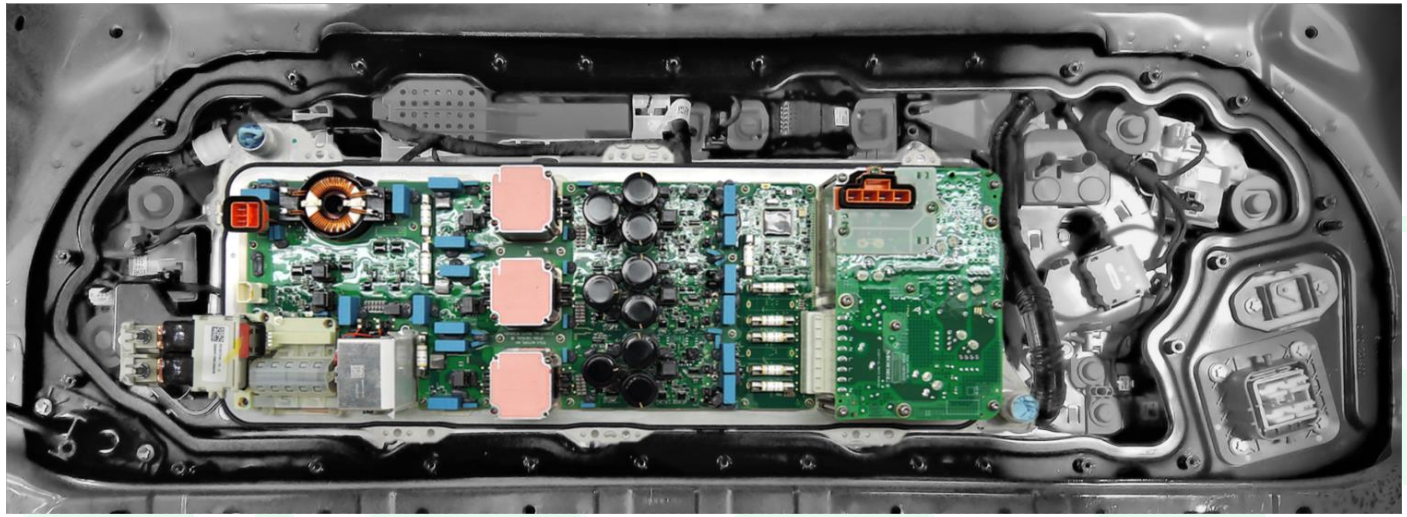


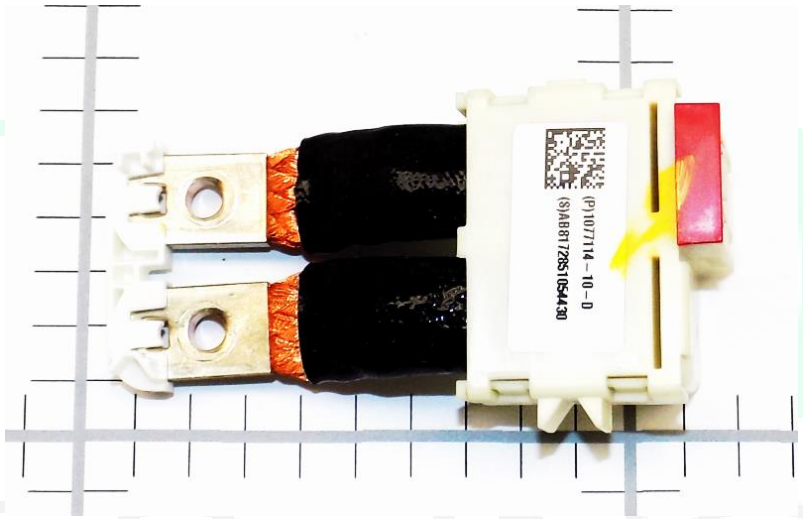
Power Conversion System Boards (PCS)



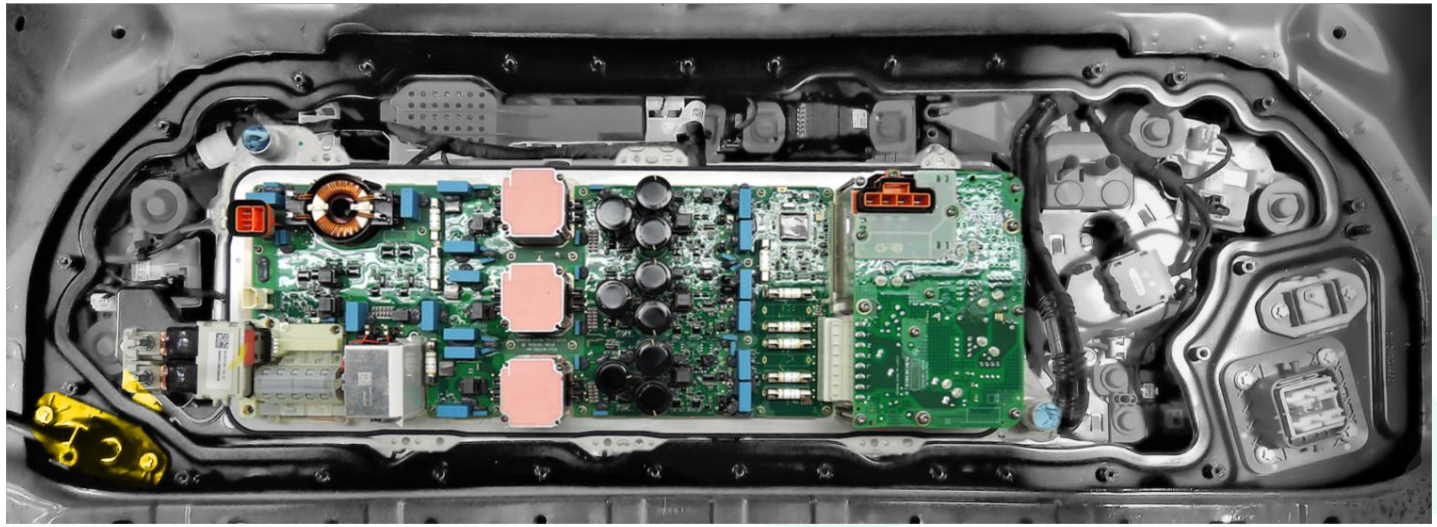


12V DC-DC Jumper

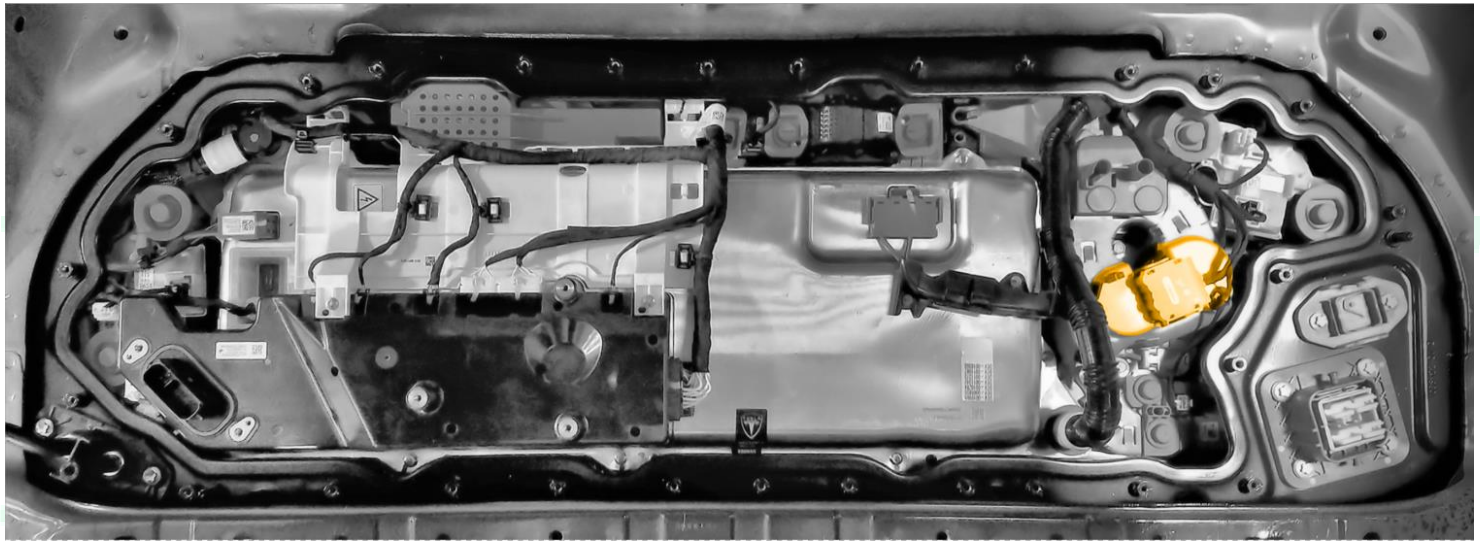




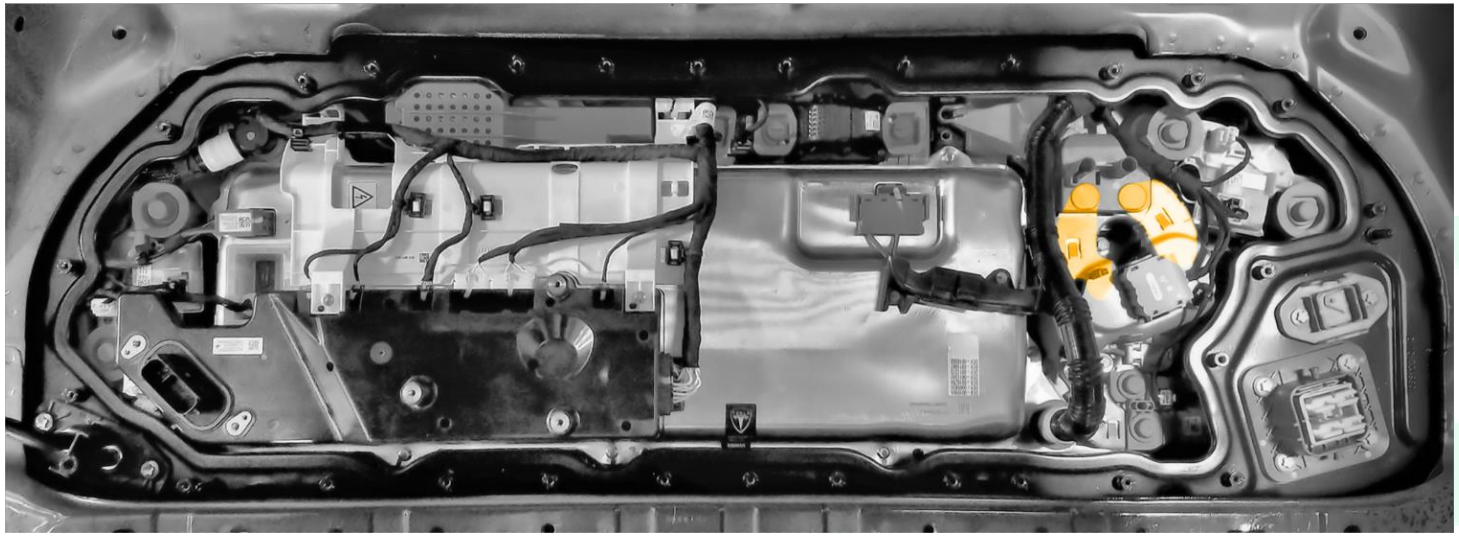
12V Output to Vehicle Electronics



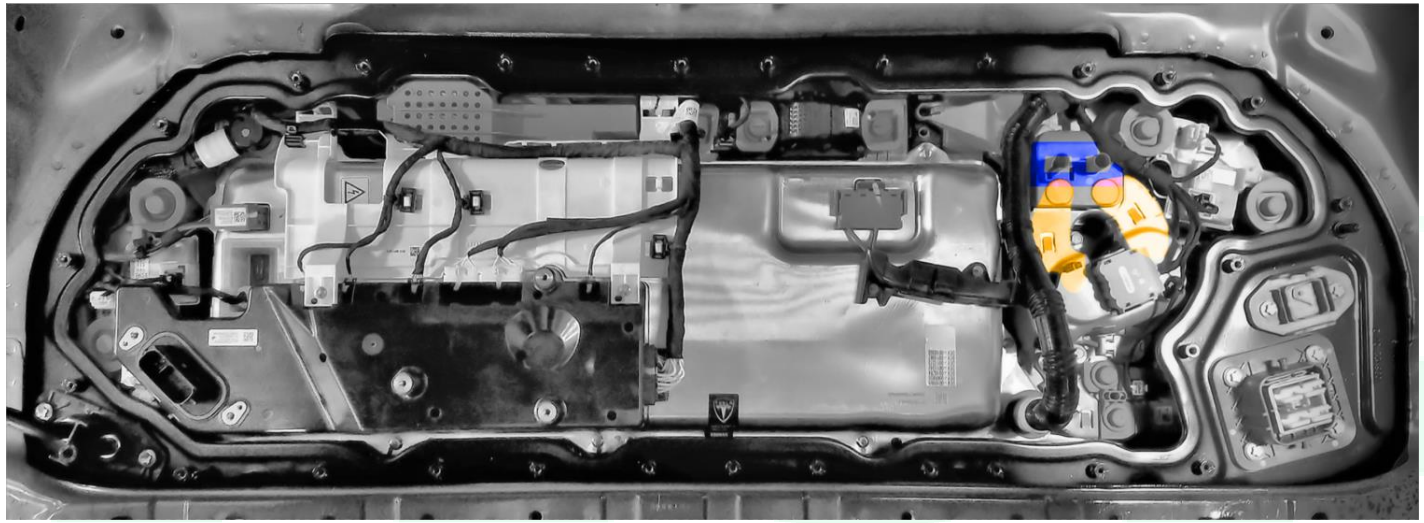
Fast Charge Contactor

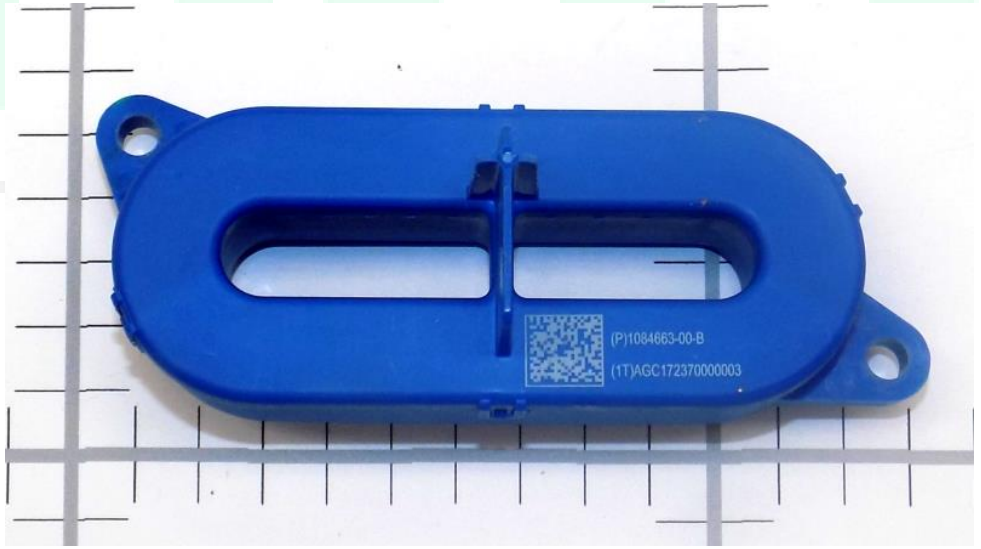


Flexible Busbars

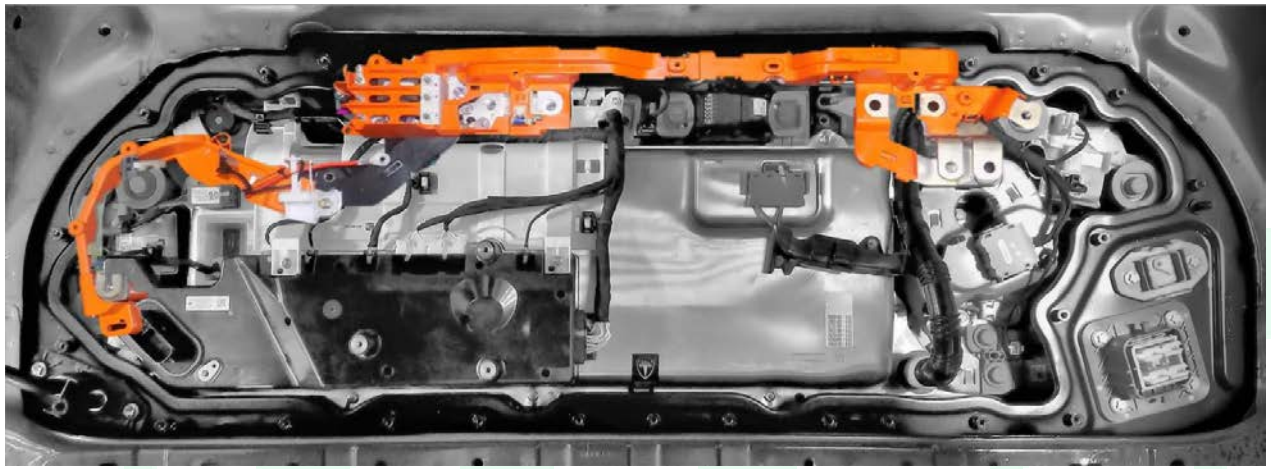


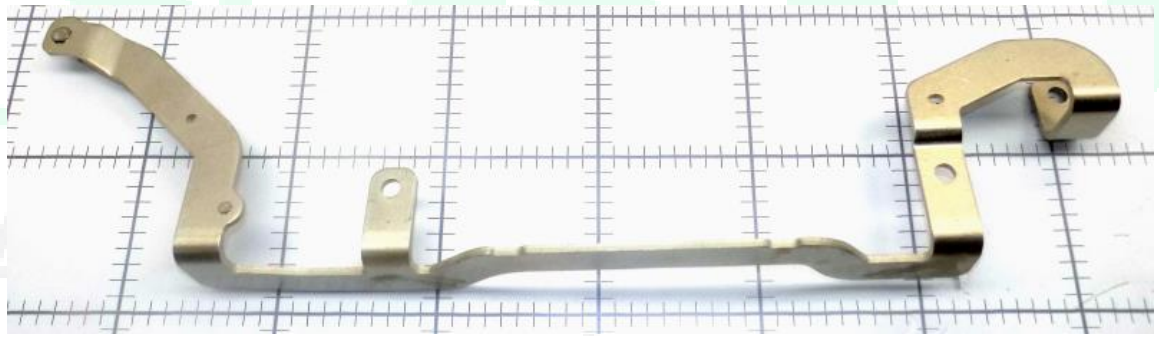
Filter Choke



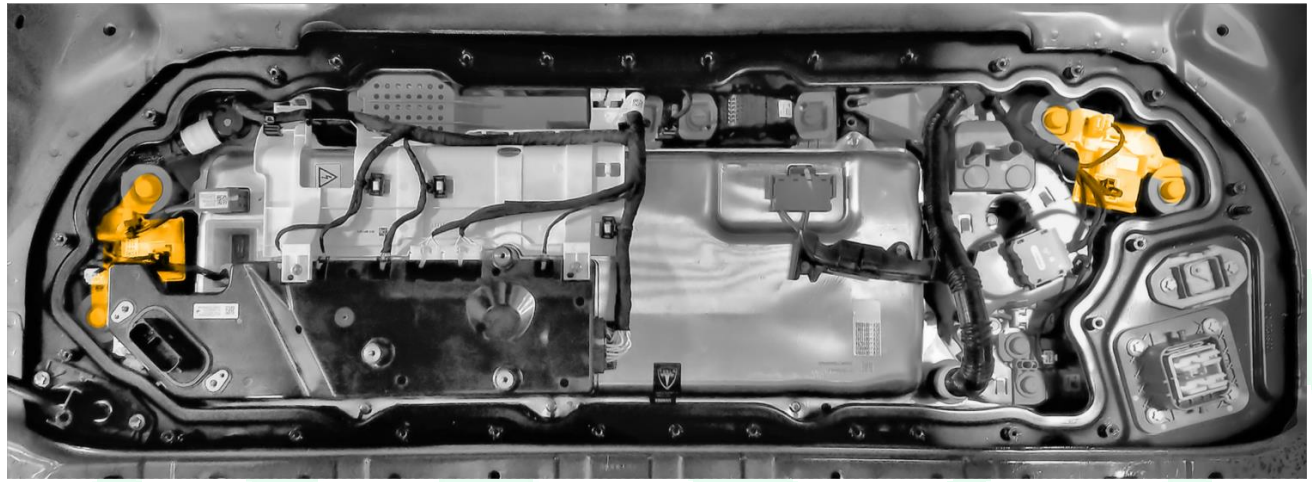


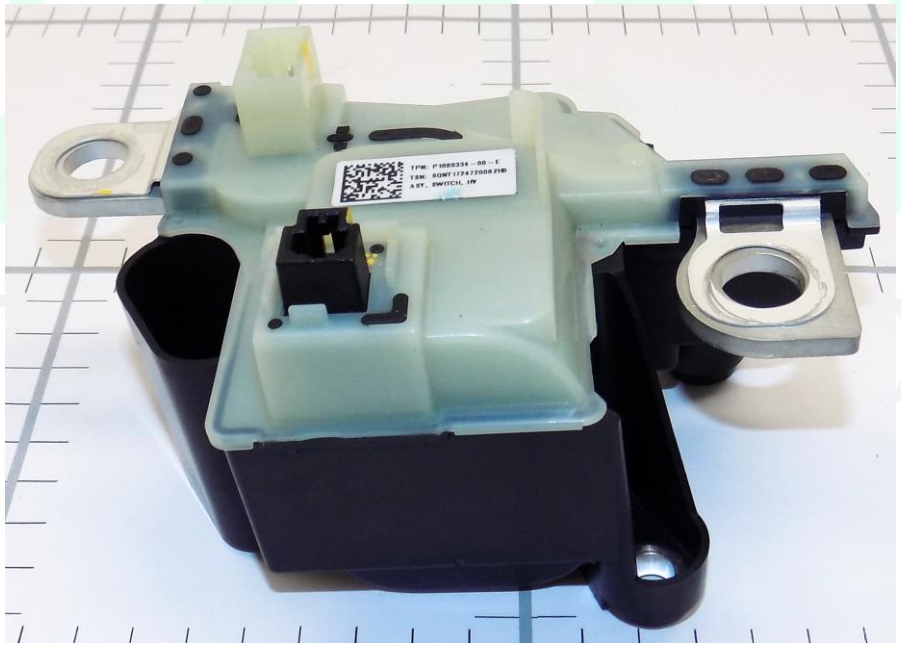
HV Travel Busbars



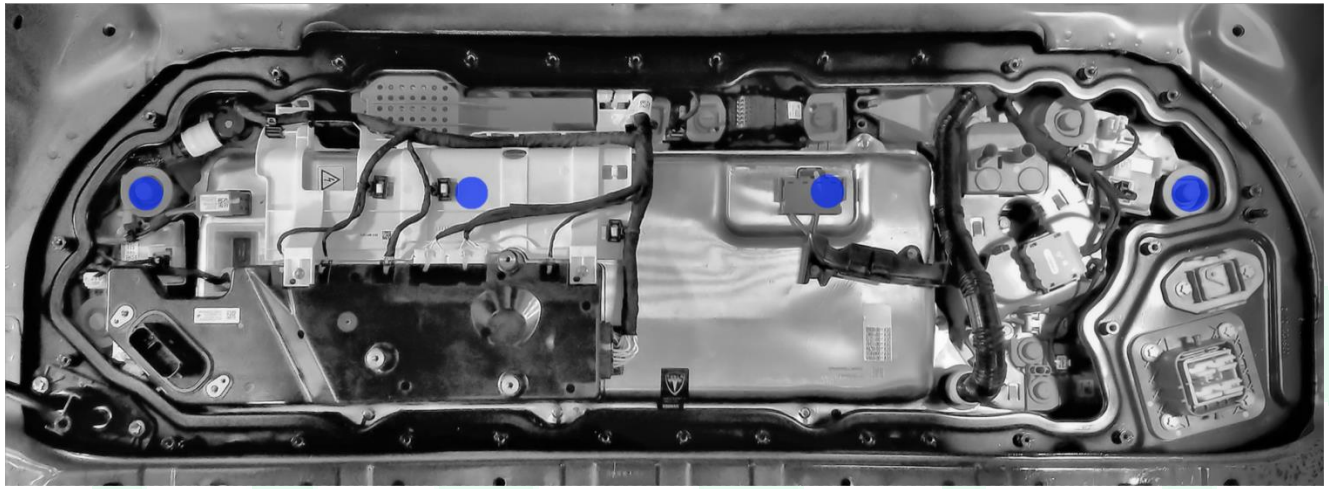


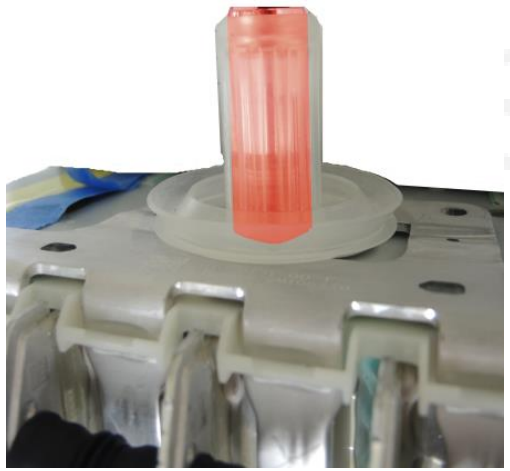
Battery Pack Contactors

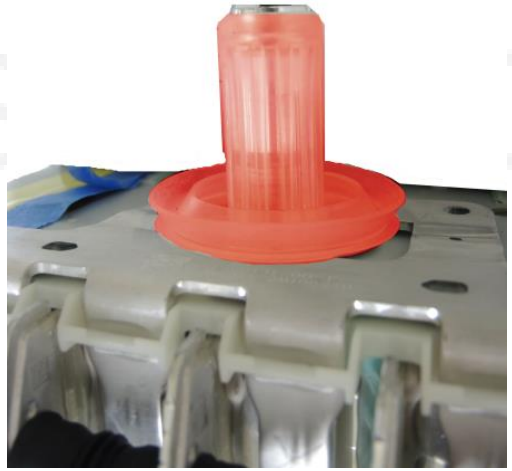


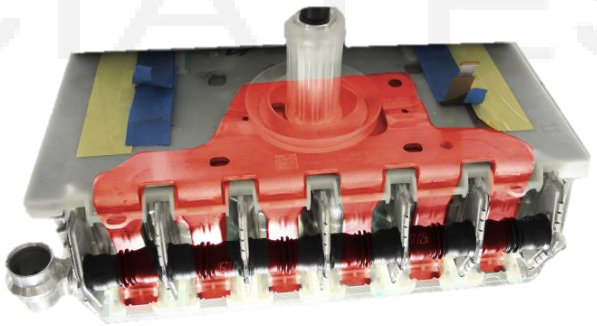


Battery Pack Contacts

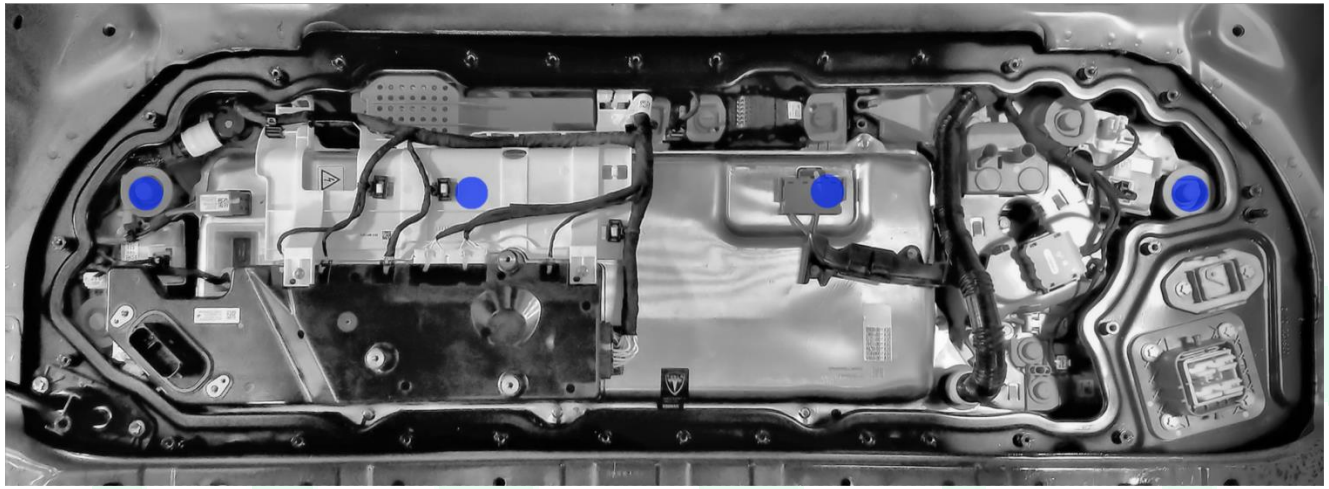


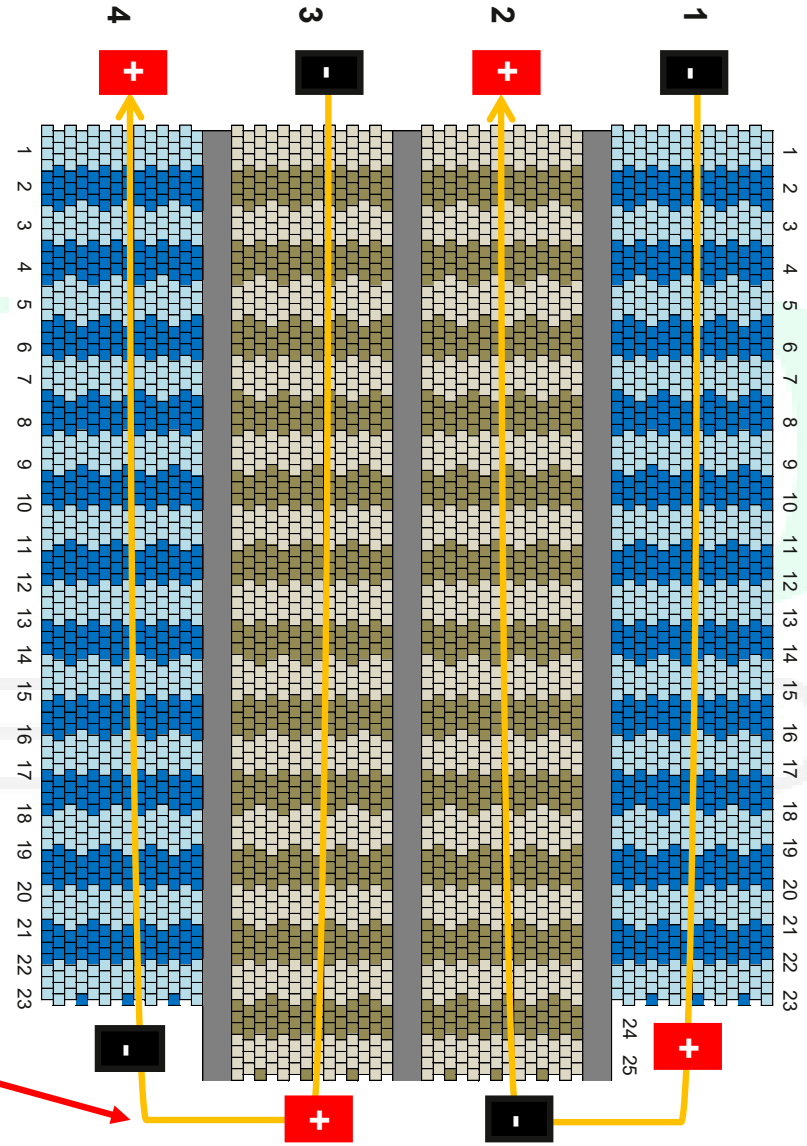






Battery Pack Contacts

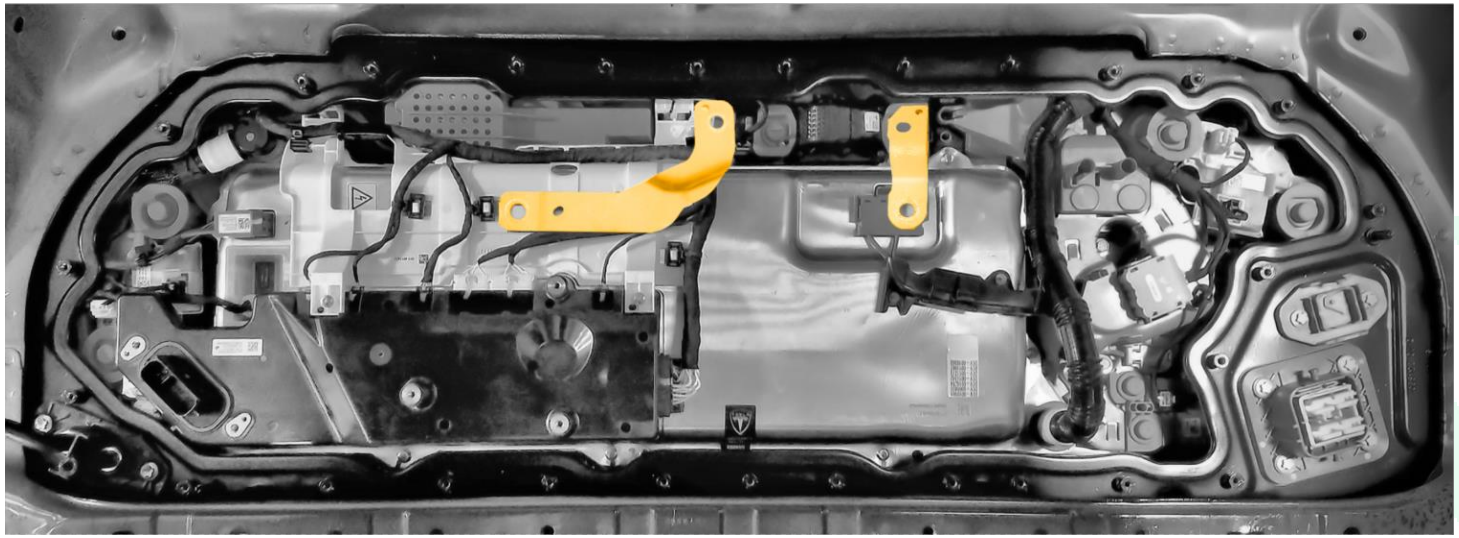


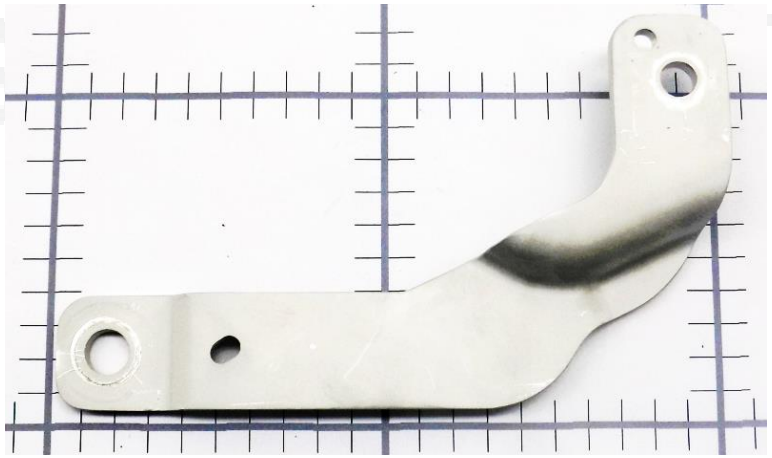


Talk about return connections through battery packs 3 and 2. Important for upcoming slides.

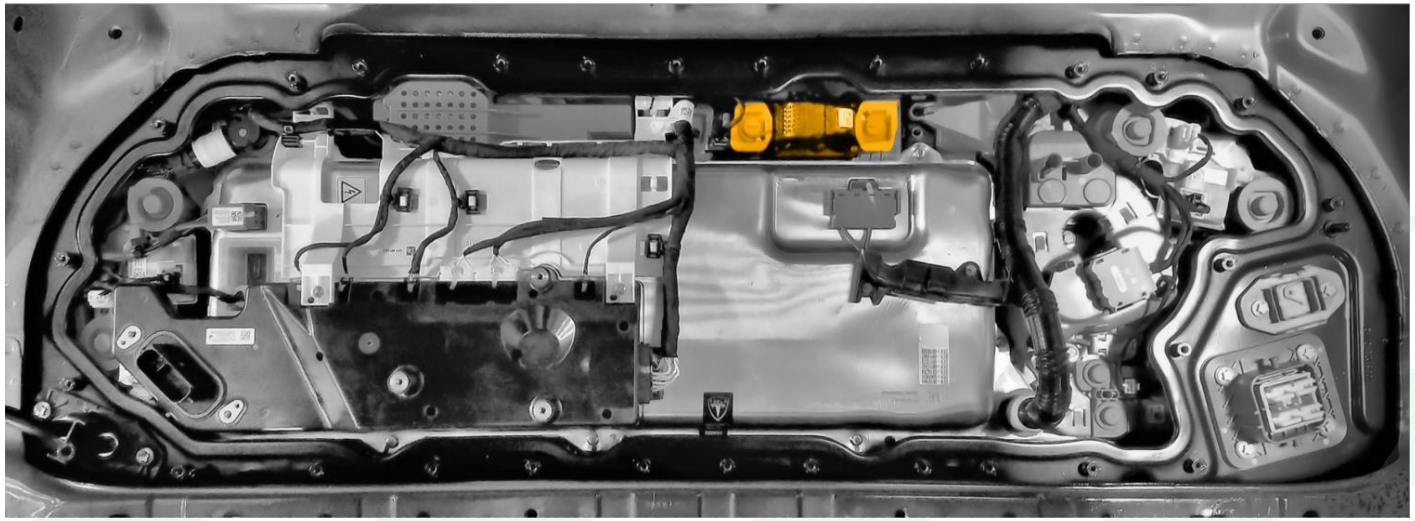
Talk About Busbars connected to front of packs. FIND PHOTOS!!

Battery Busbars

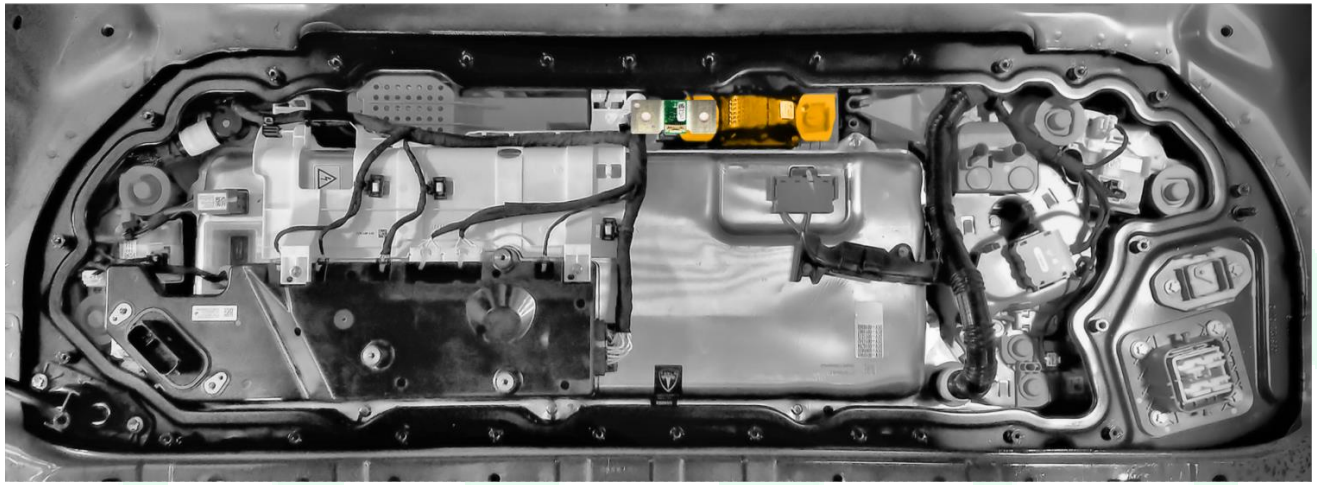




Pryo, Battery Disconnect

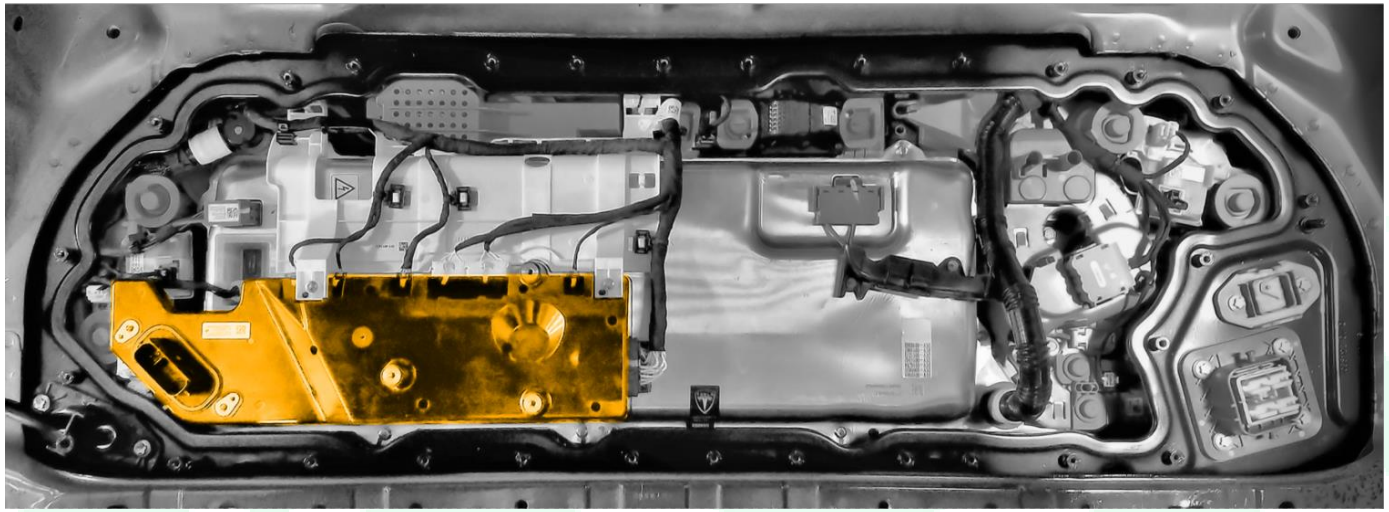


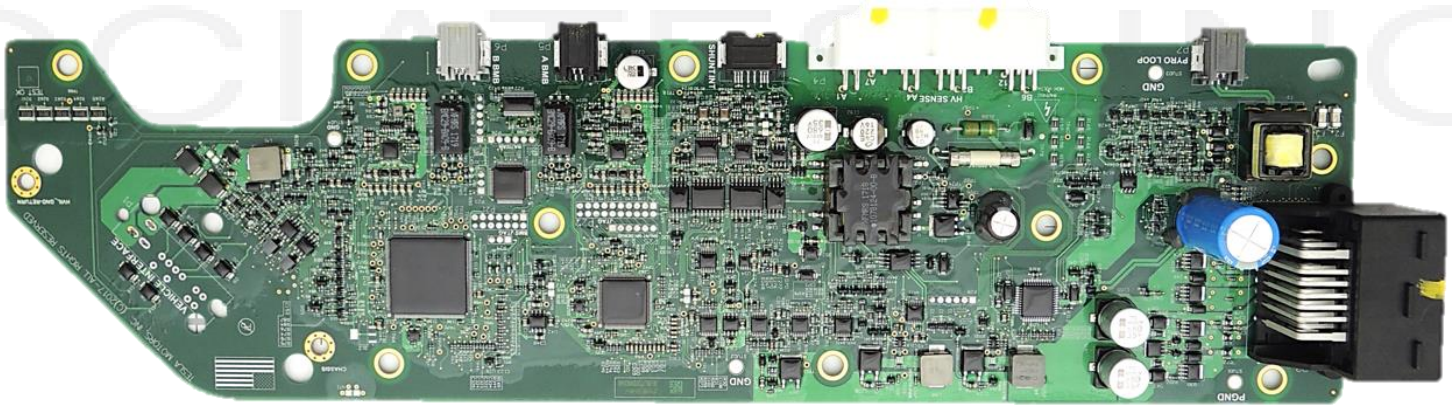
Current Monitoring Shunt



Circuit Complete

Battery Management





Side-by-Side Comparison

Battery Pack

Tesla Model 3

Cost	Weight (kg)
[redacted]	441.86

BMW i3

Cost	Weight (kg)
[redacted]	230.19

Chevy Bolt

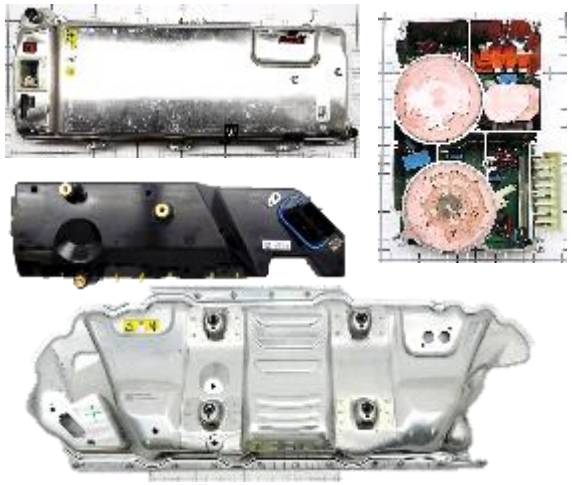
Cost	Weight (kg)
[redacted]	428.11

- Tesla Model 3 has a 75 kWh battery pack with a range of 310 miles. The BMW i3 has a 22 kWh battery pack with a range of 80-100 miles. The Chevy Bolt has a 60 kWh battery pack with a range of 238 miles.

Side-by-Side Comparison

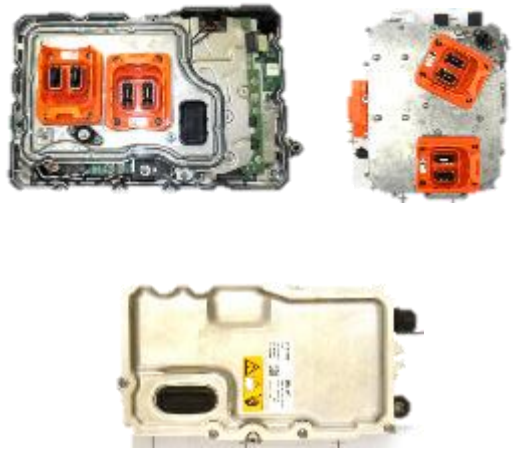
Battery Management and Charging Electronics

Tesla Model 3



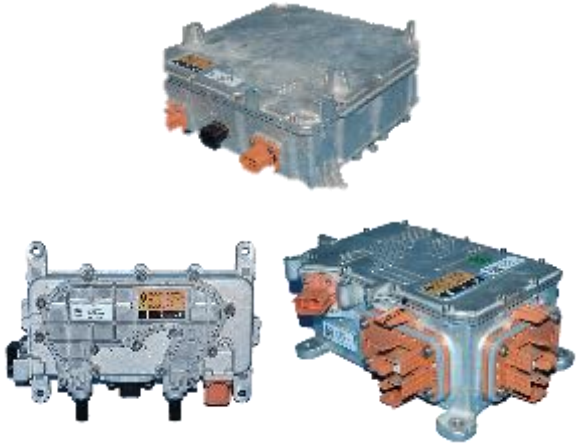
Cost	Weight (kg)
[redacted]	28.54

BMW i3



Cost	Weight (kg)
[redacted]	16.56

Chevy Bolt



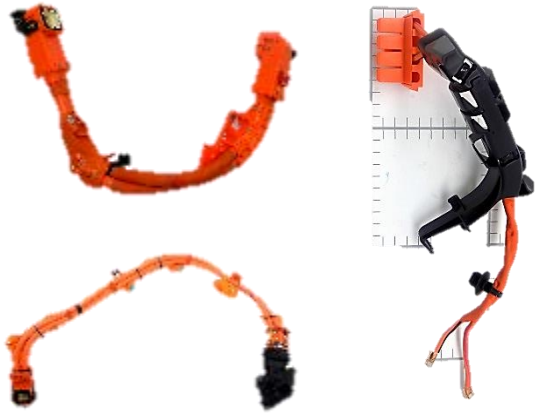
Cost	Weight (kg)
[redacted]	21.19

- Tesla Model 3 has significantly more components and weight in the battery management and charging electronics systems than th e BMW i3 and the Chevy Bolt. The weight and cost distributions are in line with the mileage range and battery capacity of each vehicle.

Side-by-Side Comparison

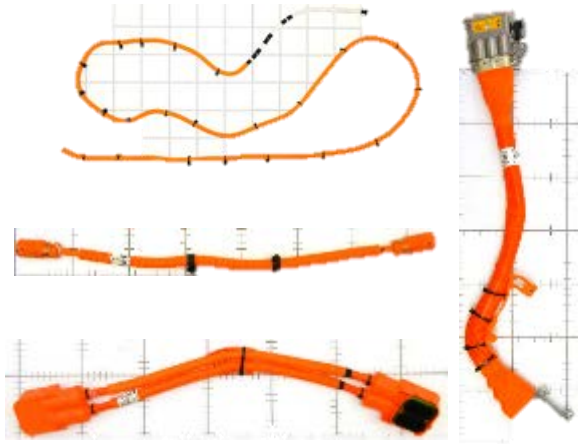
High Voltage Wire Harnesses

Tesla Model 3



Cost	Weight (kg)
[redacted]	13.58

BMW i3



Cost	Weight (kg)
[redacted]	12.07

Chevy Bolt

Cost	Weight (kg)
[redacted]	13.98

- Tesla Model 3 has an extruded aluminum wire trough running the length of the underbody that adds weight (3.624 kg) and cost. Otherwise, the costs are fairly proportionate to the weight of high voltage cables and wiring used in each vehicle.

The End

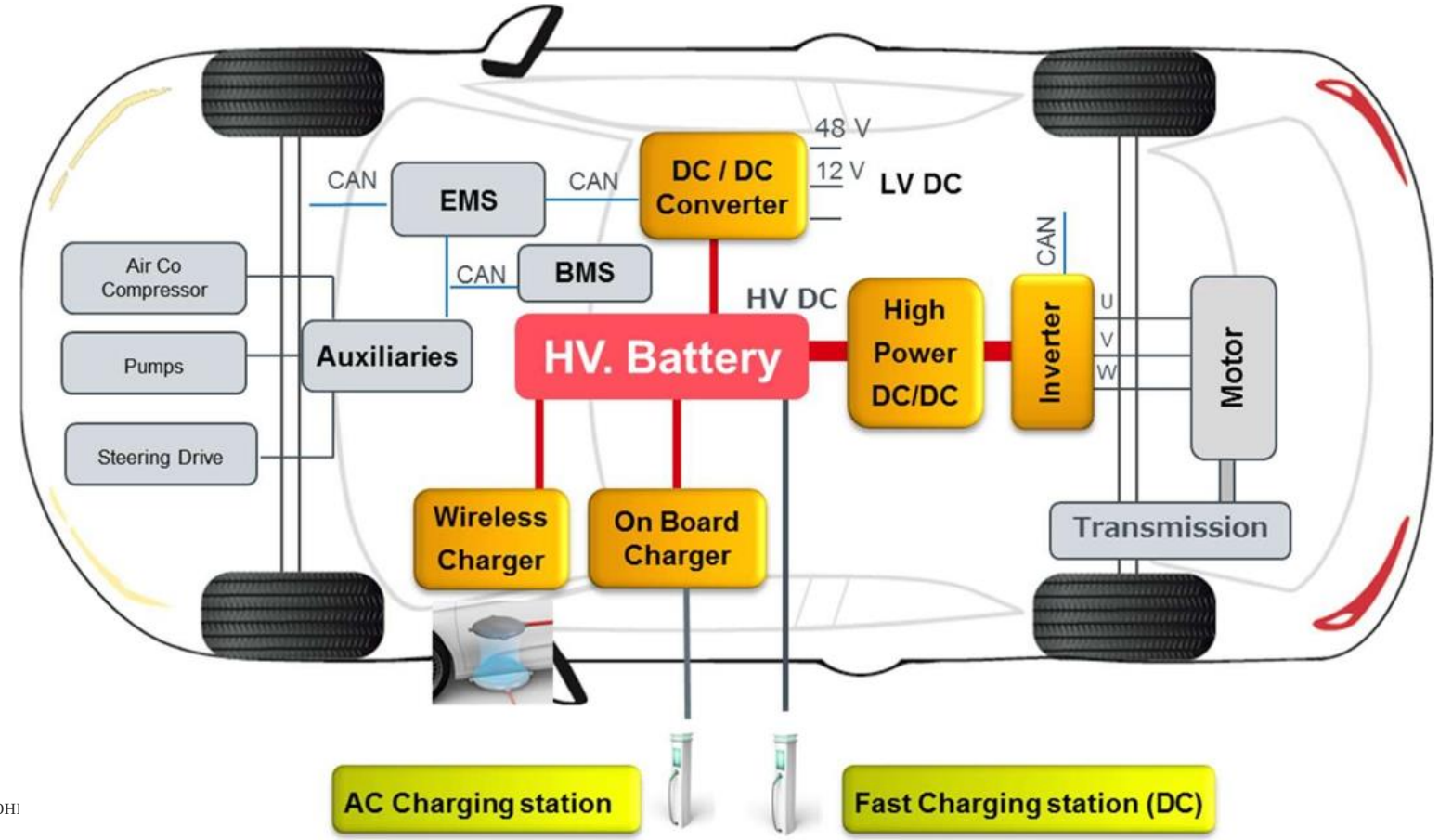
Thank You for Your Time

...the most valuable

asset you possess!!

xEV

More than 25 companies use ROHM SiC SBDs and MOSFETs in various automotive (on-board) applications.



3G SiC MOSFET Discrete development

Automotive grade (AEC-Q101 qualified)

650V	Part No. / Status	17mΩ	22mΩ	30mΩ	60mΩ	80mΩ	120mΩ
TO-247N	SCT3xxxALHR New	√	√	√	√	√	√
TO-263-7L	SCT3xxxAW7HR MP: Q4/19			√	√	√	√

1200V	Part No. / Status	22mΩ	30mΩ	40mΩ	80mΩ	105mΩ	160mΩ
TO-247N	SCT3xxxKLHR New	√	√	√	√	√	√
TO-263-7L	SCT3xxxKW7HR MP: Q4/19			√	√	√	√

* as of July 2019

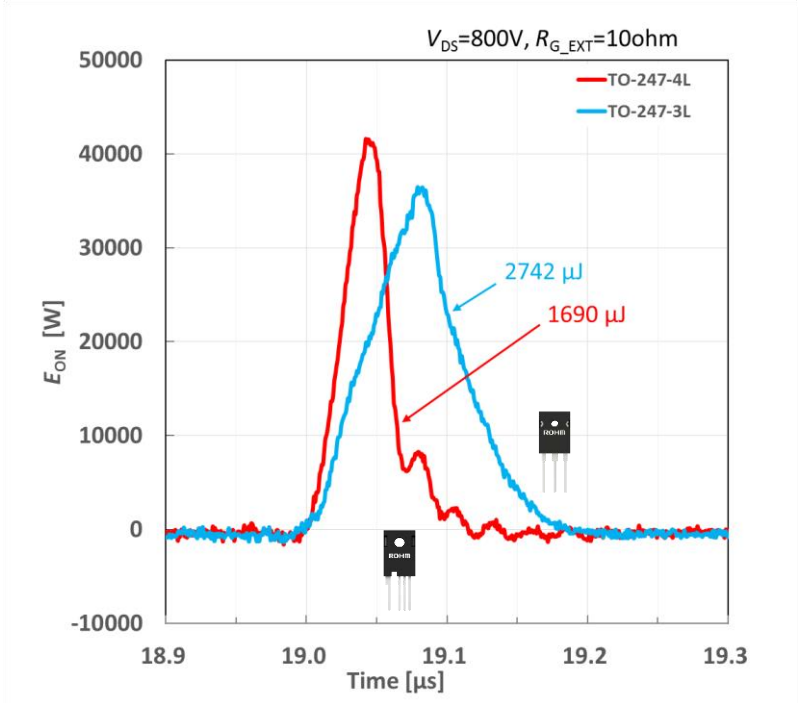
MP: Mass production

√ Mass Production

√ Under development

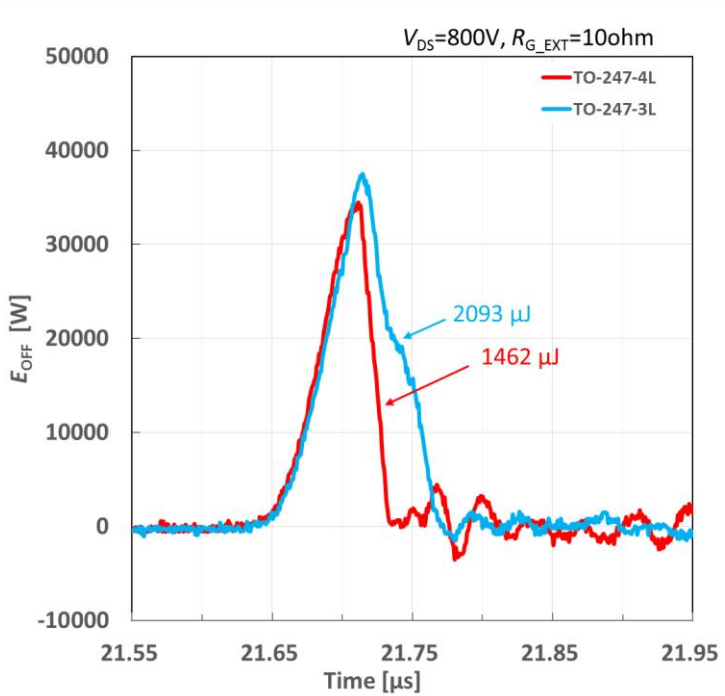
Switching Loss comparison

Turn on



38% lower

Turn off

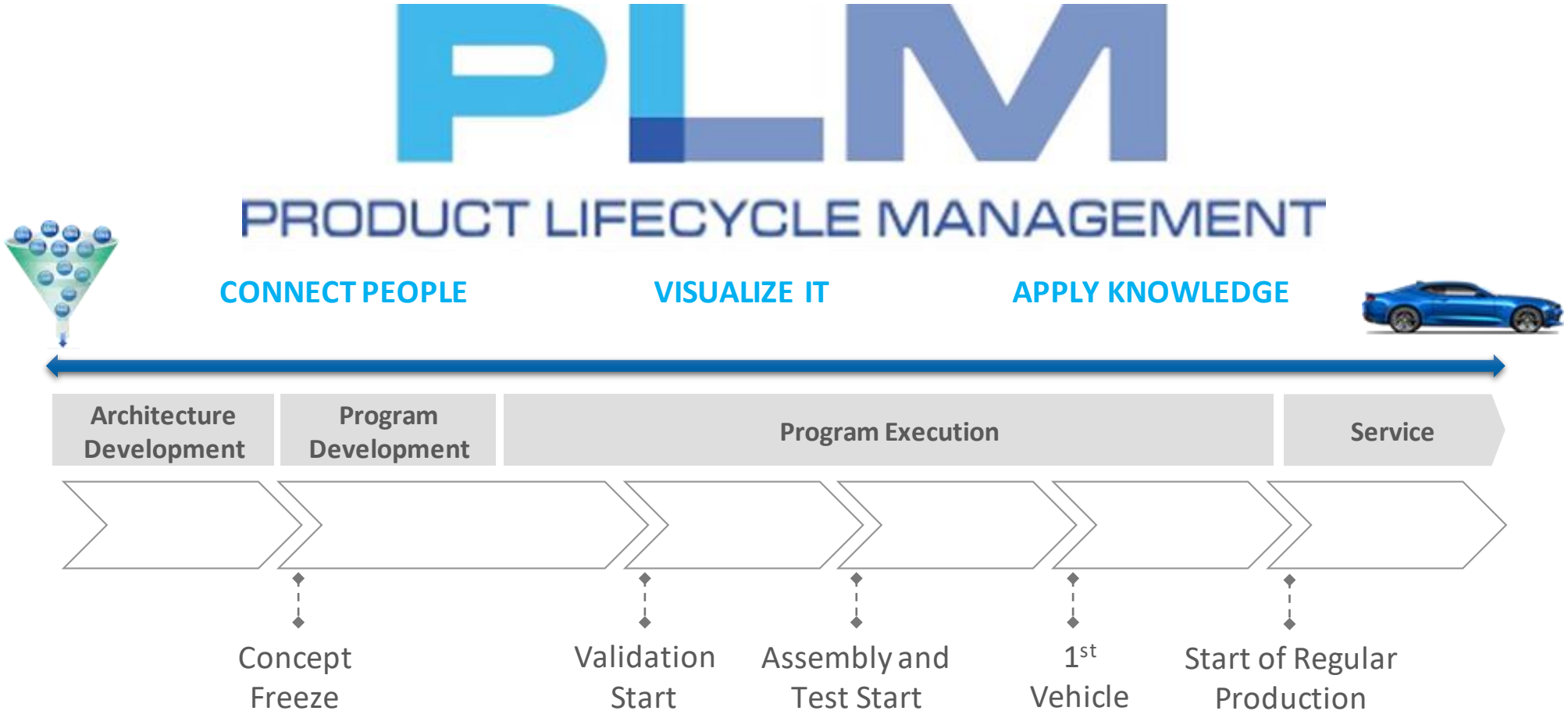


30% lower

SCT3040K**R** (1200V/40mohm/TO-247-4L)

SCT3040KL (1200V/40mohm/TO-247-3L)

The Vision to Enable Strategy Execution



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What's Important:

1. Battery Systems require active thermo management.
2. Knowledge is being gained as more and more experiences, especially with autos.
3. Battery packaging is very flexible, must optimize for both thermo management and vehicle dynamics.
4. Battery Management Systems are critical to range and durability, likely to be improved during product life.
5. Visualizing field insights and discussing them in context of visual BOM is critical for product upgrades.

3D collaboration accelerates design and knowledge application.

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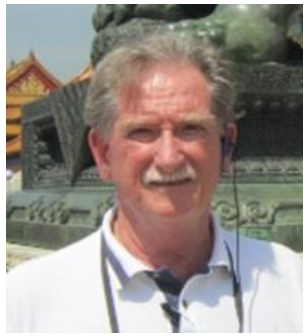
DesignNews webinar

Questions? Please submit your questions via the text box.



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Mark Ellis
Sr. Master Lean Design®
and Battery Consultant
Munro & Associates, Inc.

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