GSA Phase One – Hybrid and Electric Vehicle

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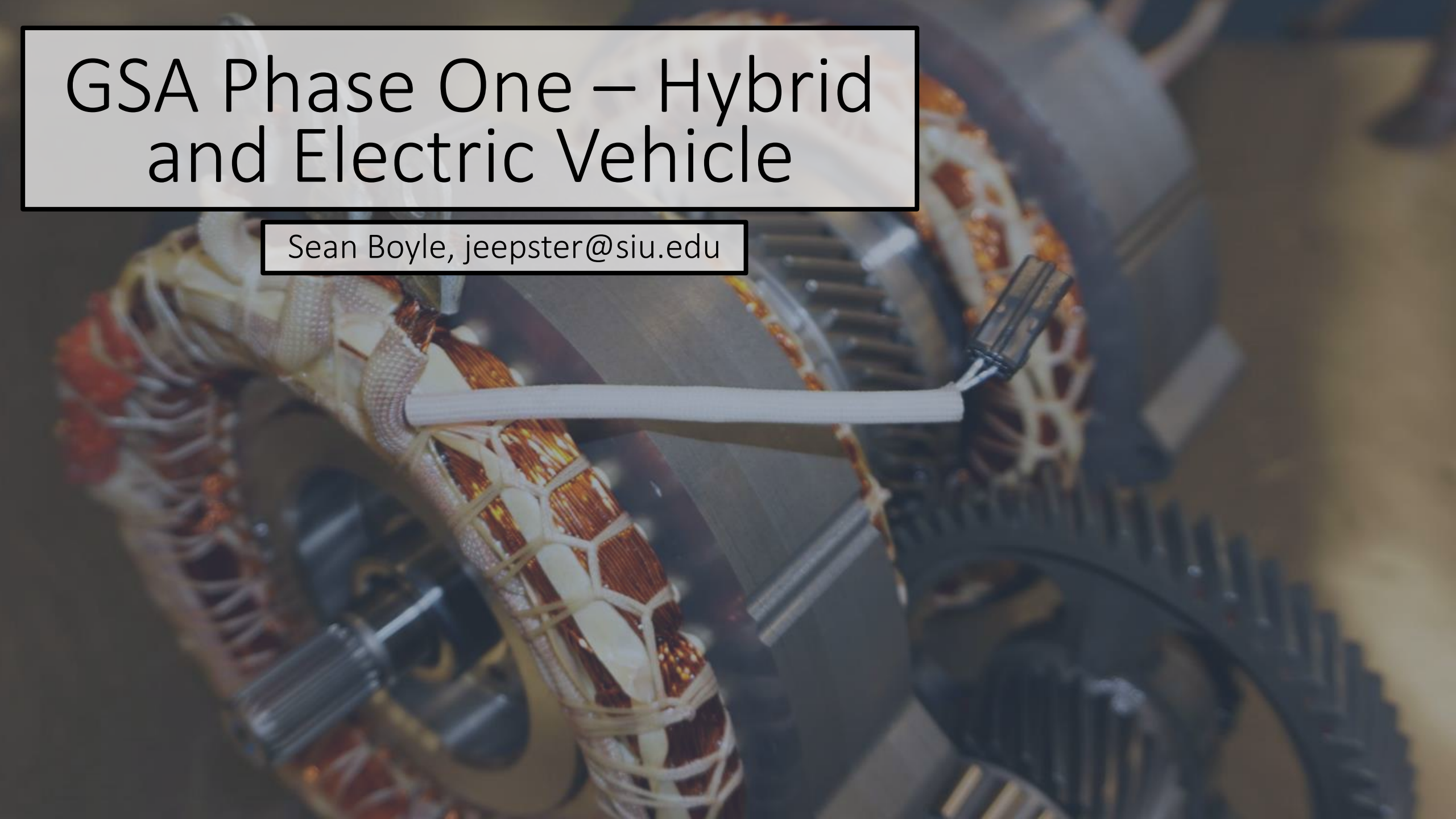


Comments and questions on Survey

General:

- Overview and basic understanding of hybrid and EV
- Differences between hybrids
- EV layout
- Which one is more beneficial

Maintenance and Repair:

- Considerations on maintenance and repair
- How to avoid battery issues
- Proper maintenance
- Battery service
- Effects of weather on batteries
- High voltage safety

Specific Operation and Functions:

- Regen braking
- Electric motor operation
- Different battery types
- Different charger types and adapters

Management:

- Cost effective strategies for EV fleet operation
- How can I tell if a vendor is competent
- Manufacturing costs
- Recycling

Questions to answer:

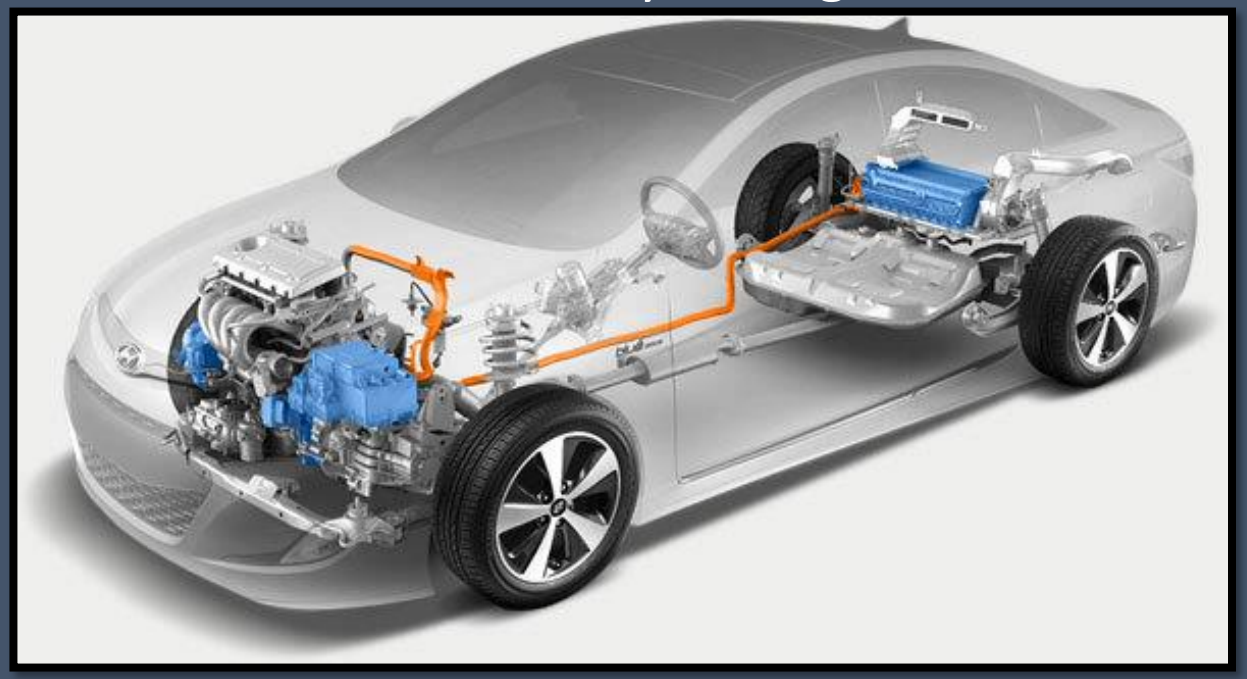
- What's the benefit of a hybrid or an EV?
- How are xEVs configured?
  - Hybrid
    - Parallel
    - Series
    - Series/Parallel
  - Full hybrid vs. mild hybrid
  - Plug-in Hybrid
  - EV
- What makes them different?
  - Engine
  - Electric motor
  - Inverter Technology
  - Cooling system
  - Battery
    - High voltage
    - Low voltage
    - Charging
  - Braking System
  - Regenerative Braking
  - AC/Heating System

Questions to answer:

- What are some service considerations?
  - Hybrids engines are similar to conventional vehicles
    - Oil changes
    - Spark plugs
    - Air filter
    - Cooling system
  - Brake systems
  - Tire rotation/Balancing
  - Cooling system maintenance
- What are some usage considerations?
  - Towing requirements
  - Charging requirements
- Practicality
- Management
- Recycling

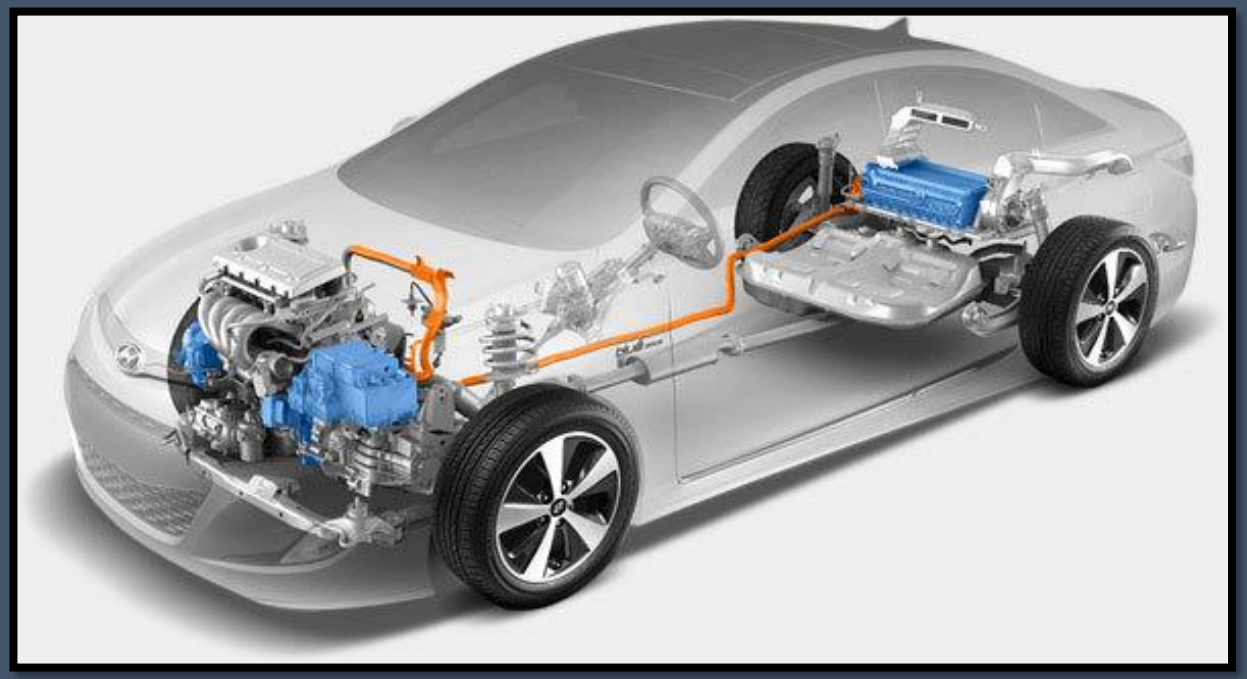
What's the benefit of a Hybrid vehicle?

- Recover energy lost through friction (heat)
  - Generate electricity during braking and deceleration
  - Use that electricity during acceleration

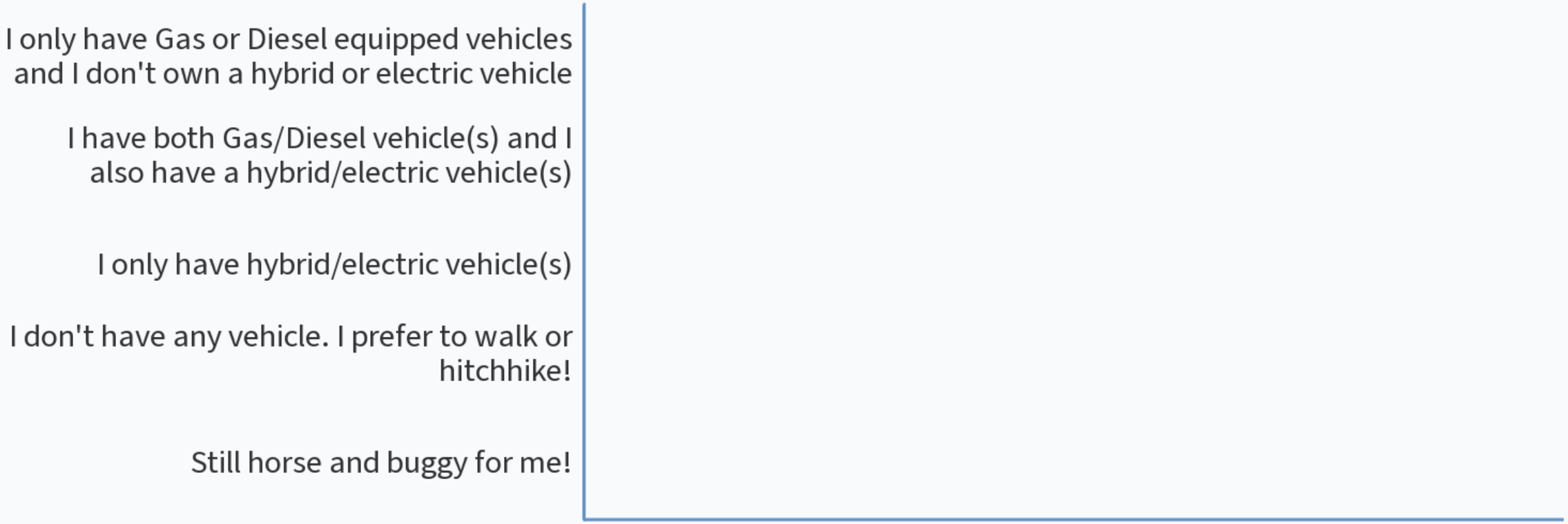


What's the benefit of a Hybrid vehicle?

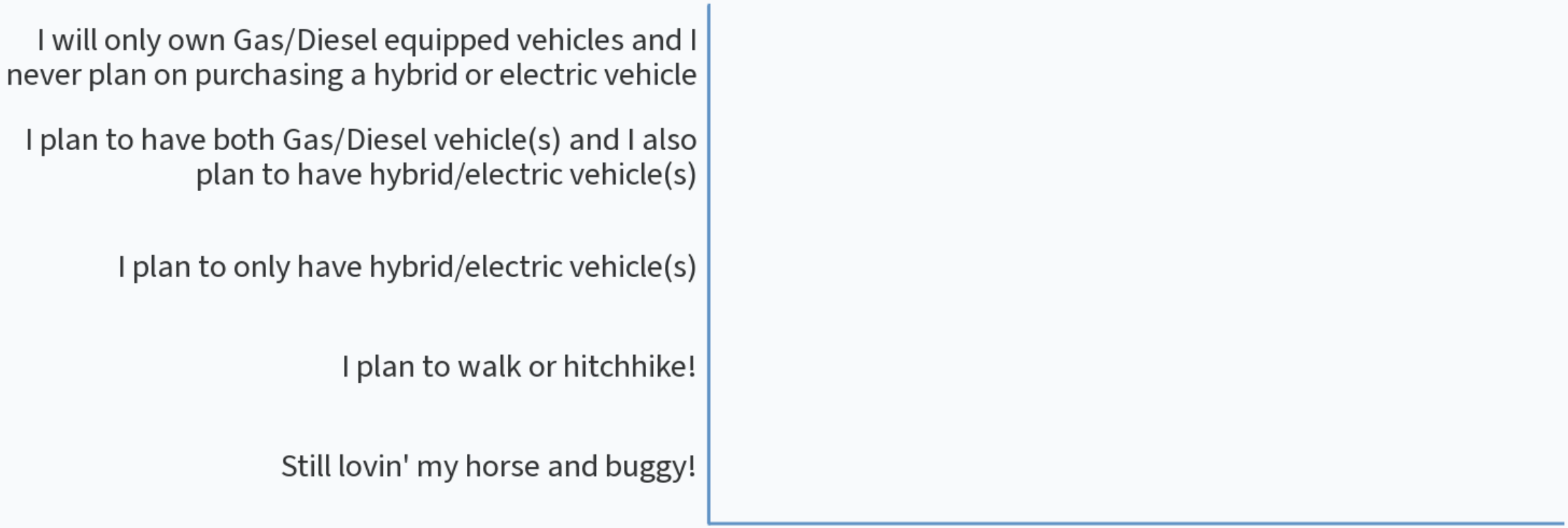
- Combination engine and electric drive
  - Efficient engines provide mid range RPM torque
  - Electric motors provide excellent low RPM torque
  - Good combination



Which of the following best describes your "vehicle" situation?



What do you think about the near future regarding vehicle ownership?



Volt test drive

How are xEVs configured?

Series

Parallel

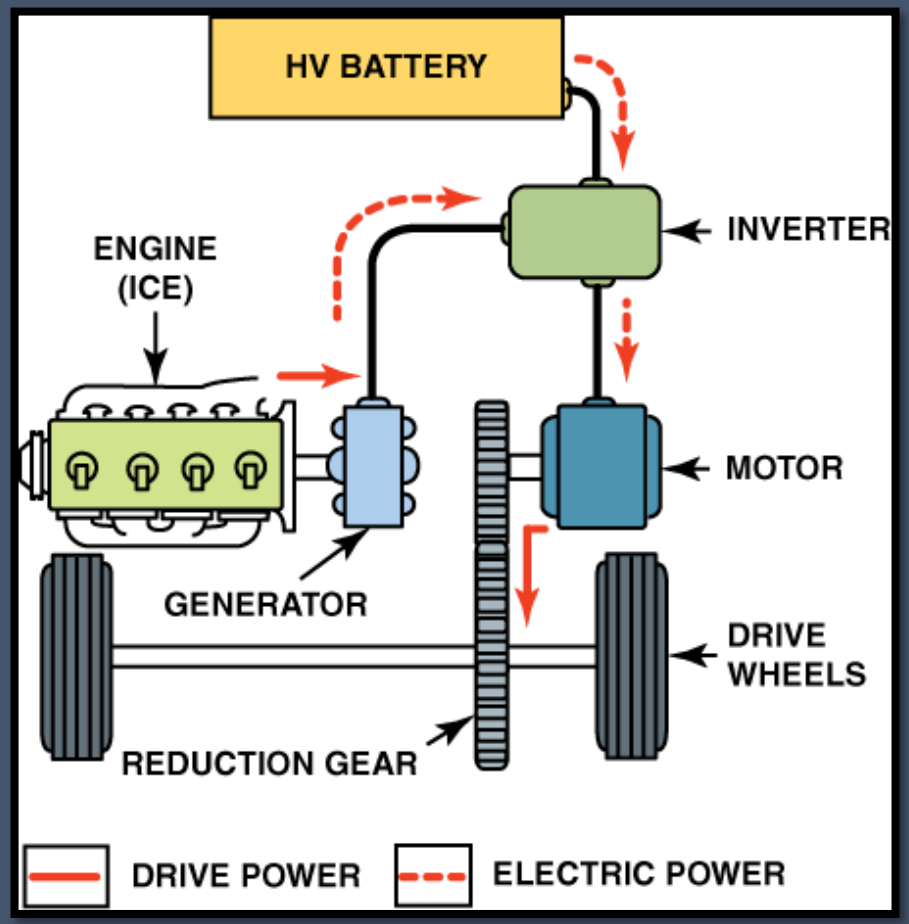
Series/Parallel

Plug-in Hybrid

Full Electric

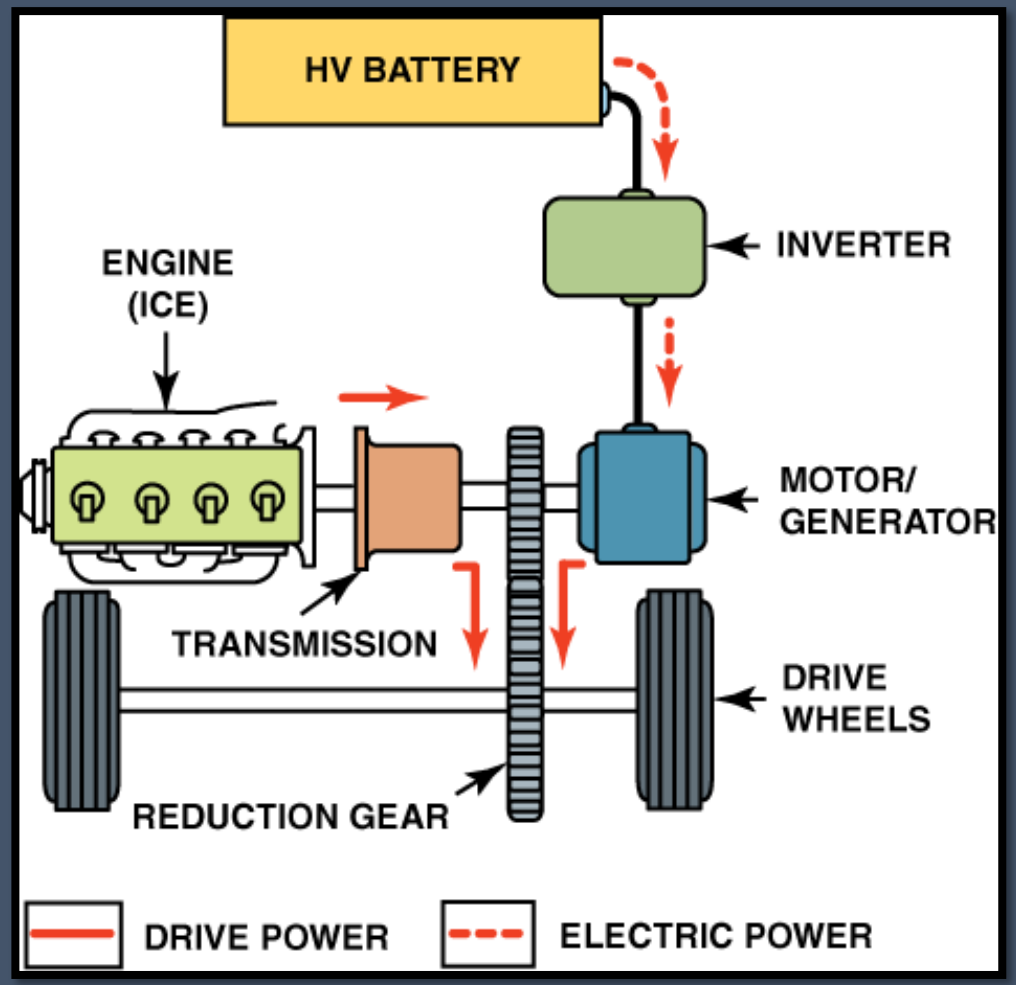
Series

- Chevrolet Volt, Honda Clarity, Accord, Insight…



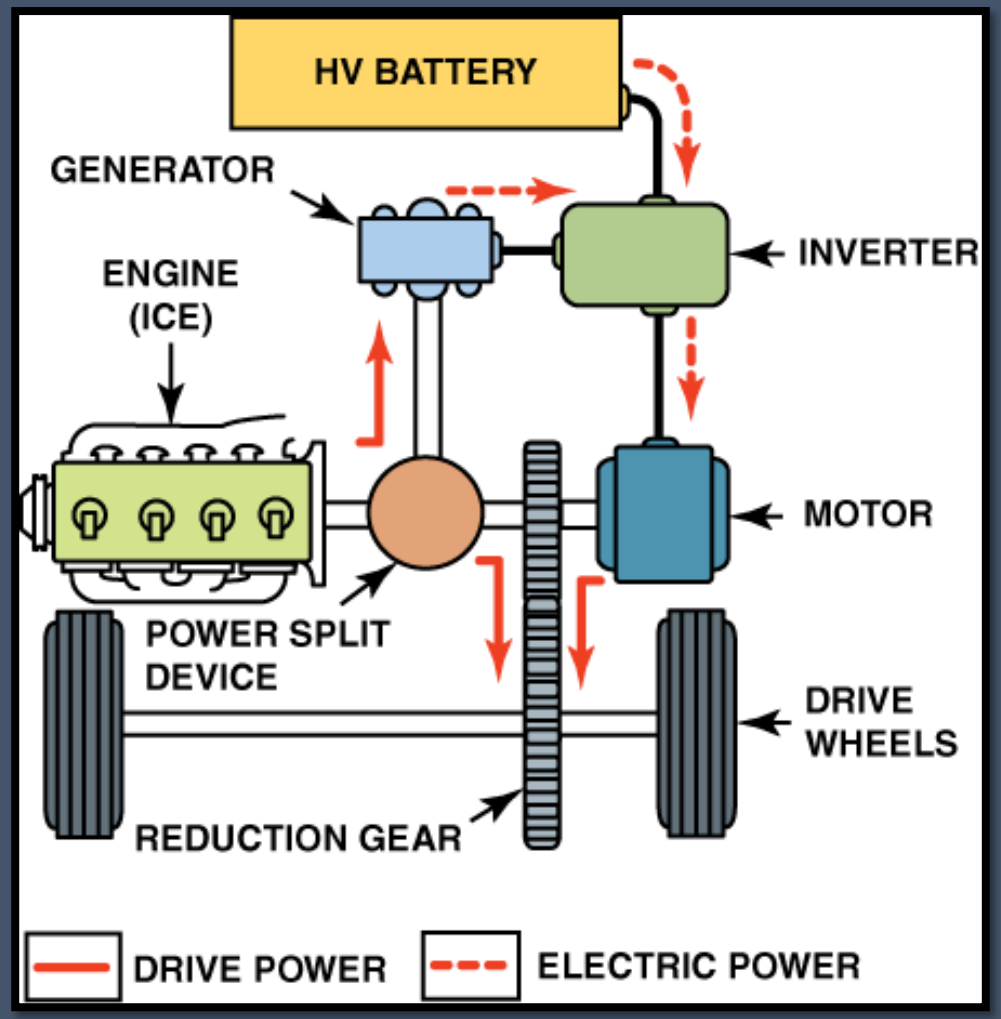
Parallel

EX: Early Honda Civic/Insight, Jeep/Ram eTorque, Subaru Crosstek



Series/Parallel

- Toyota, Ford, and Nissan hybrids



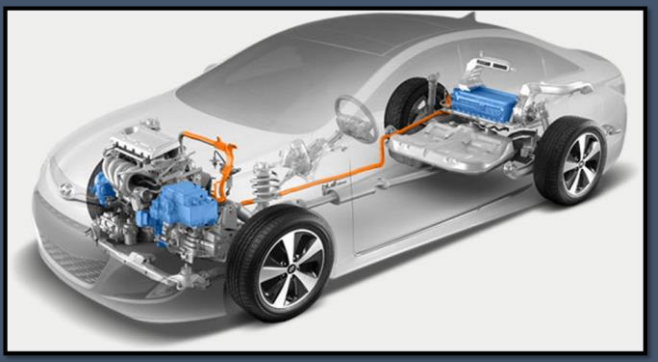
Plug-in Hybrid

- Same as previous designs, but with bigger battery

Full Electric

- No ICE!

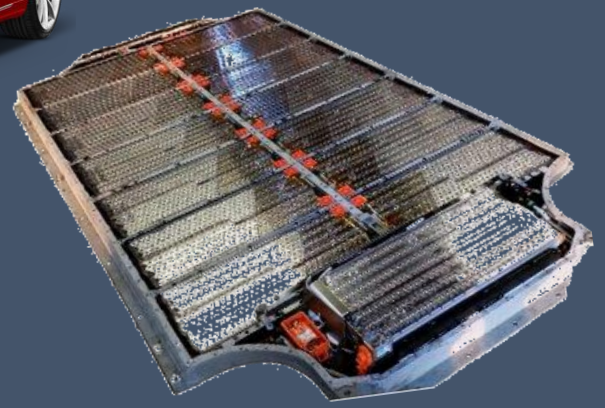
Battery Layout Examples



- Hybrid vehicle
  - Smaller battery
  - Needs to store energy recovered from braking
- Plug-in hybrid vehicle
  - Medium battery
  - Store energy from braking
  - Store enough to drive EV only for 20 – 50 miles or so
- EV
  - Large battery
  - Range vs cost vs weight

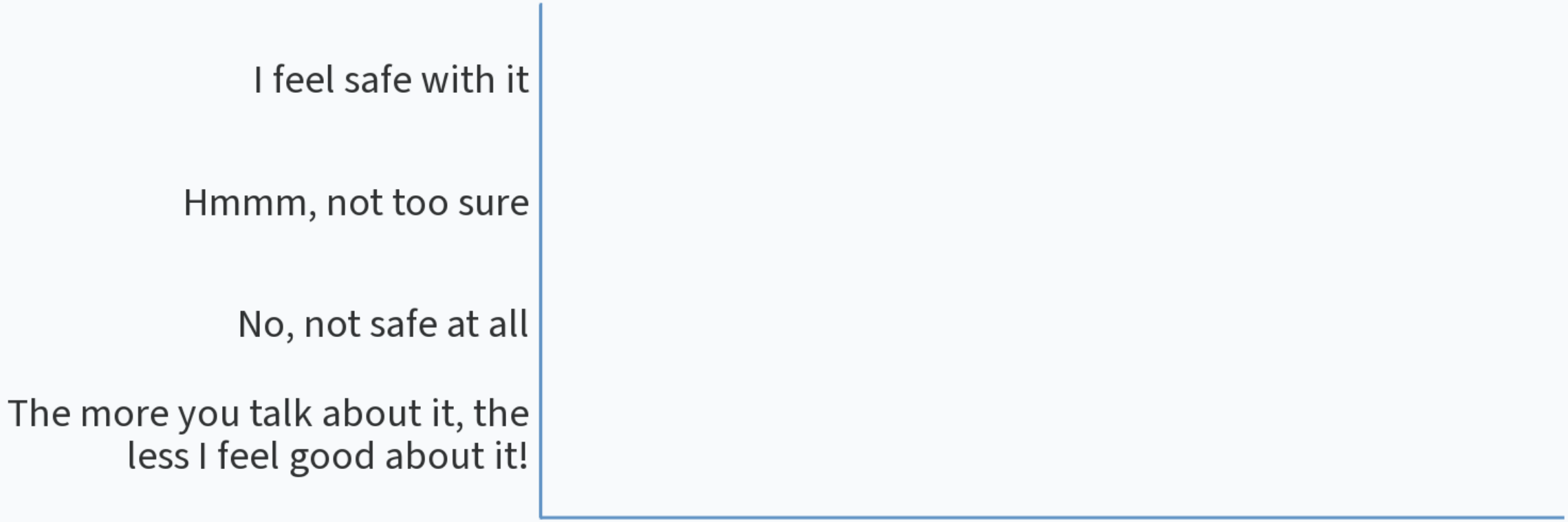
Battery Layout Examples

- Tesla Model S – 7104 cells

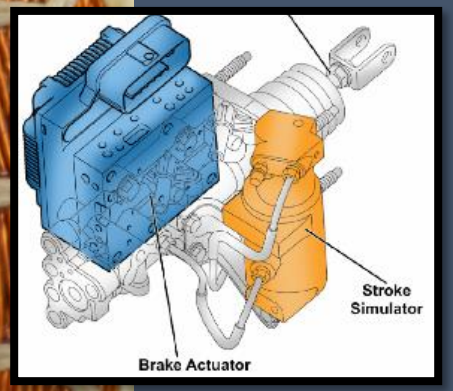


- Lucid Air – 6600 cells

How comfortable are you knowing that you are sitting on thousands of batteries and hundreds of volts?



What makes them different?



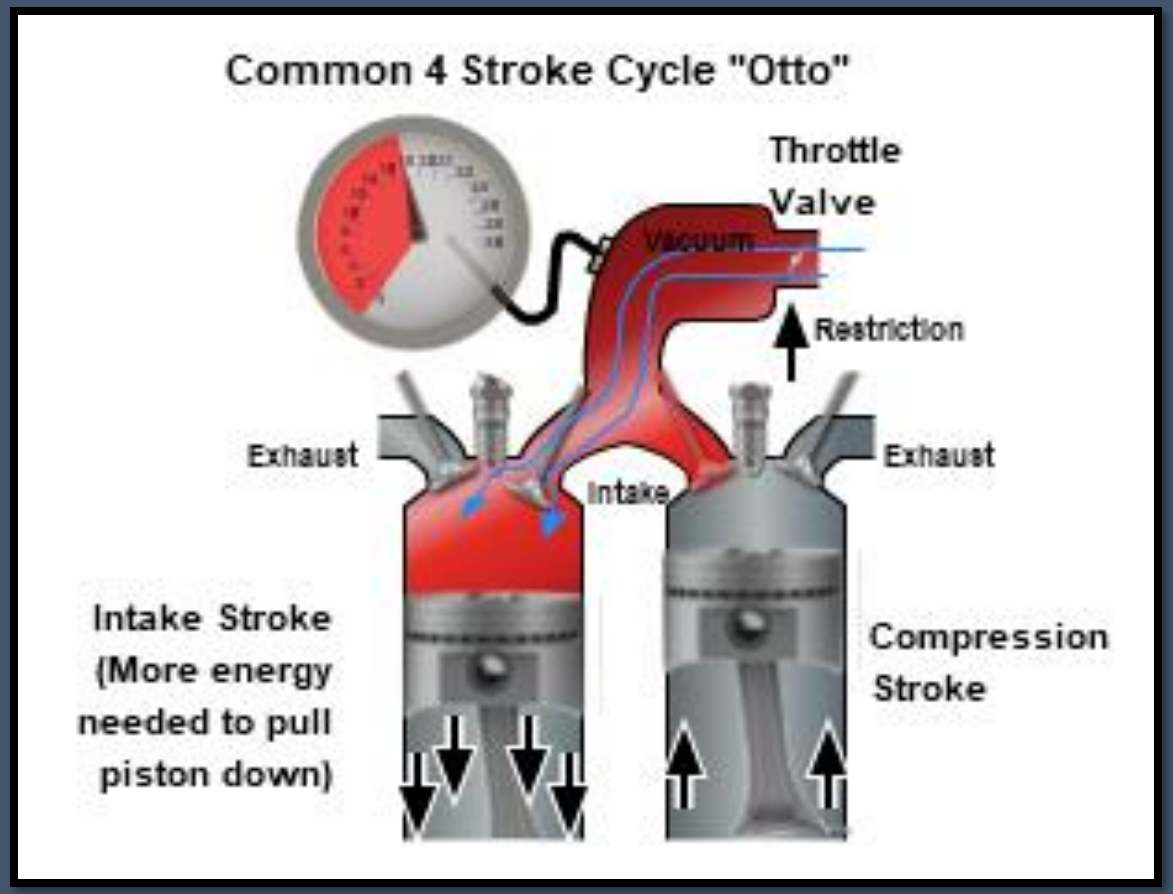
- Electric drive
  - High Voltage Battery
  - Invertor
  - Electric Motors
- Regenerative Braking
  - Charging the high voltage battery by using the transaxle motors as generators
- Electronic Braking
  - Disable hydraulic wheel brakes to allow maximum regenerative braking
  - Modulate hydraulic brakes “on” as the generator loses effectiveness
- Electronic Air Conditioning
  - Not belt driven – high voltage electric pump

What makes them different? - Engine

- Belt driving vs. full electric accessories
  - On some, no belt driven alternator
  - On some, no belt driven water pump
  - On some, no belt driven air conditioner
- Electric power steering

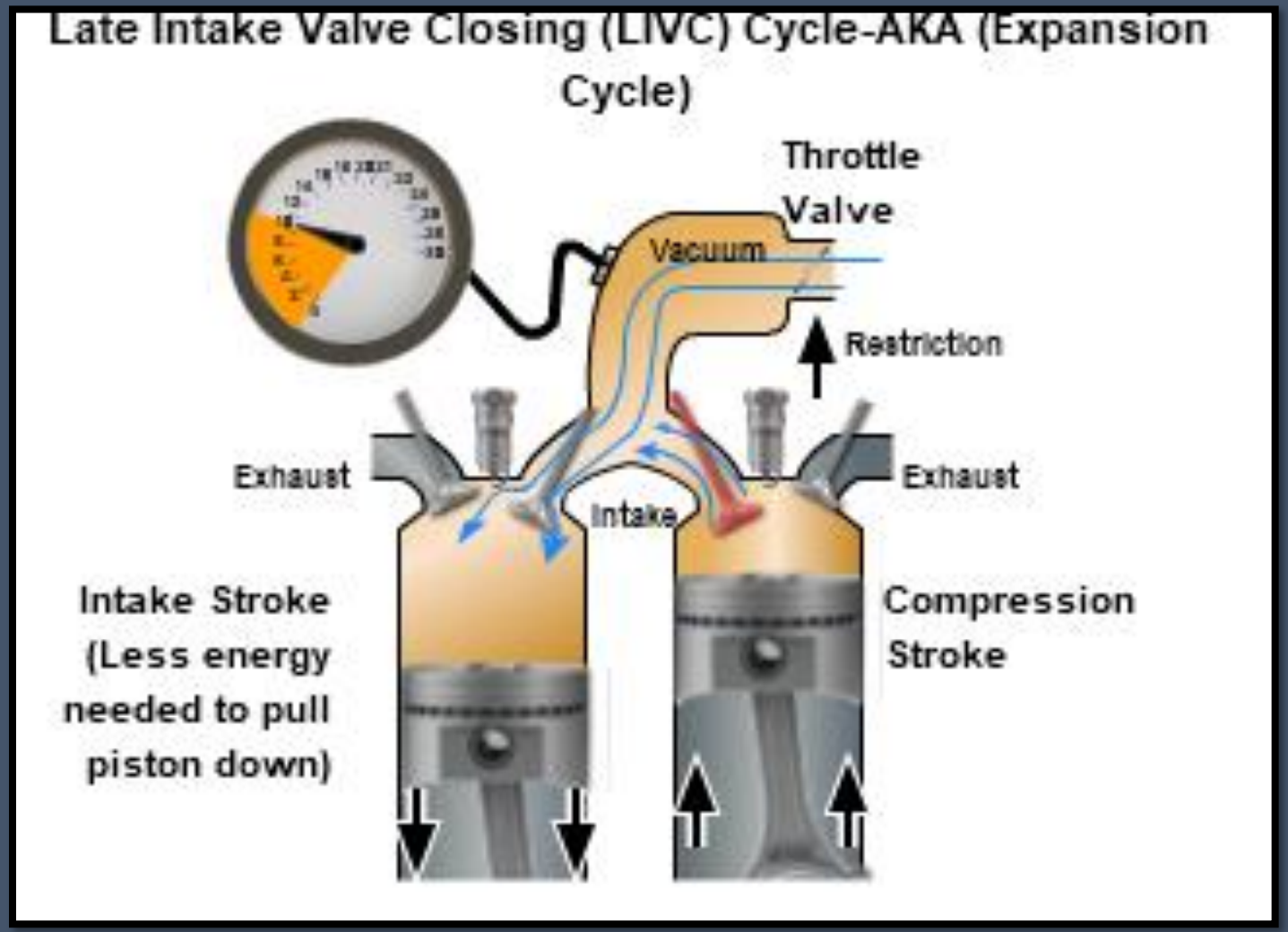
Engine

- Atkinson style engine leaves the intake open further into the compression stroke
- Low low-rpm torque, but high efficiency



Engine

- Atkinson engine will have less intake vacuum



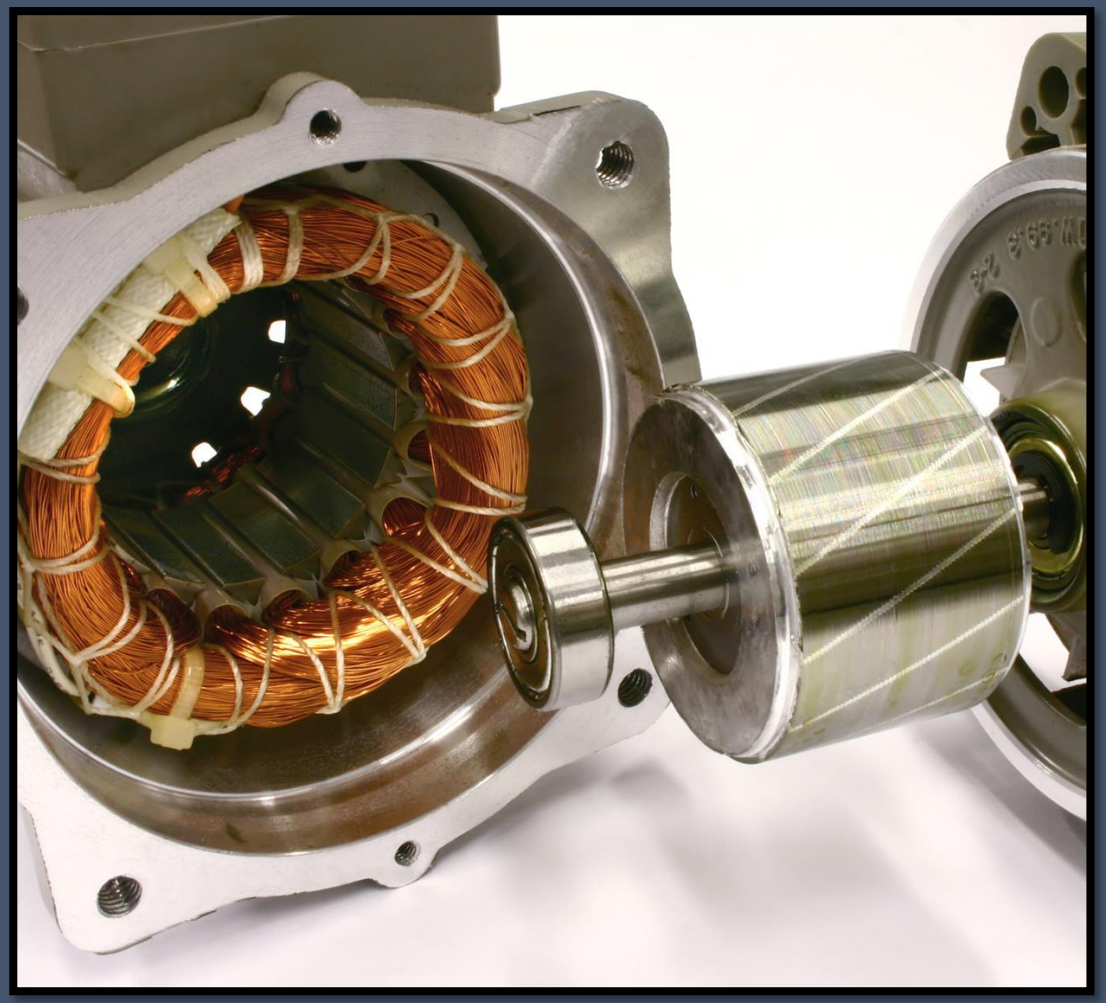
Engine

- Some engines require high octane gas – Refer to owner's manual

11-15 MY Volt owner's manual:
“Use premium unleaded gasoline meeting ASTM specification D4814 with a posted octane rating of 91 or higher. If the octane is less than 91, damage to the engine may occur and may void the vehicle warranty.”

16-19 MY Volt owner's manual:
“Use regular unleaded gasoline meeting ASTM specification D4814 with a posted octane rating of 87 or higher. Do not use gasoline with an octane rating below 87, as it may cause engine damage and will lower fuel economy.”

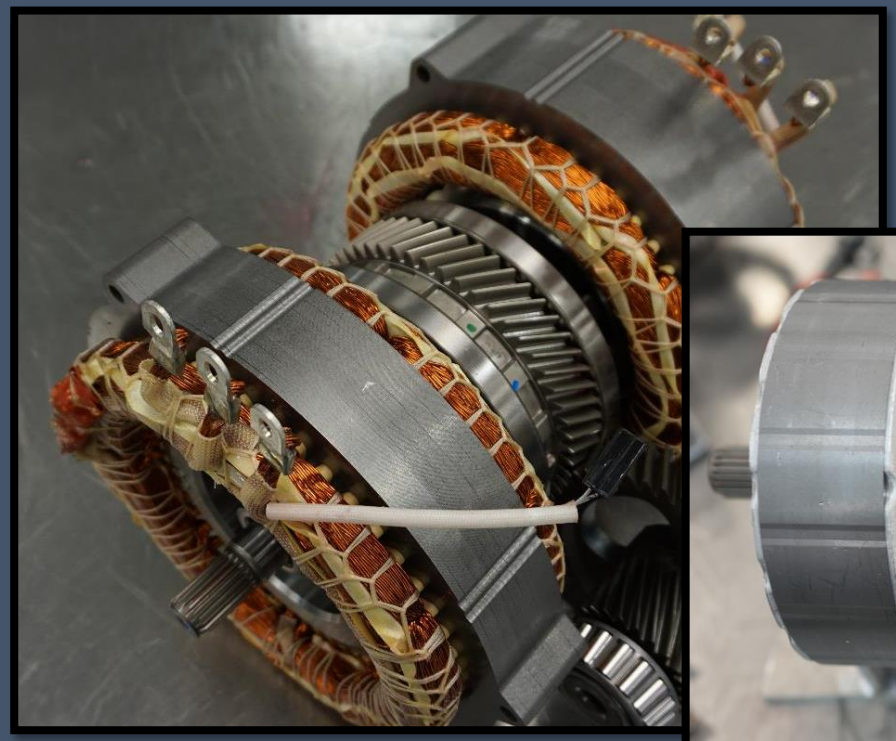
Basic Motor Operation

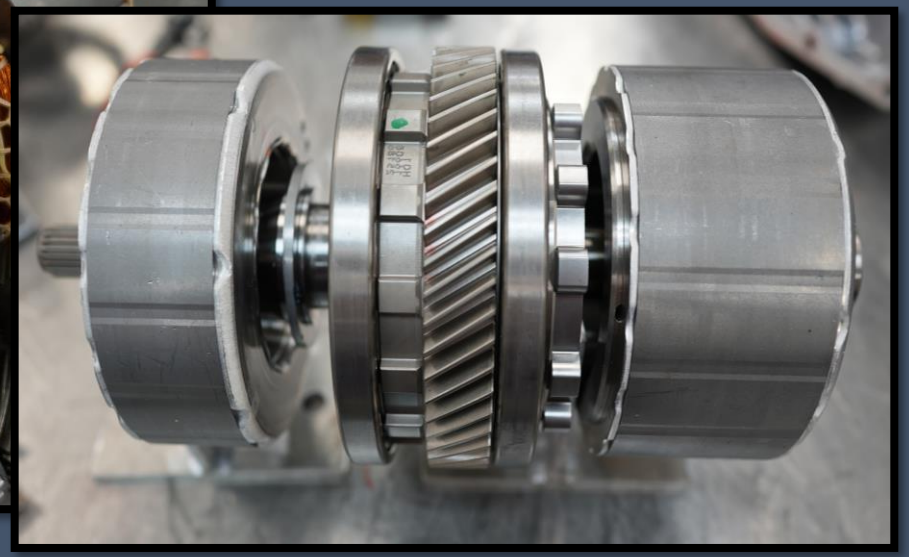


- Main components
  - Stator
    - Windings to create a “rotating magnetic field”
  - Rotor
    - Most common - Permanent magnet to chase that rotating magnetic field

Transaxles – Toyota/Nissan/Ford/Hyundai

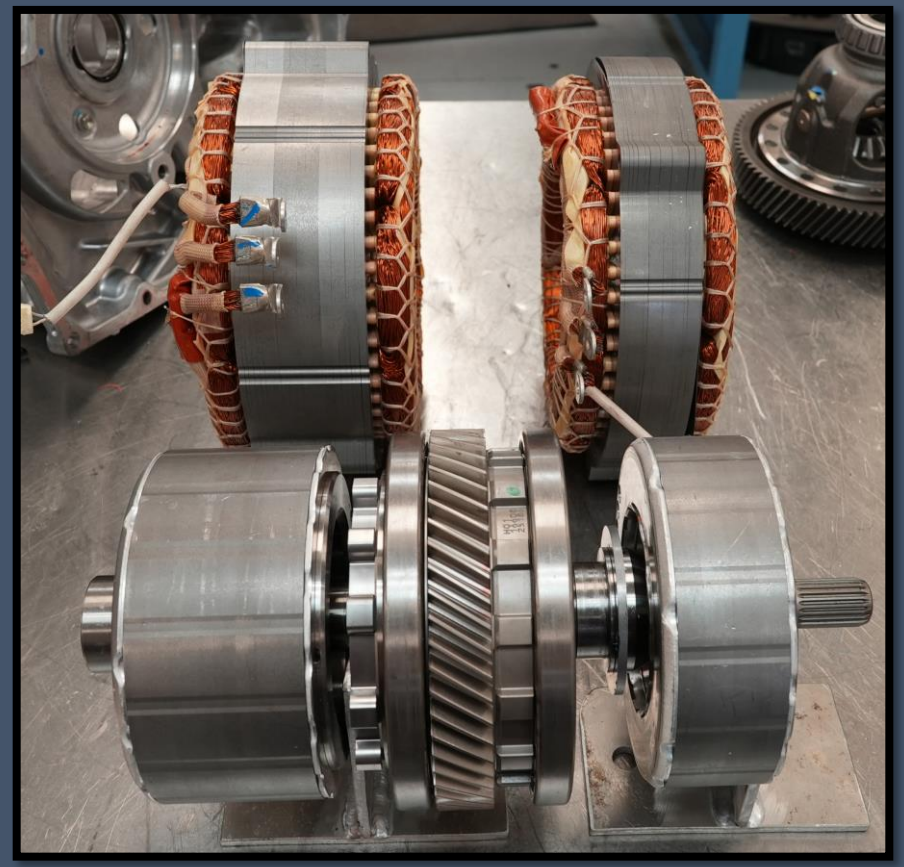
- Two Electric Motors (in one transaxle housing)
  - Permanent magnets in rotors
  - 3-phase stator windings





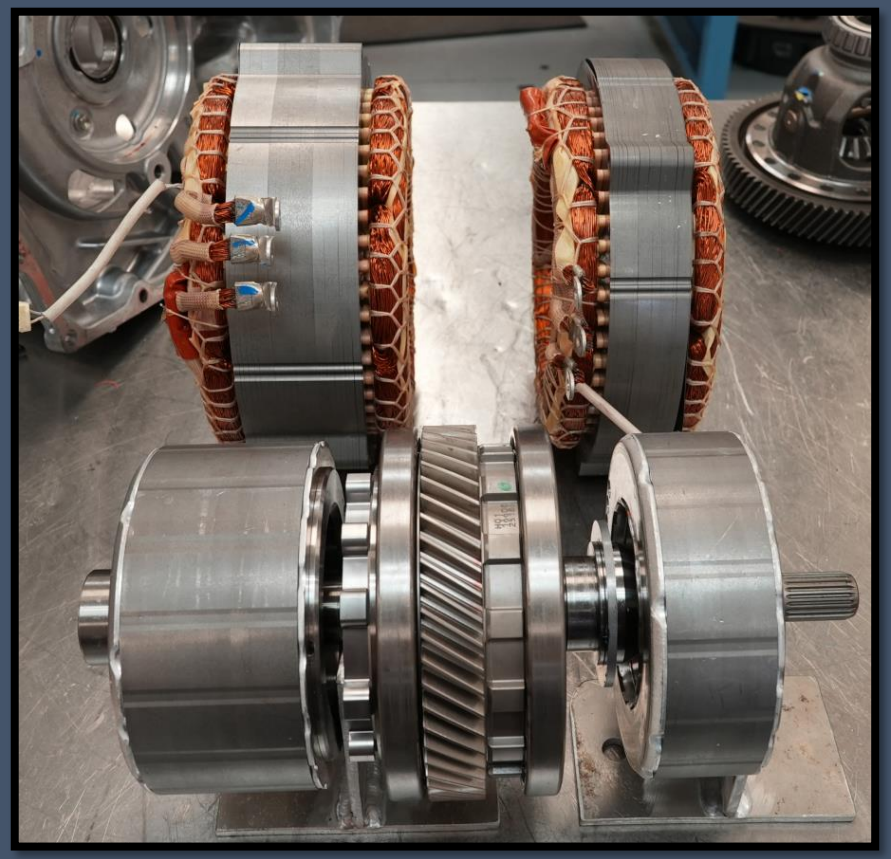
Transaxles – Toyota/Nissan/Ford/Hyundai

- MG 1 (smaller)
  - Works as a generator
  - Works as an engine starter
  - Provides resistance to a planetary gear to allow the engine to vary RPM



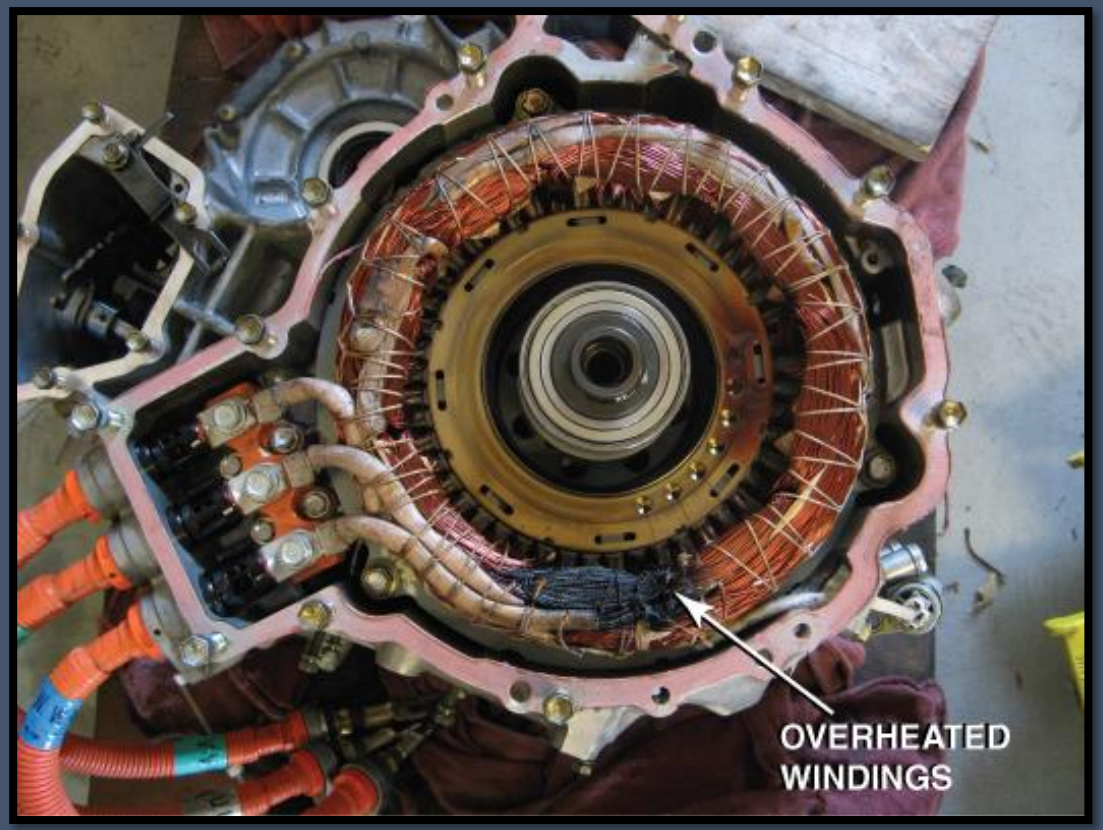
Transaxles – Toyota/Nissan/Ford/Hyundai

- MG 2 (larger)
  - Drives the wheels
  - Generates electricity during braking (regen)



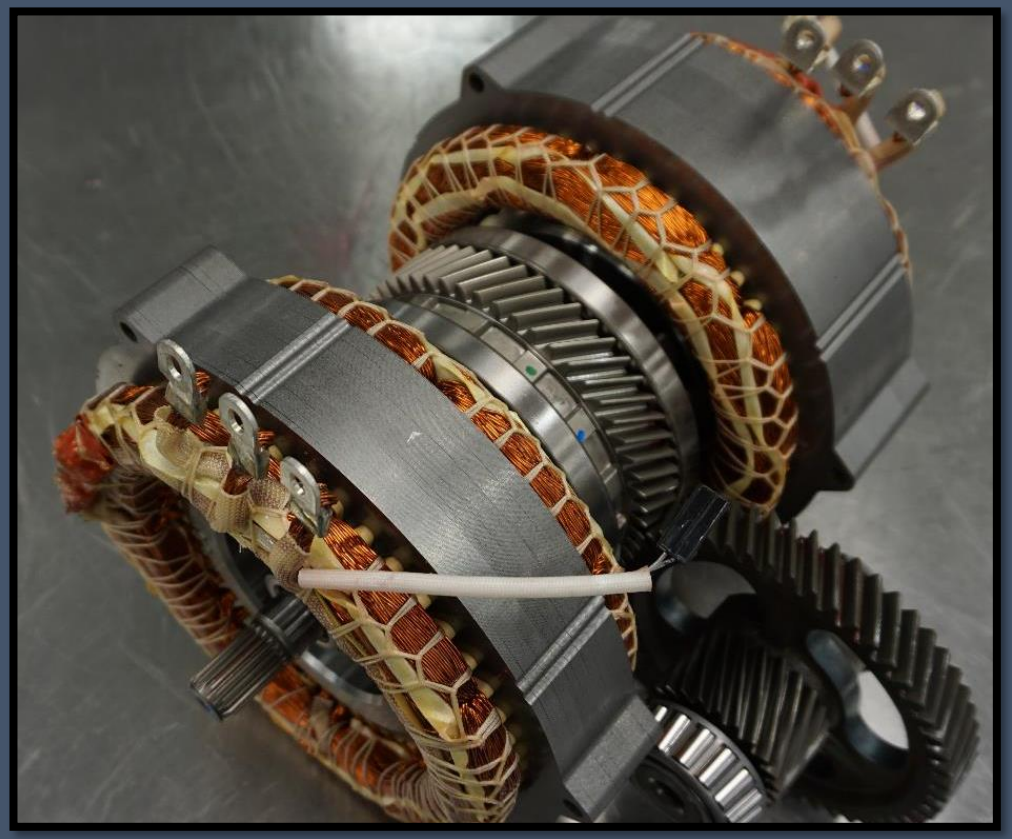
Toyota/Nissan/Ford/Hyundai

- High voltage
  - Secure connections
  - Good insulation
  - Orange cables indicate high voltage



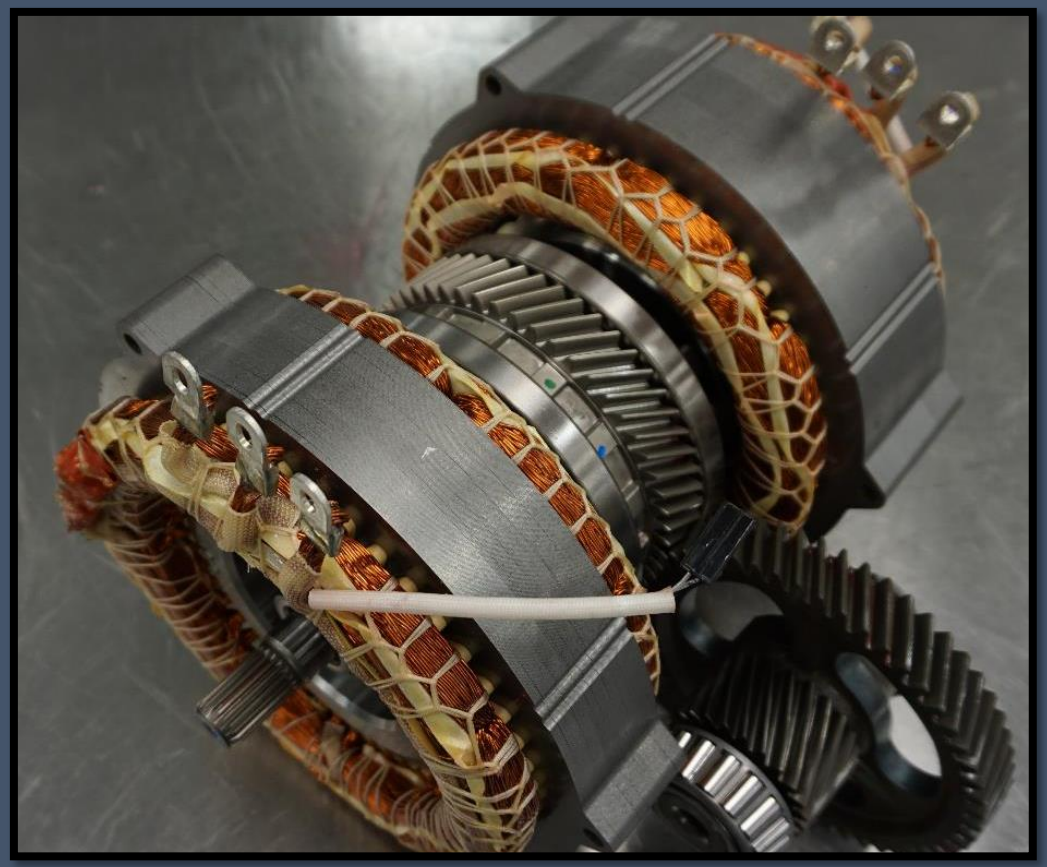
Toyota/Nissan/Ford/Hyundai

- Simple design
  - No hydraulic clutches
  - No one-way clutches
  - No valve body



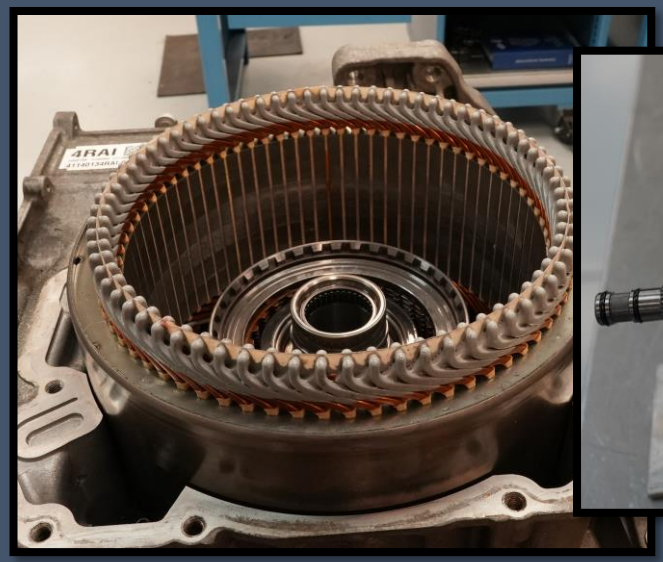
Toyota/Nissan/Ford/Hyundai

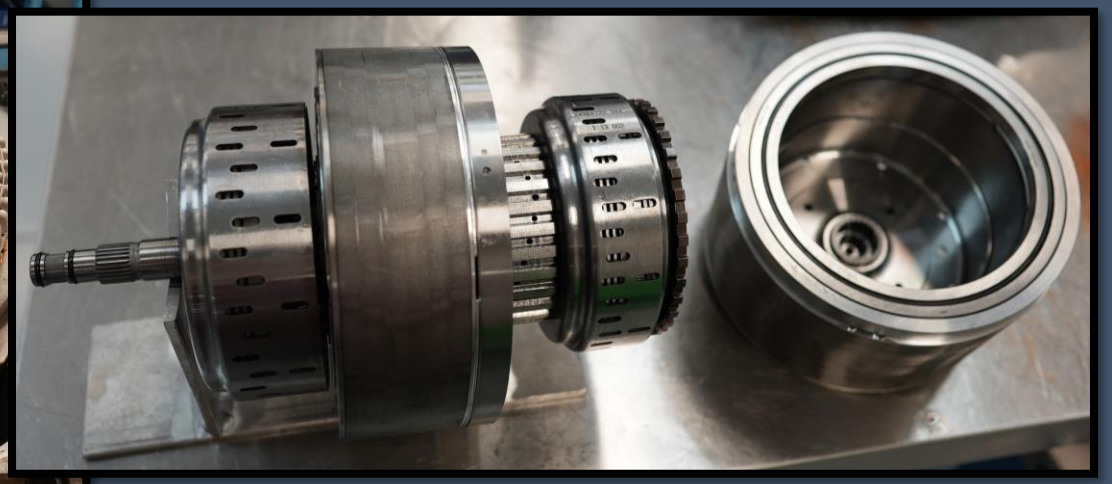
- Oil pump to lubricate gears and cool electric motors
- Planetary gearset to join the two electric motors and the engine



Volt/Honda 2-motor design

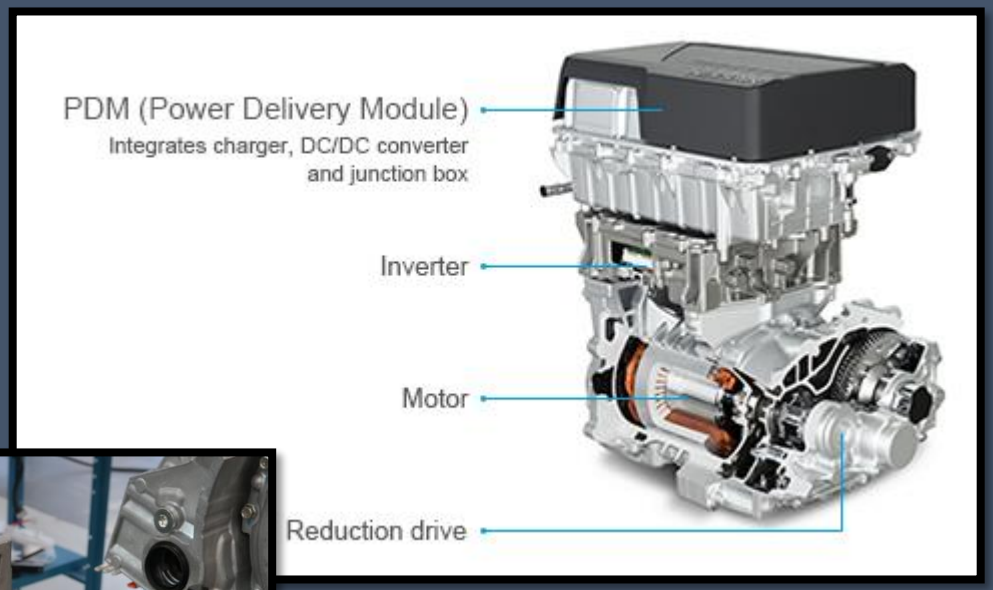
- MG1 (small) works as a generator and starter
- MG2 (big) drives the wheels
- Three clutches
  - One connects engine to MG1
  - One connects MG1 to MG2 through a gearset
  - One provides a “low” range for low speeds

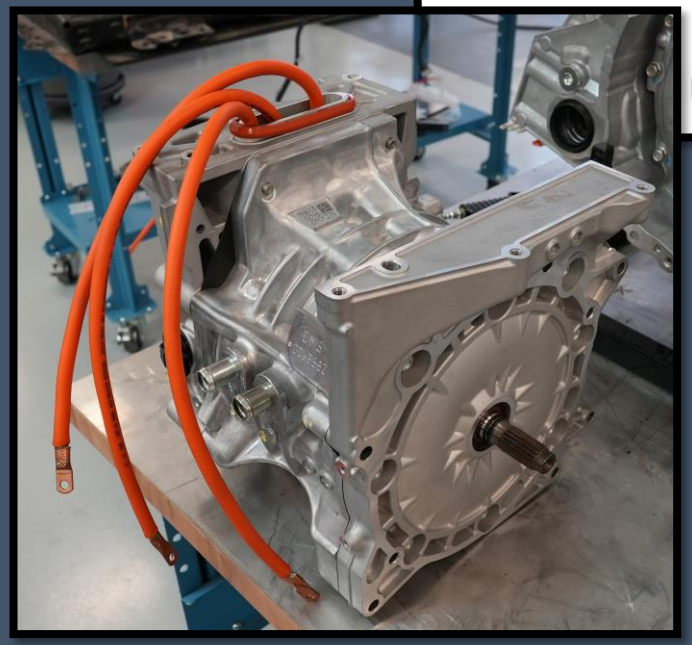


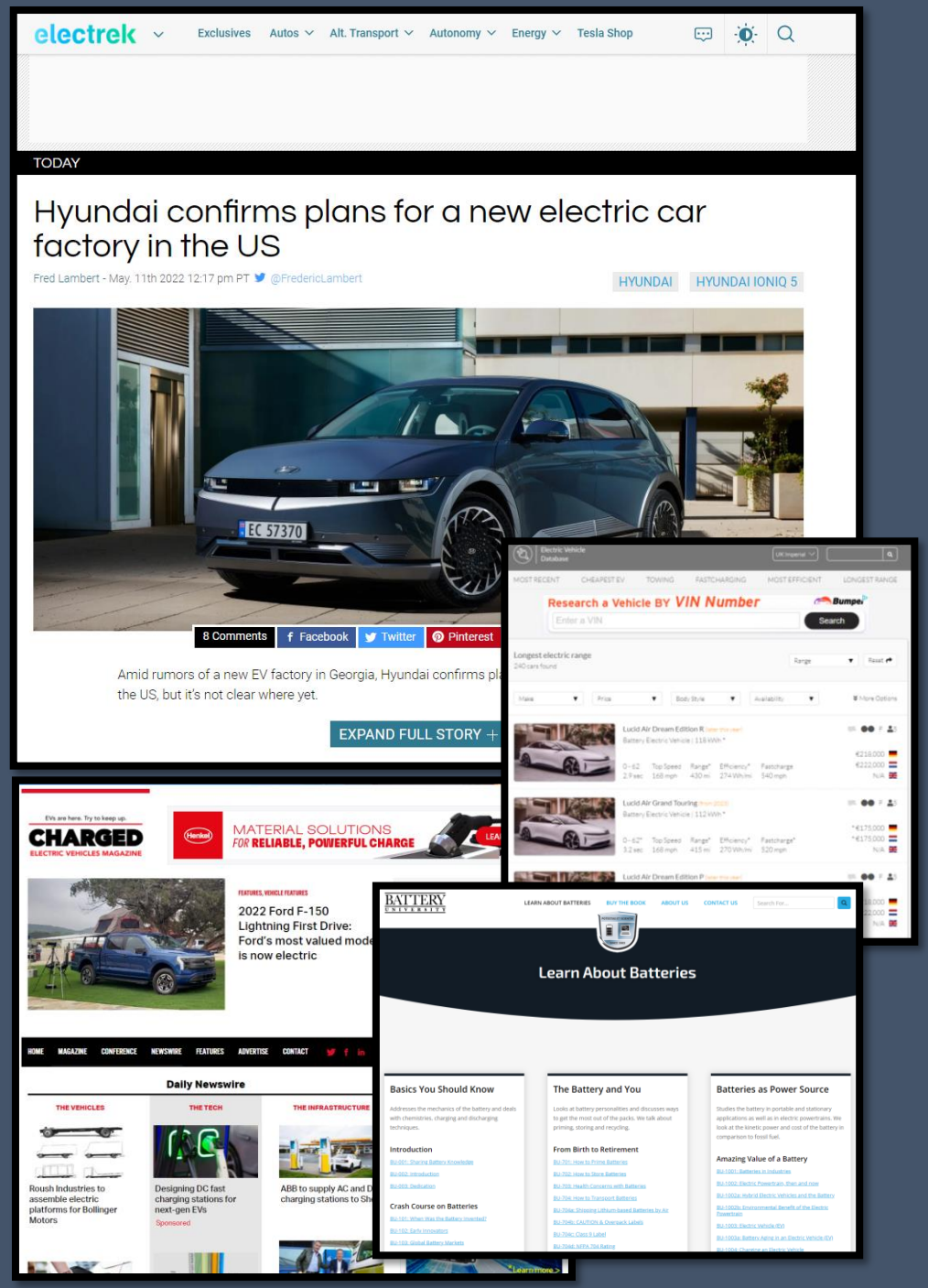


Nissan Leaf Motor

- 80-110kW motor







Great Resources

- Ev-database.org
- Chargedevs.com
- Electrek.co
- Batteryuniversity.com
- Greencarreports.com
- Insideevs.com
- evspecifications.com

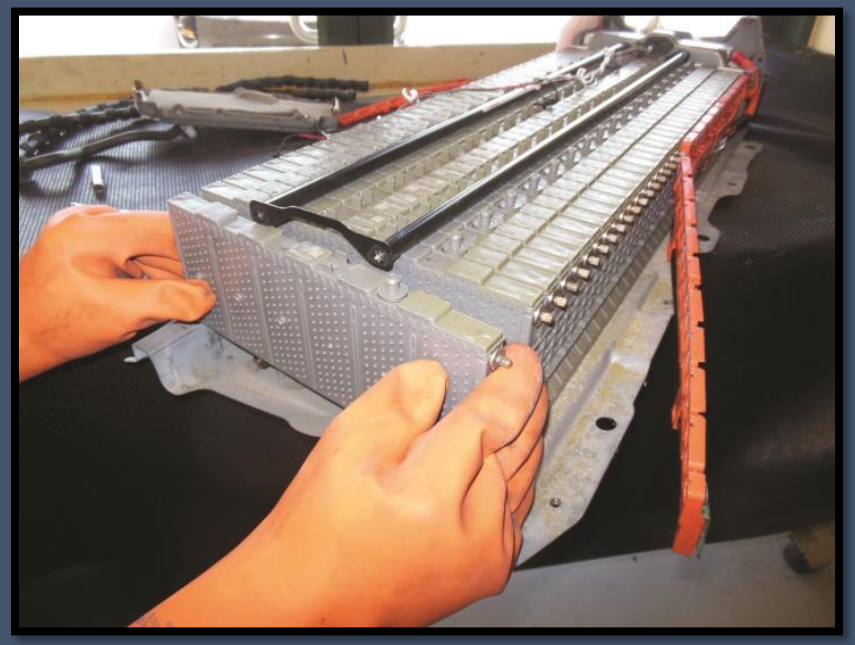
BREAK Hour one

High voltage battery

- Common locations
  - Under the rear seat
  - Behind the rear seat/in the trunk
  - Floor pan of vehicle

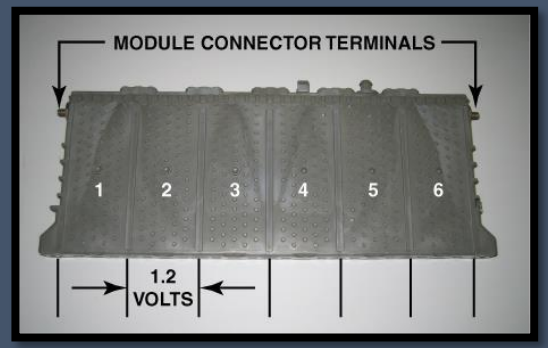
What makes them different? – Batteries

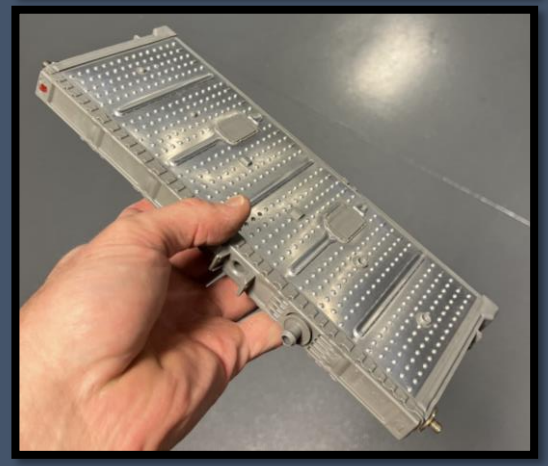
- High voltage battery
  - NiMH – Nickel Metal Hydride common with hybrid vehicles
  - Li-ion – Lithium Ion common on hybrid, plug in hybrid and electric vehicles
  - Made up of modules made up of battery cells



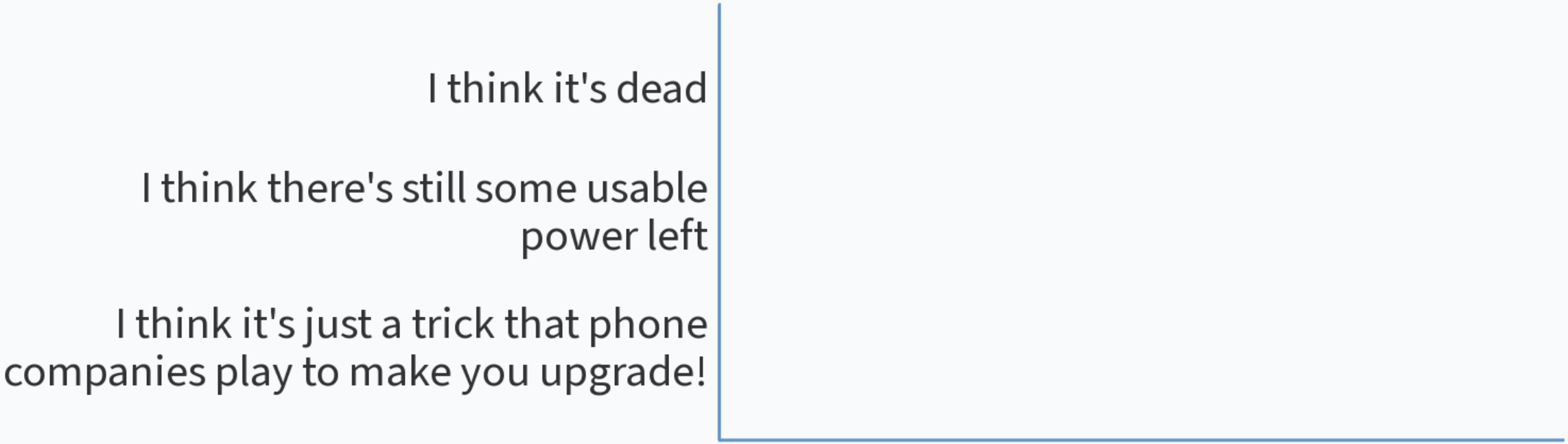
What makes them different? – Batteries

- Series connections to make a high voltage battery
- Parallel connections to make high capacity



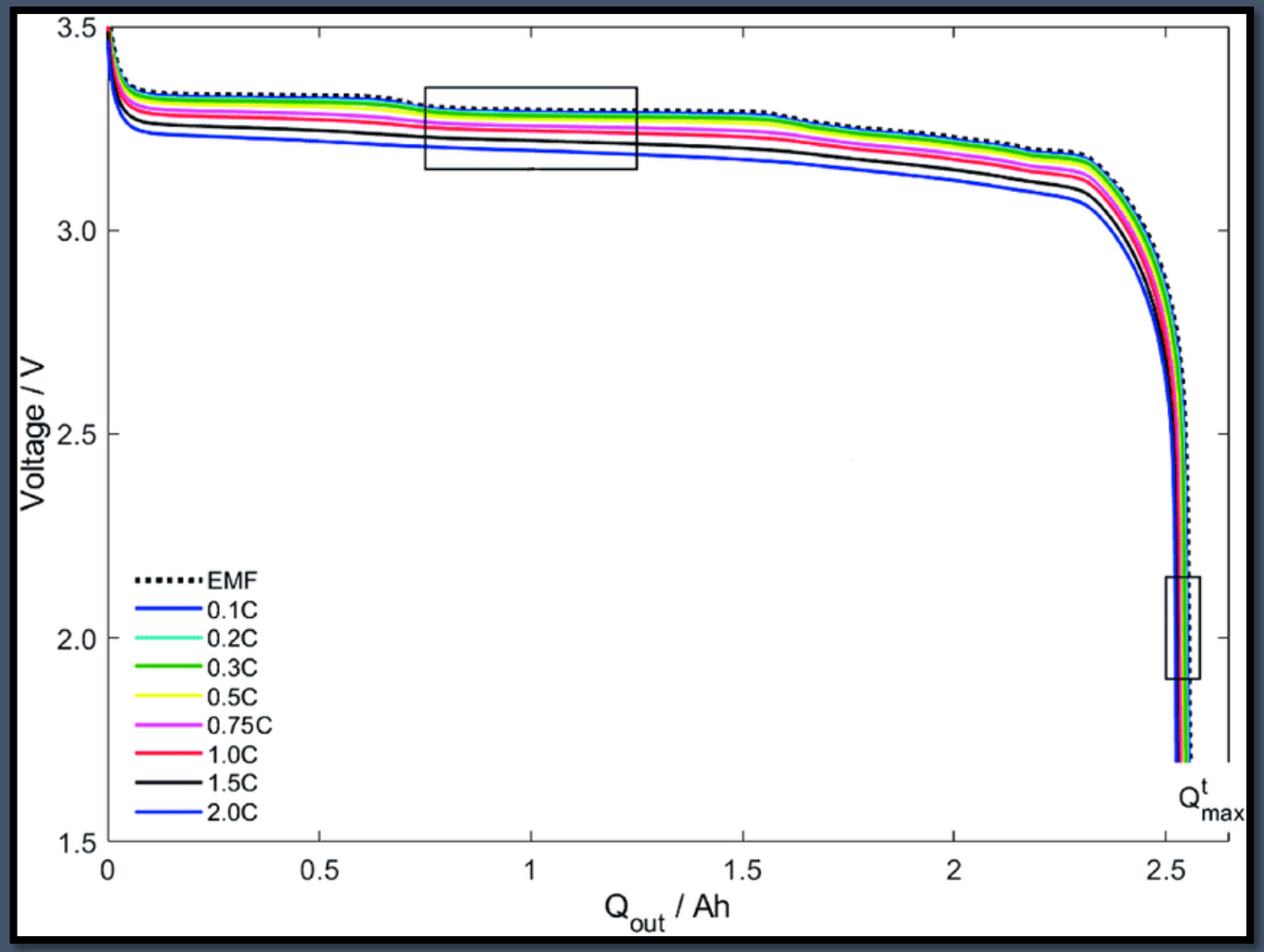


When your cell phone dies, do you think the battery went dead or is there still some power left in it?



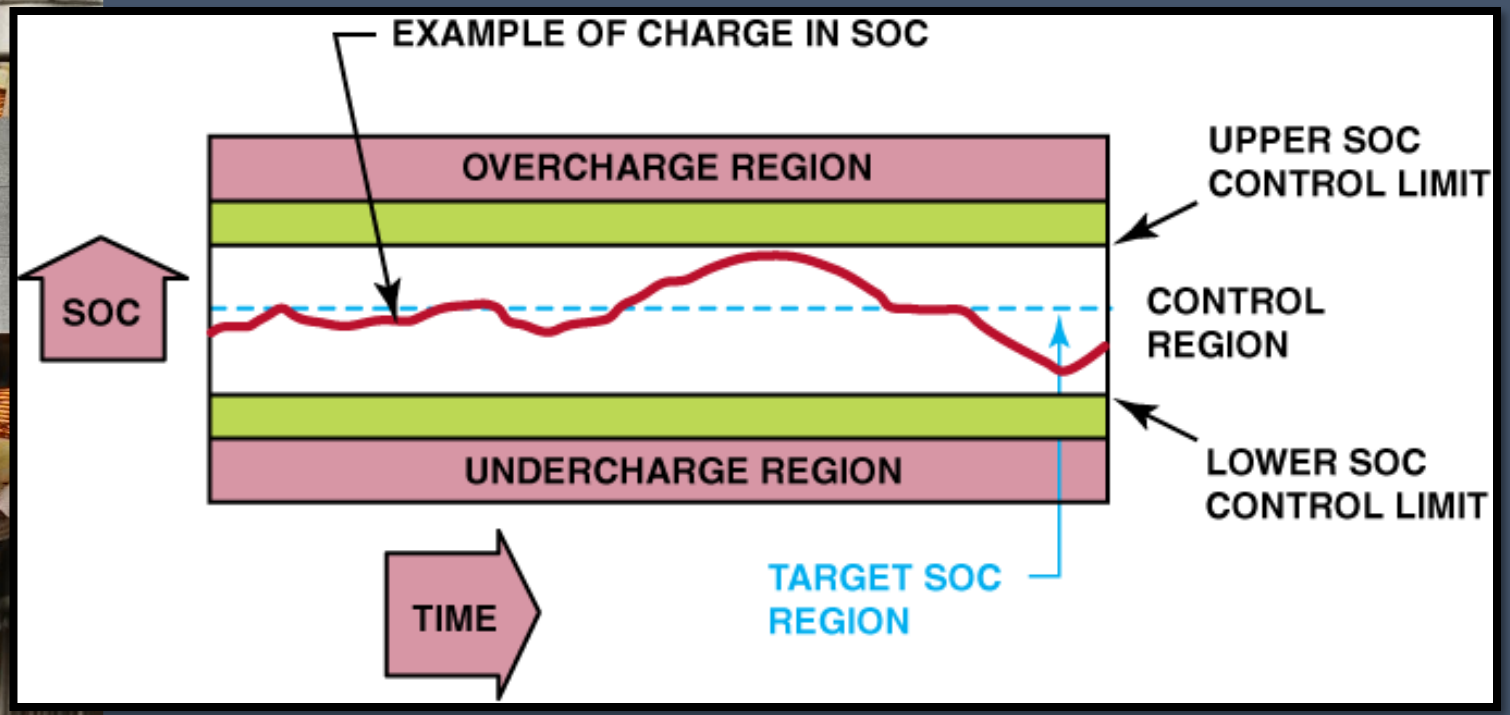
Li Ion Power Curve (LFP example)

- Difficult to gauge level of charge

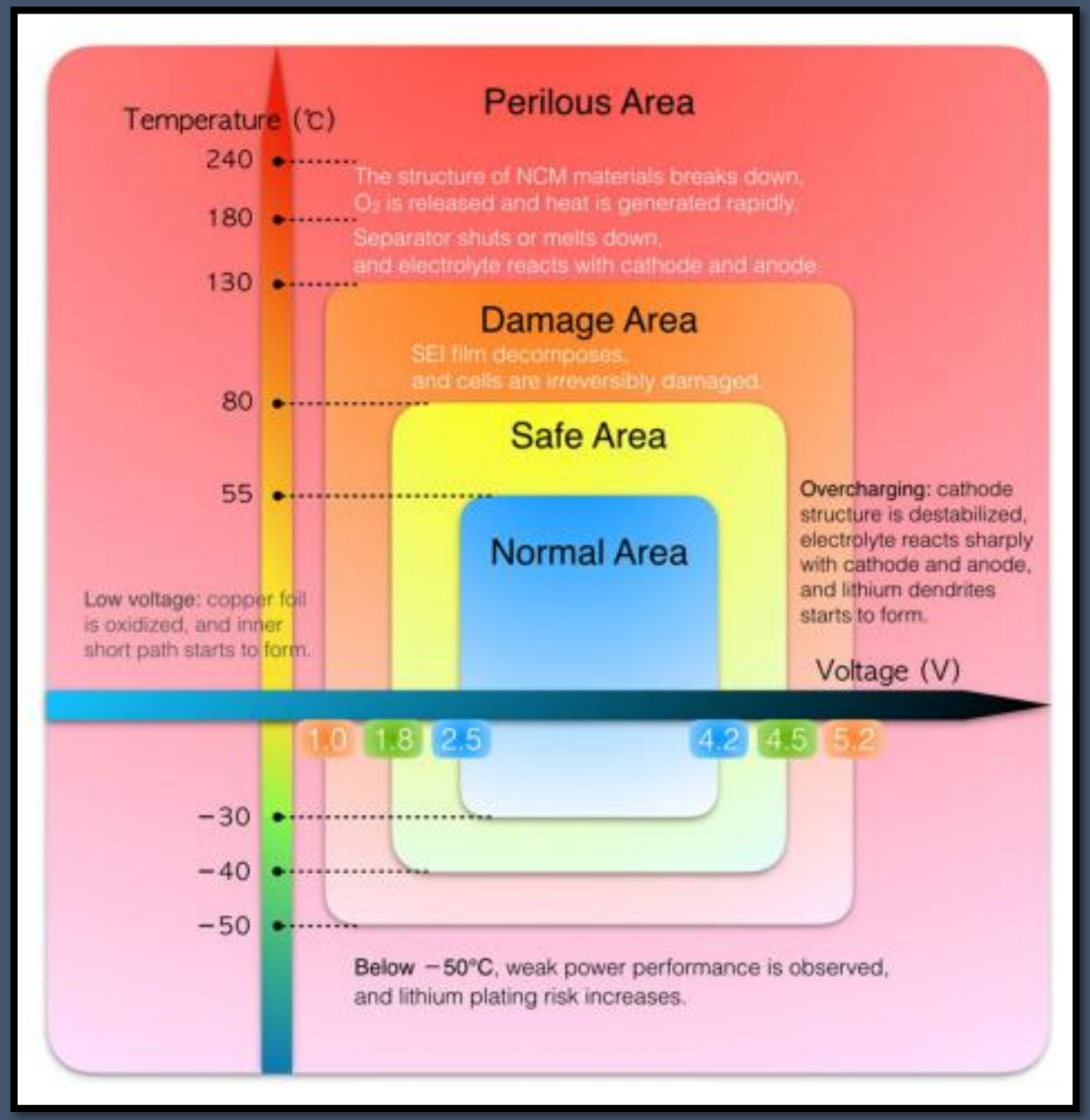


High voltage battery

- Batteries vary state of charge (SOC) within an optimal voltage range
- It’s a balance between driving range and battery life and safety

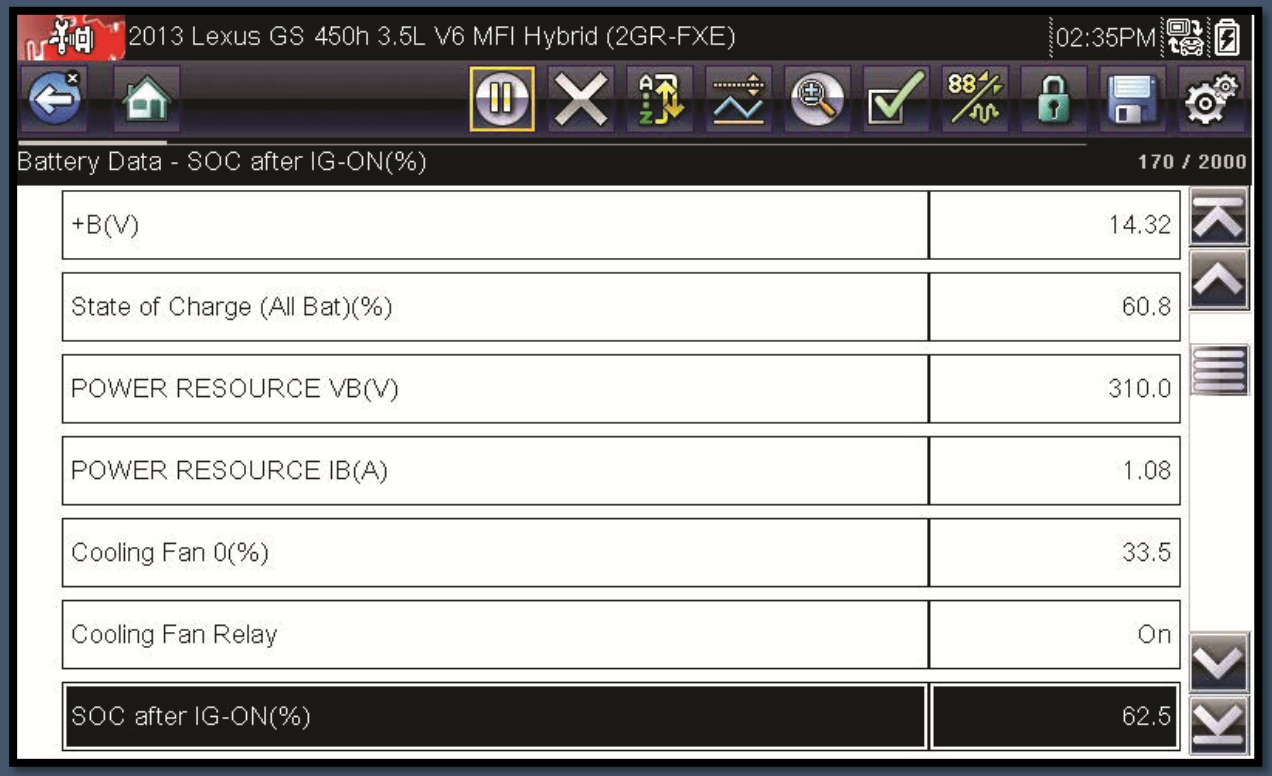


High voltage battery – Lithium Ion



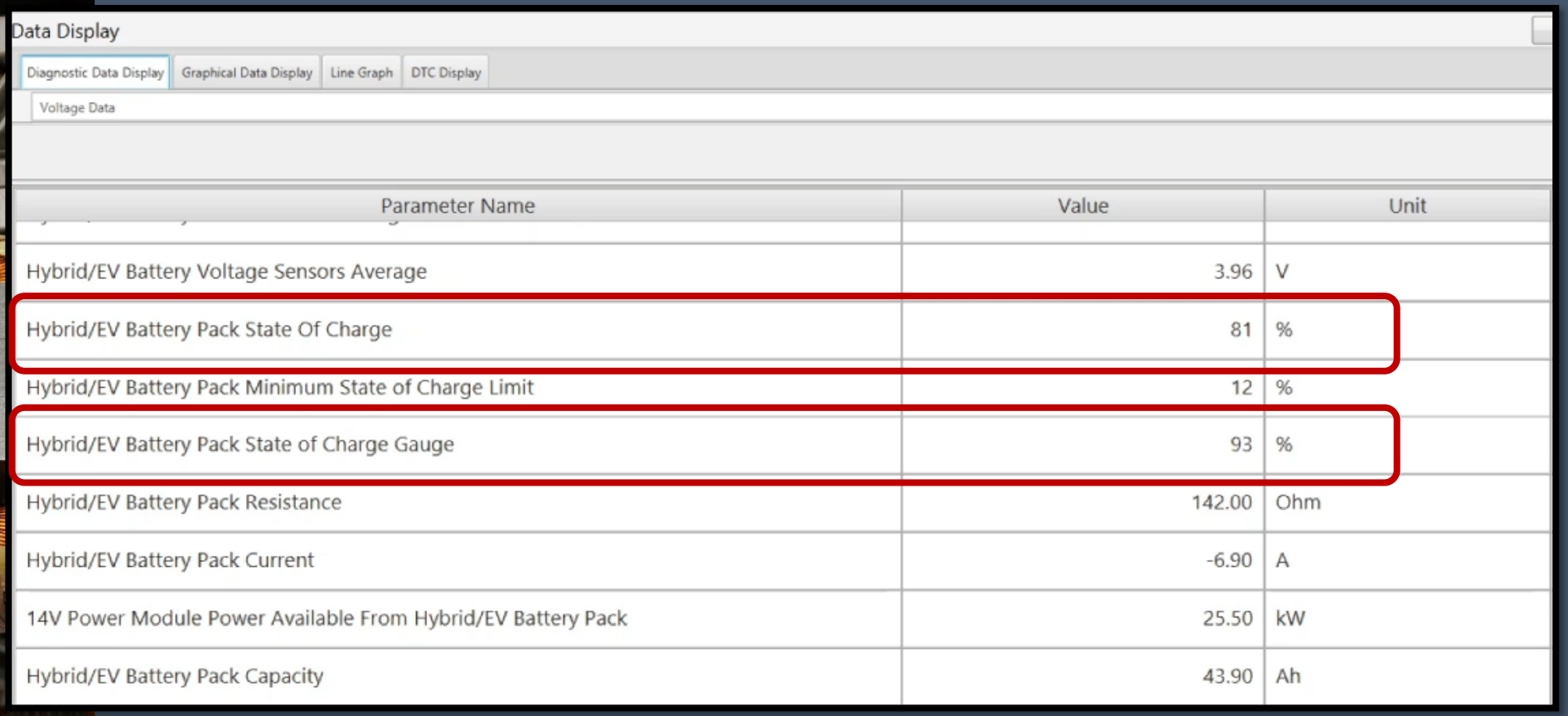
High voltage battery

- These batteries won't completely discharge and they won't ever achieve 100% charge under normal circumstances



High voltage battery

- The instrument panel gauge is not a *true* charge indicator



Parameter Name	Value	Unit
Hybrid/EV Battery Voltage Sensors Average	3.96	V
Hybrid/EV Battery Pack State Of Charge	81	%
Hybrid/EV Battery Pack Minimum State of Charge Limit	12	%
Hybrid/EV Battery Pack State of Charge Gauge	93	%
Hybrid/EV Battery Pack Resistance	142.00	Ohm
Hybrid/EV Battery Pack Current	-6.90	A
14V Power Module Power Available From Hybrid/EV Battery Pack	25.50	kW
Hybrid/EV Battery Pack Capacity	43.90	Ah

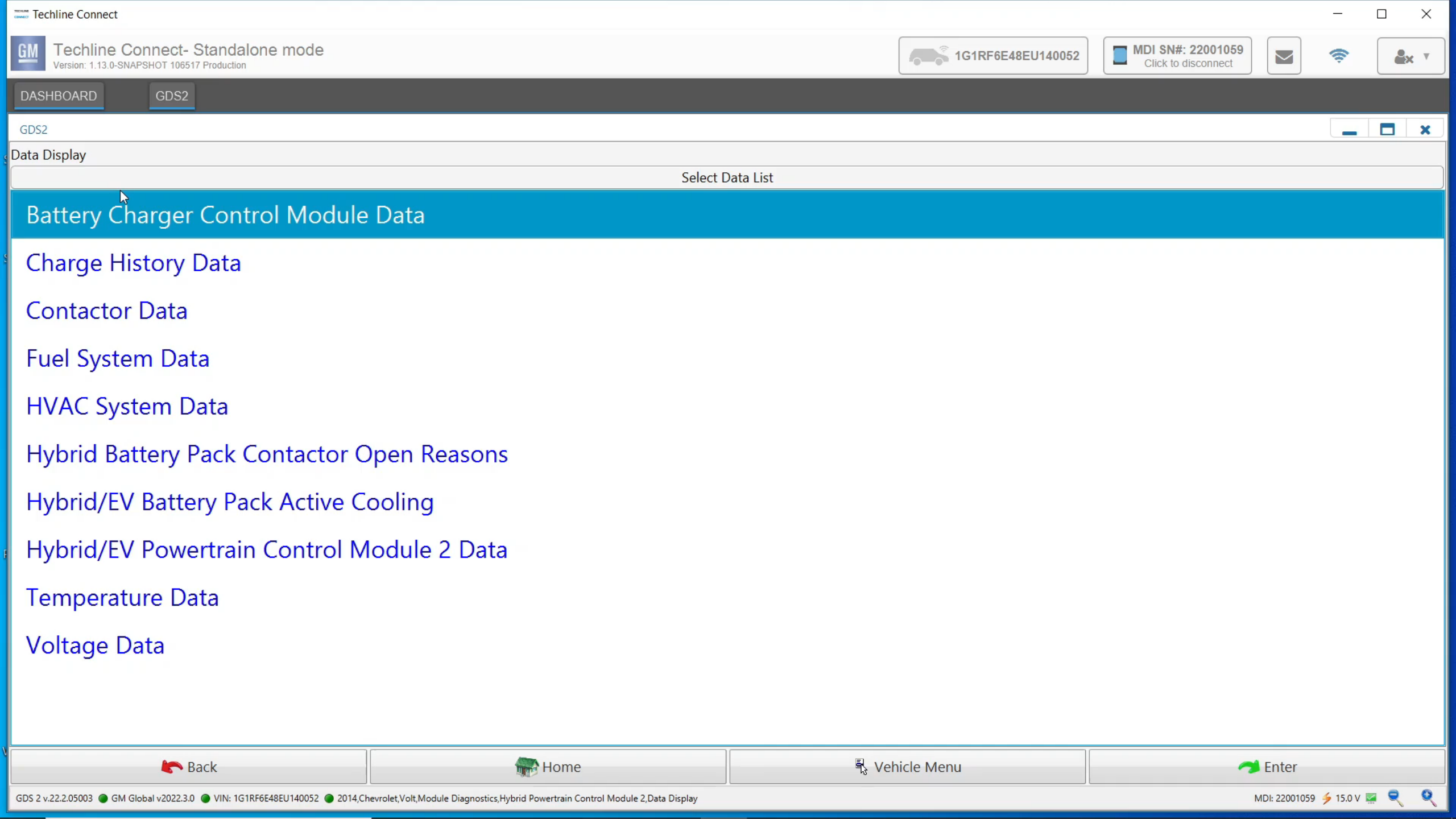
High voltage battery

- Plenty of data regarding the high voltage battery

Parameter	Value	Unit	Parameter	Value	Unit
MIL Status	ON		Battery Block Vol -V03	15.06	V
Mileage after Malfunc	0	mile	Battery Block Vol -V04	15.02	V
Battery State of Charge	58.5	%	Battery Block Vol -V05	15.04	V
Delta SOC	0.0	%	Battery Block Vol -V06	15.02	V
Batt Pack Current Val	7.21	A	Battery Block Vol -V07	15.04	V
Inhaling Air Temp	66.7	F	Battery Block Vol -V08	15.04	V
VMF Fan Motor Voltage	0.0	V	Battery Block Vol -V09	15.04	V
Auxiliary Battery Vol	14.0	V	Battery Block Vol -V10	15.03	V
Charge Control Val	-20.0	KW	Battery Block Vol -V11	14.98	V
Discharge Control Val	20.5	KW	Battery Block Vol -V12	15.06	V
Cooling Fan Mode	0		Battery Block Vol -V13	15.04	V
ECU Control Mode	0		Battery Block Vol -V14	15.08	V
Charge Control Signal	ON		Internal Resistance R01	0.019	ohm
Equal Charg Out Rly Sig	OFF		Internal Resistance R02	0.019	ohm
EQTR Charge Perm Sig	OFF		Internal Resistance R03	0.019	ohm
Standby Blower Request	OFF		Internal Resistance R04	0.019	ohm
Temp of Batt TB1	66.9	F	Internal Resistance R05	0.019	ohm
Temp of Batt TB2	67.6	F	Internal Resistance R06	0.019	ohm
Temp of Batt TB3	67.1	F	Internal Resistance R07	0.019	ohm
Battery Block Num	14		Internal Resistance R08	0.019	ohm
Batt Block Minimum Vol	14.99	V	Internal Resistance R09	0.019	ohm
Minimum Batt Block No	10		Internal Resistance R10	0.019	ohm
Batt Block Max Vol	15.07	V	Internal Resistance R11	0.019	ohm
Max Battery Block No	13		Internal Resistance R12	0.019	ohm
Battery Block Vol -V01	15.08	V	Internal Resistance R13	0.019	ohm
Battery Block Vol -V02	15.06	V	Internal Resistance R14	0.019	ohm

High voltage battery

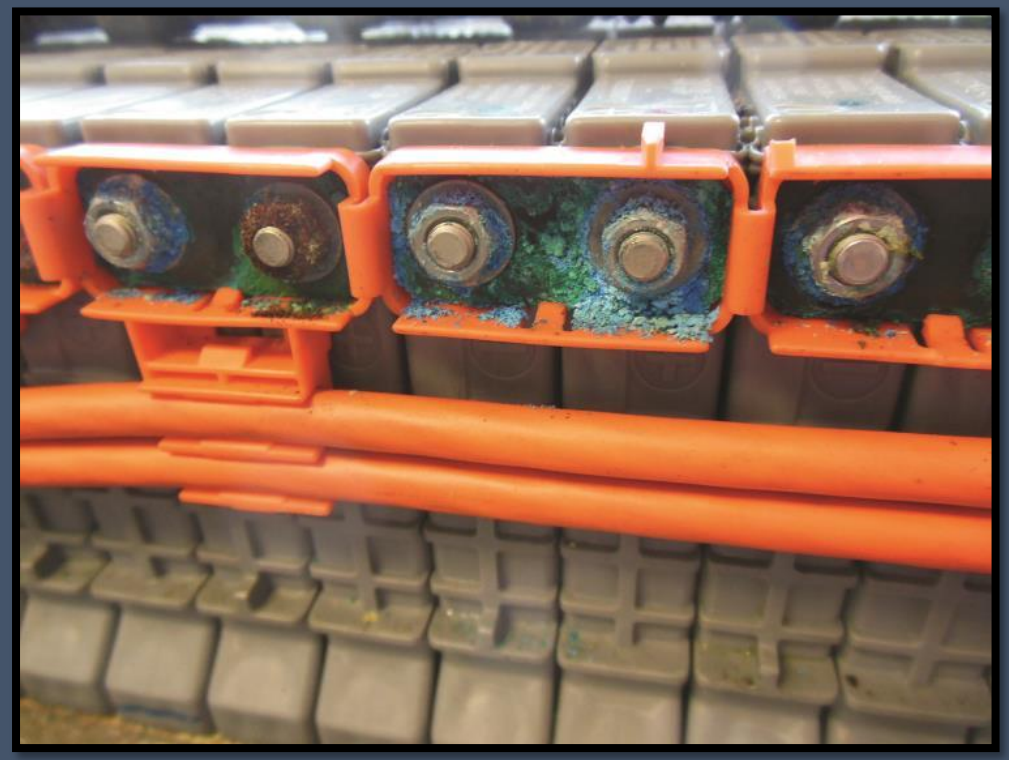
Name	Value
NUMBER OF BATT BLOCK	14
BATTERY BLOCK MINIMUM(V)	14.95
MINIMUM BATT BLOCK No	13
BATTERY BLOCK MAX(V)	16.2
MAX BATT BLOCK #	8
BATTERY SOC(%)	69
AUXILIARY BATT VOLTAGE(V)	11.4
BATTERY TEMPERATURE1 (°F)	69
BATTERY TEMPERATURE2 (°F)	69
BATTERY TEMPERATURE3 (°F)	69
BATTERY BLOCK(V)-V01	16.14
BATTERY BLOCK(V)-V02	16.19
BATTERY BLOCK(V)-V03	16.15
BATTERY BLOCK(V)-V04	[illegible]
BATTERY BLOCK(V)-V05	14.94
BATTERY BLOCK(V)-V06	[illegible]
BATTERY BLOCK(V)-V07	16.16
BATTERY BLOCK(V)-V08	15.84
BATTERY BLOCK(V)-V09	16.21
BATTERY BLOCK(V)-V10	16.16
BATTERY BLOCK(V)-V11	16.17
BATTERY BLOCK(V)-V12	[illegible]
BATTERY BLOCK(V)-V13	14.97
BATTERY BLOCK(V)-V14	16.11
INTERNAL RESISTANCE(OHMS)-R01	0.03
INTERNAL RESISTANCE(OHMS)-R02	0.02
INTERNAL RESISTANCE(OHMS)-R03	0.03
INTERNAL RESISTANCE(OHMS)-R04	0.03
INTERNAL RESISTANCE(OHMS)-R05	0.03
INTERNAL RESISTANCE(OHMS)-R06	0.03
INTERNAL RESISTANCE(OHMS)-R07	0.03
INTERNAL RESISTANCE(OHMS)-R08	0.03
INTERNAL RESISTANCE(OHMS)-R09	0.03
INTERNAL RESISTANCE(OHMS)-R10	0.03
INTERNAL RESISTANCE(OHMS)-R11	0.03
INTERNAL RESISTANCE(OHMS)-R12	0.03
INTERNAL RESISTANCE(OHMS)-R13	0.03
INTERNAL RESISTANCE(OHMS)-R14	0.03


Techline Connect
Techline Connect- Standalone mode
Version: 1.13.0-SNAPSHOT 106517 Production
1G1RF6E48EU140052
MDI SN#: 22001059
Click to disconnect
DASHBOARD
GDS2
GDS2
Data Display
Select Data List
Battery Charger Control Module Data
Charge History Data
Contactor Data
Fuel System Data
HVAC System Data
Hybrid Battery Pack Contactor Open Reasons
Hybrid/EV Battery Pack Active Cooling
Hybrid/EV Powertrain Control Module 2 Data
Temperature Data
Voltage Data
Back
Home
Vehicle Menu
Enter
GDS 2 v.22.2.05003
GM Global v2022.3.0
VIN: 1G1RF6E48EU140052
2014,Chevrolet,Volt,Module Diagnostics,Hybrid Powertrain Control Module 2,Data Display
MDI: 22001059
15.0 V

High voltage battery

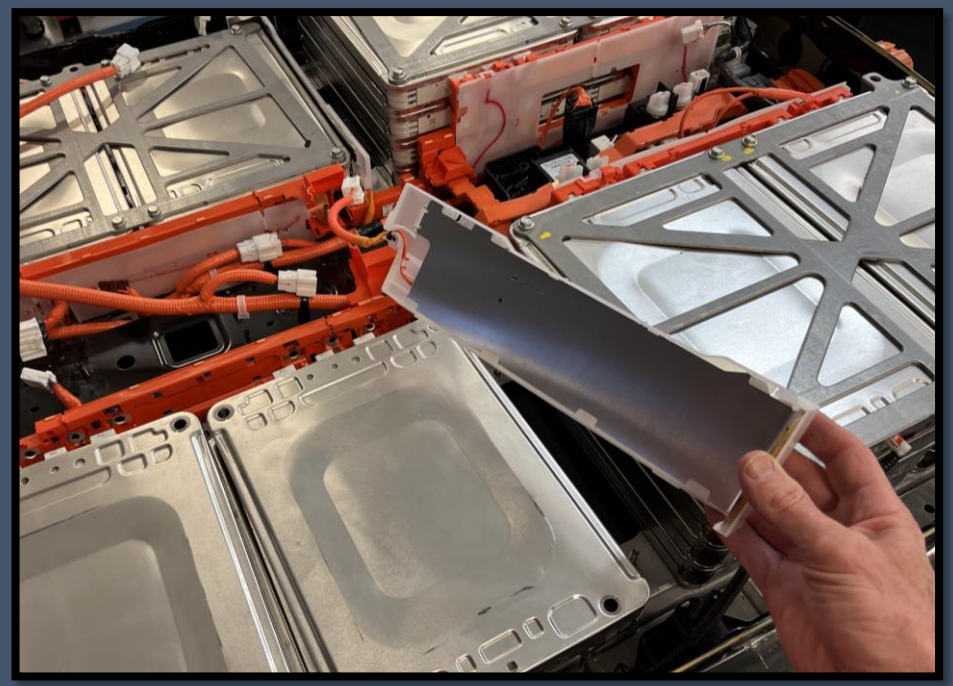
- The Hybrid/EV module can detect problems with the battery
  - Cell Balance
  - Module voltage
  - Internal resistance of module
  - Battery temperature
  - Short circuits
  - Open circuits
  - Ground issues
  - Cooling issues
  - Contactor (relay) issues

High voltage battery



High voltage battery temperature

- Li Ion doesn’t perform as well in cold temperature
  - Battery heater
    - PTC – electric resistance heater
    - Heats battery pack as needed



High voltage battery temperature

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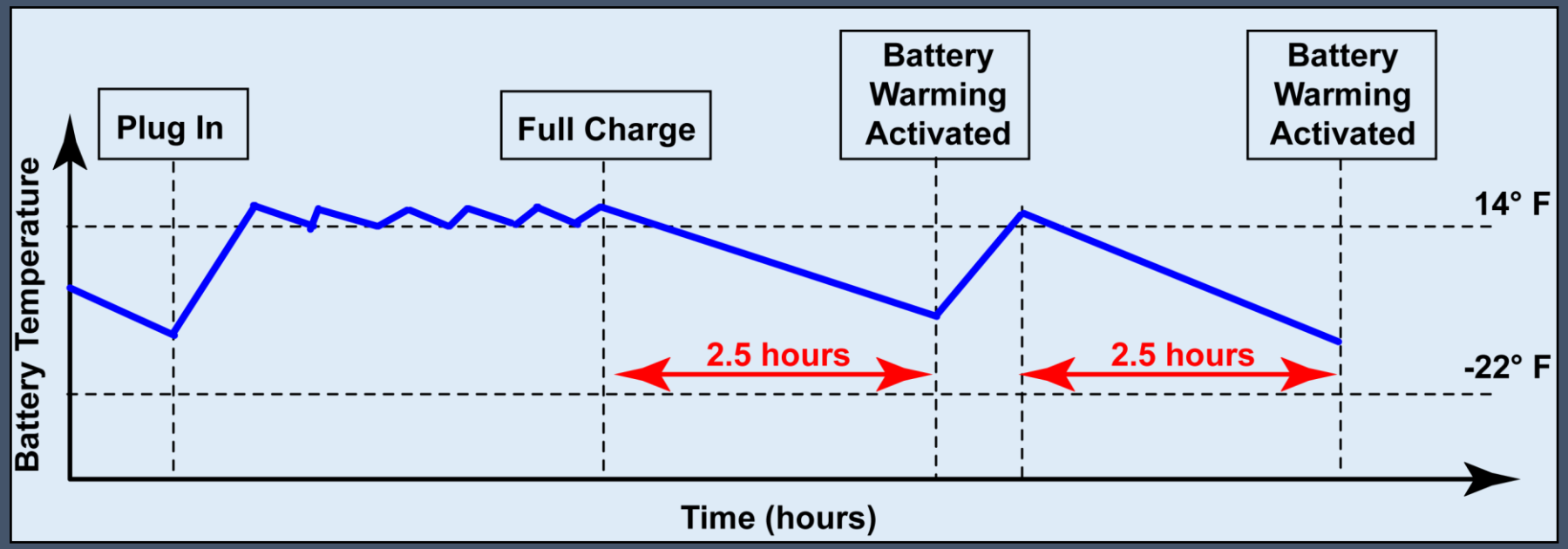
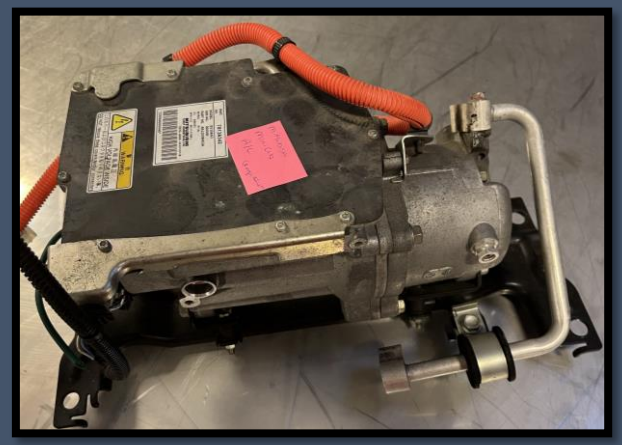
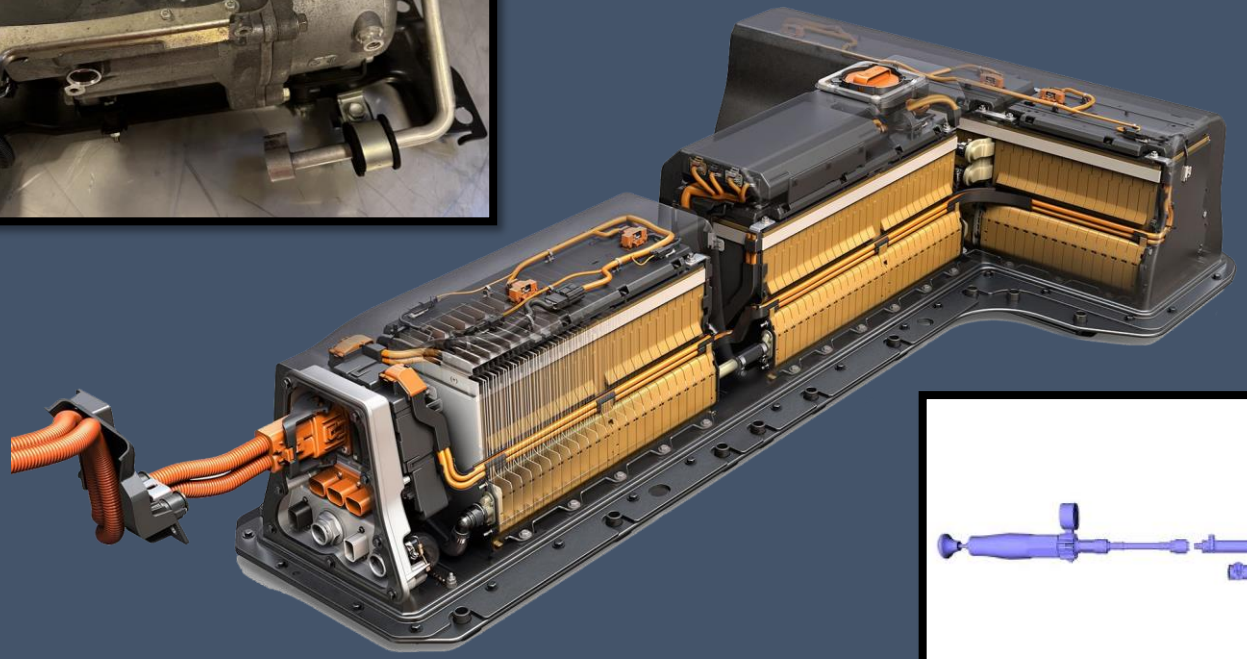
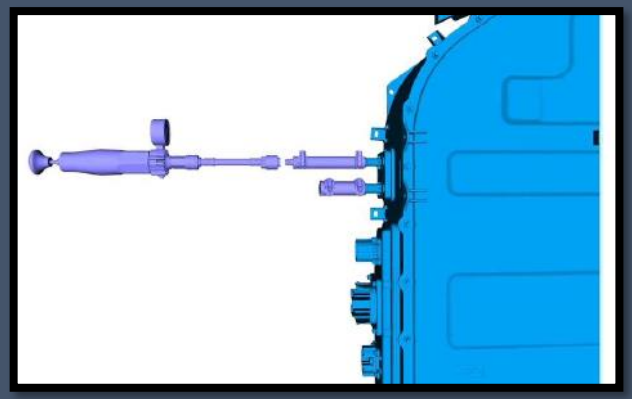


High voltage battery temperature

- Li Ion needs to be cooled in high temperatures



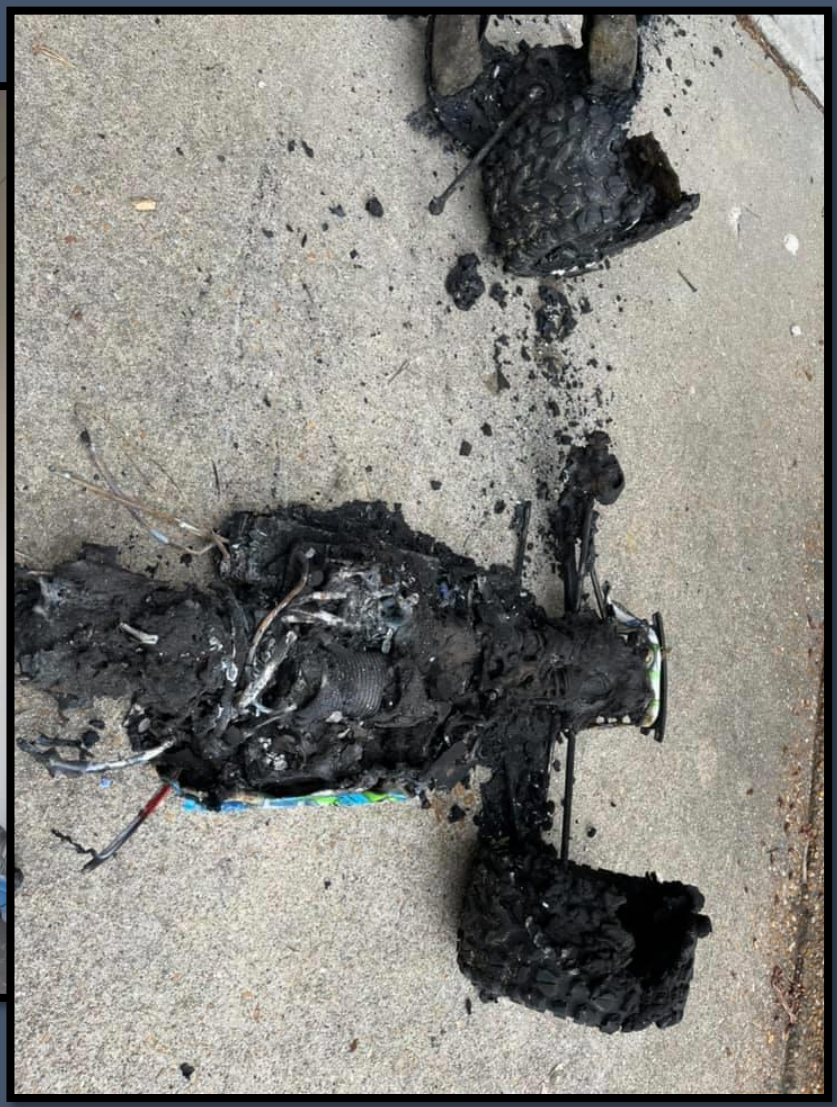





Temperature (℃)
Perilous Area
240
The structure of NCM materials breaks down, O_2 is released and heat is generated rapidly.
180
Separator shuts or melts down, and electrolyte reacts with cathode and anode.
130
Damage Area
SEI film decomposes, and cells are irreversibly damaged.
80
Safe Area
55
Overcharging: cathode structure is destabilized, electrolyte reacts sharply with cathode and anode, and lithium dendrites starts to form.
Normal Area
Low voltage: copper foil is oxidized, and inner short path starts to form.
Voltage (V)
1.0
1.8
2.5
4.2
4.5
5.2
−30
−40
−50
Below −50°C, weak power performance is observed, and lithium plating risk increases.

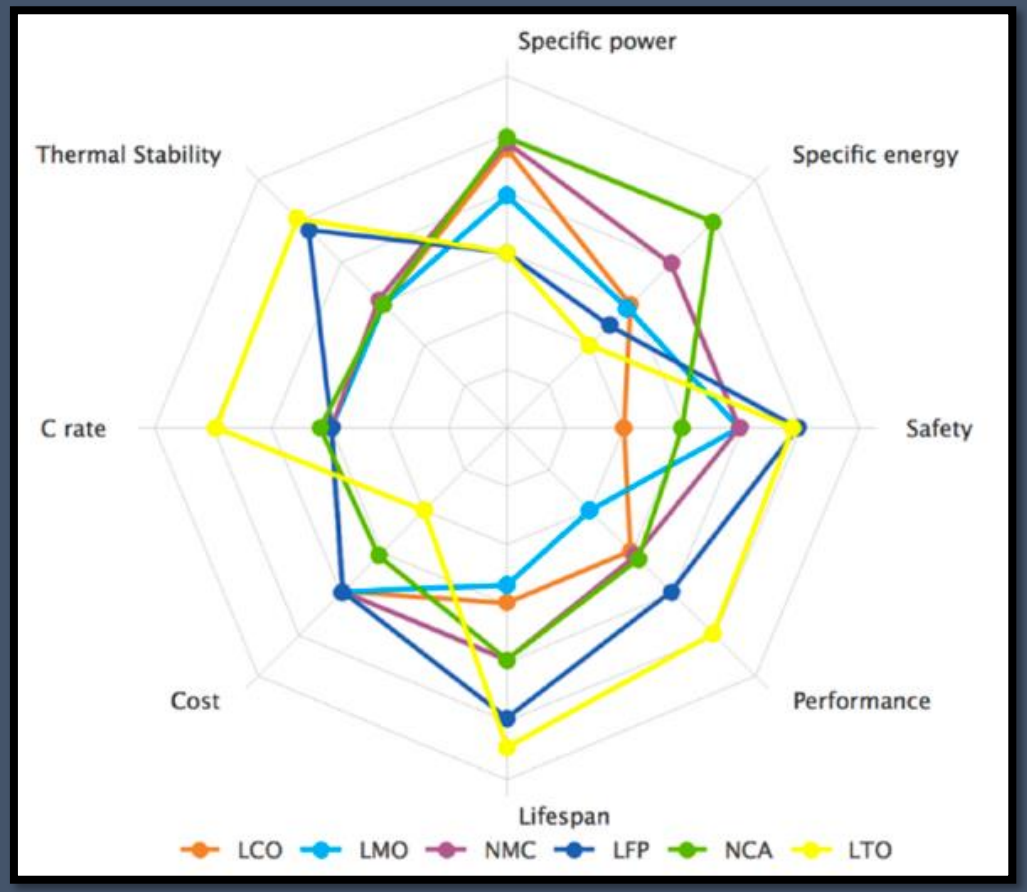

FORD


RUBICON
Jeep



Lithium Battery Chemistries:

- Lithium Cobalt Oxide (LCO)
- Lithium Nickel Cobalt Aluminum Oxide (NCA)
- Lithium Nickel Manganese Cobalt Oxide (NMC)
- Lithium Manganese Oxide (LMO)
- Lithium Titanate Oxide (LTO)
- Lithium Iron Phosphate (LFP)



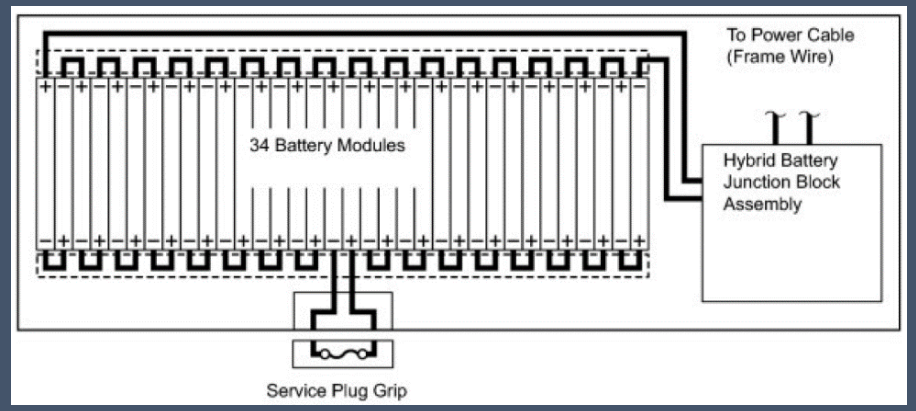
	Lithium Titanate (Li_2TiO_3) — LTO	Lithium Manganese Oxide (LMO)	Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2) — NMC	Lithium Iron Phosphate(LiFePO4) — LFP	Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO2) — NCA	Lithium Cobalt Oxide(LiCoO2) — LCO
Voltages Nominal (Volt)	2.40V	3.70V	3.70V	3.30V	3.70V	3.70V
Typical operating range (V/cell)	1.8V–2.85V	3.0V – 4.2V	3.0V–4.2V	2.5V–3.65V	3.0 V–4.2V	3.0 V–4.2V
Specific energy (Wh/kg)	50–80Wh/kg	100-150 Wh/kg	150–220Wh/kg	90–120Wh/kg	200-260Wh/kg	150–200Wh/kg.
Charge (C-rate)	1C typical; 5C maximum, charges to 2.85V	0.7 – 1.0C (3C max)	0.7–1C, charges to 4.20V	1C typical, charges to 3.65V	0.7C, charges to 4.20V, fast charging possible with some cells	0.7–1C, charges to 4.20V
Discharge (C-rate)	10C possible, 30C 5s pulse	10C (short burst at 30C)	1C, 2C possible on some cells	1C, 25C on some cells	1C	1C
Cycle life	3,000–7,000	300-700	1000–2000	5000-7000; up to 12000 possible in some cells	500	500–1000
Thermal runaway	200°C +	2°C (482°F)	210°C (410°F)	270°C (518°F)	150°C (302°F)	150°C (302°F)
Cost (per kWh)	~$1,005	-	~$420 per	~$580	~$350	-
Application	**Electric vehicles (Honda Fit, Mitsu i-MiEV)**, UPS	Less relevant now, power tools, medical devices, storage systems, **electric vehicles (Roadster)**	E-bikes, E-Rikshaw, industrial equipment, **electric vehicles (Leaf and Volt)**	E-bikes, E-Rikshaw, Battery Energy storage systems, offices and homes, **Electric Vehicles (Tesla Model 3)**	Medical devices, industrial equipment, **electric vehicles (Tesla model X and 3)**	Most common, Smart watches, mobile phones, tablets, laptops, cameras

BREAK Hour Two - Lunch

Battery Layout Examples

- Typical Hybrid:
  - Behind the seat – Toyota Camry
- Plug-in Hybrid:
  - Between the seats – Volt
- All electric
  - Floor Pan – Nissan Leaf

Camry Hybrid Battery



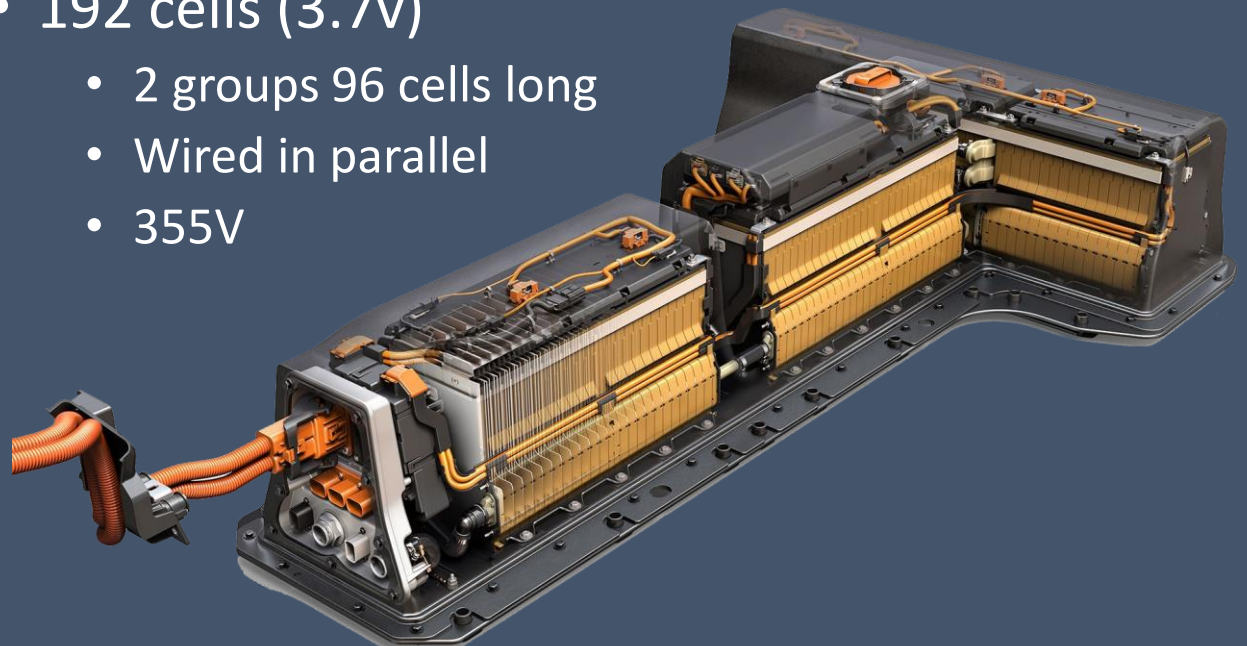
- 34 modules
  - 6 cells per module (7.2 volts)
  - 204 cells
  - 1.2v per cell
- 244.8v

Camry Hybrid Battery

- Cooling
  - Air cooled - air is pulled in from the rear seat area and drawn past the batteries to remove heat
- Disconnect
  - The “service plug” is used to disable the high voltage battery, so the vehicle is safe to work on
  - There is a fuse in the service plug

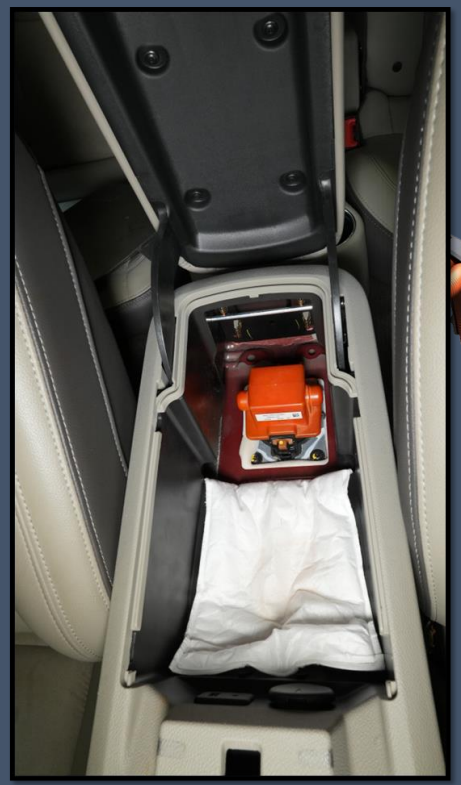
Volt Battery

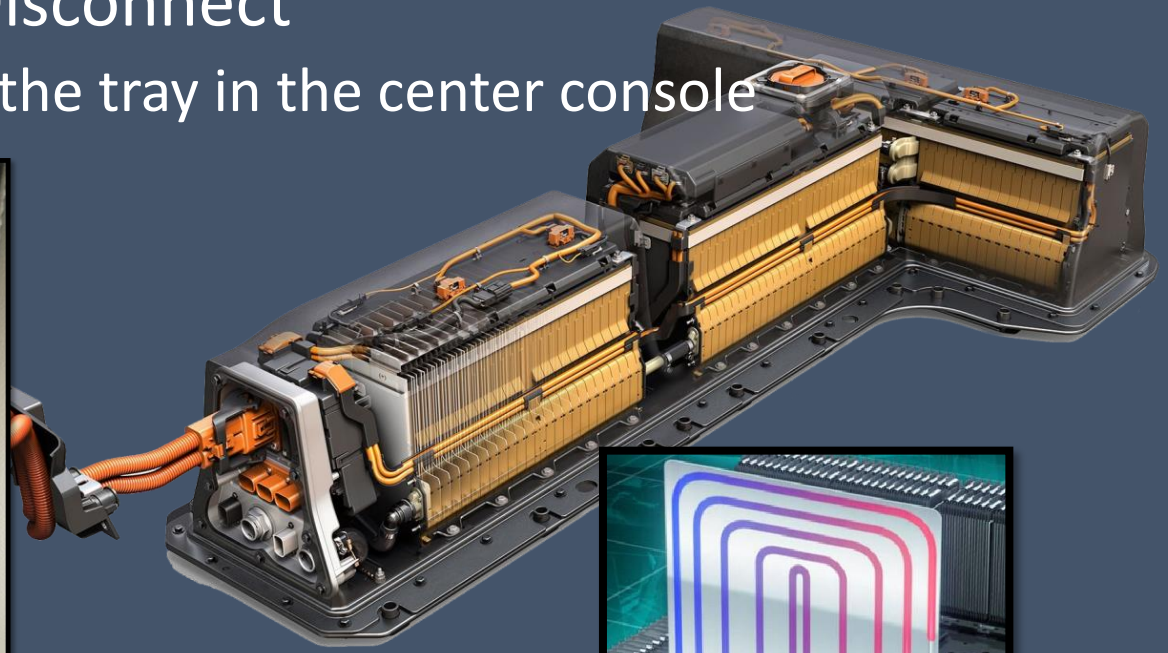
- Early version
  - 288 cells (3.7v)
    - 3 groups 96 cells long
    - Wired in parallel
    - 355V
- Late Version
  - 192 cells (3.7v)
    - 2 groups 96 cells long
    - Wired in parallel
    - 355V

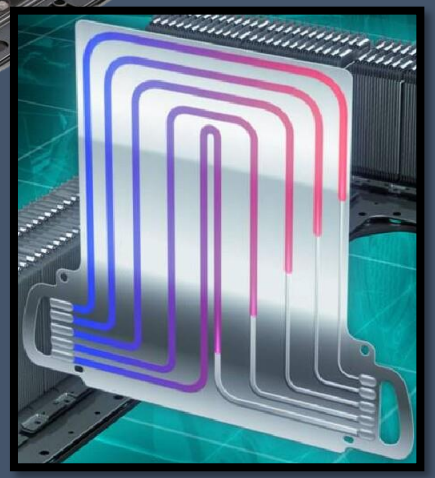


Volt Battery

- Cooling
  - Liquid cooled and heated
- Service Disconnect
  - Under the tray in the center console



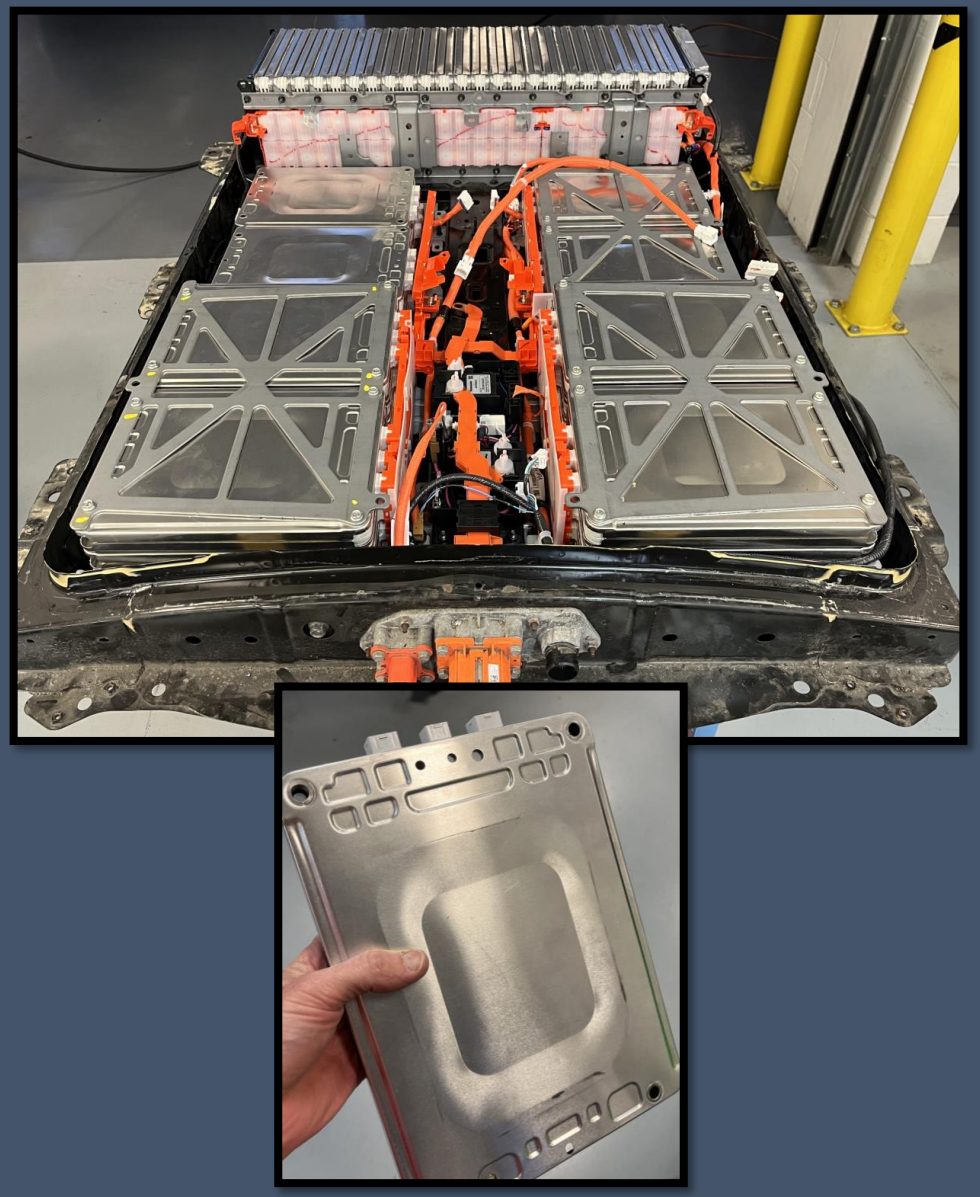




Leaf Battery

- 48 battery modules wired in series
- Each module has 7.3 volts

Leaf Battery



- 48 Minor Modules Connected in Series (192 Cells)
- Minor Module = 4 cells, 2 wired in parallel and then connected in series with the other 2
- Nominal Voltage: 360 V

Leaf Battery

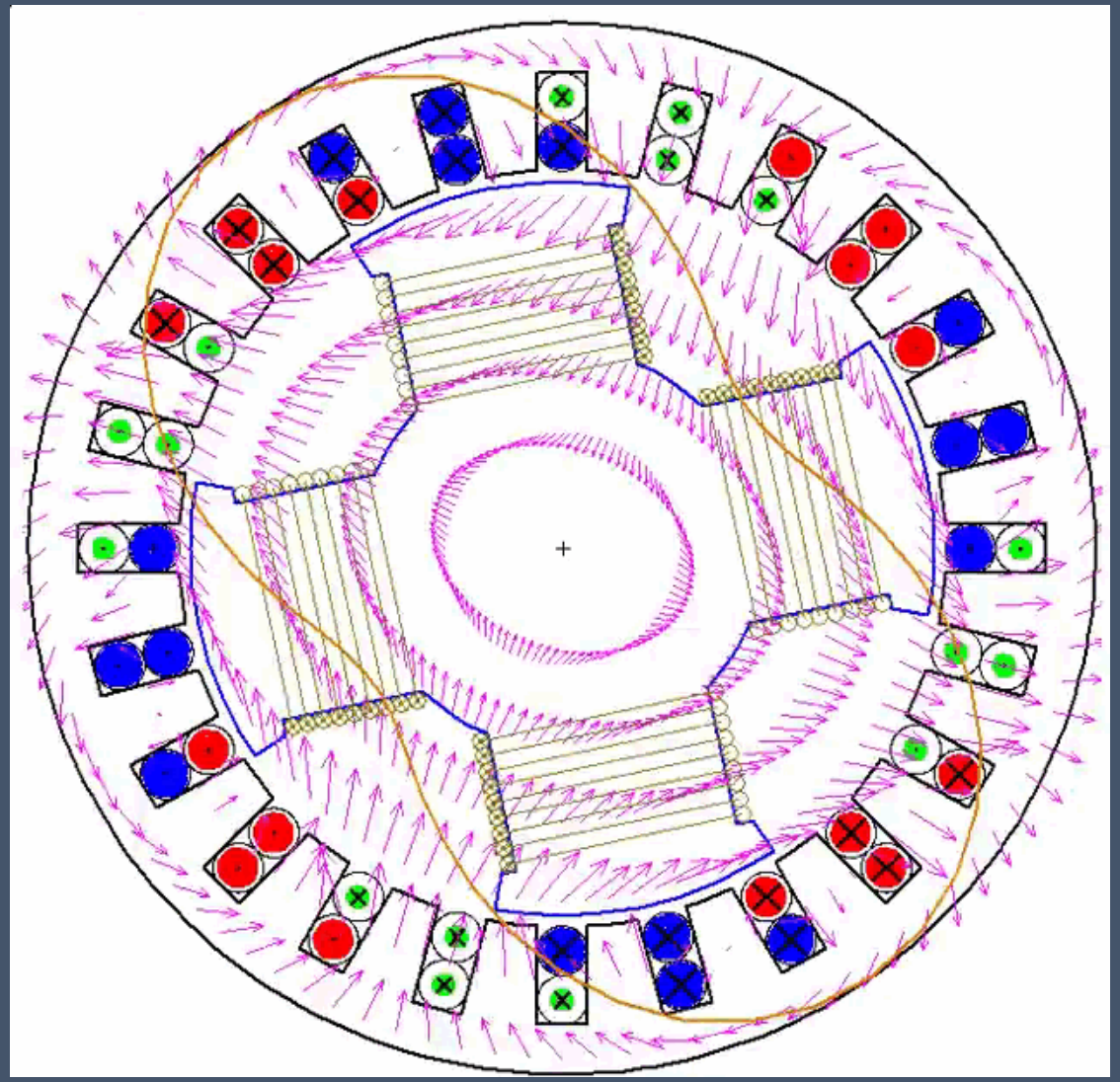
- Battery disconnect is located under a plate between the rear seats
- Electrically heated and air cooled

Inverter

Inverter Technology

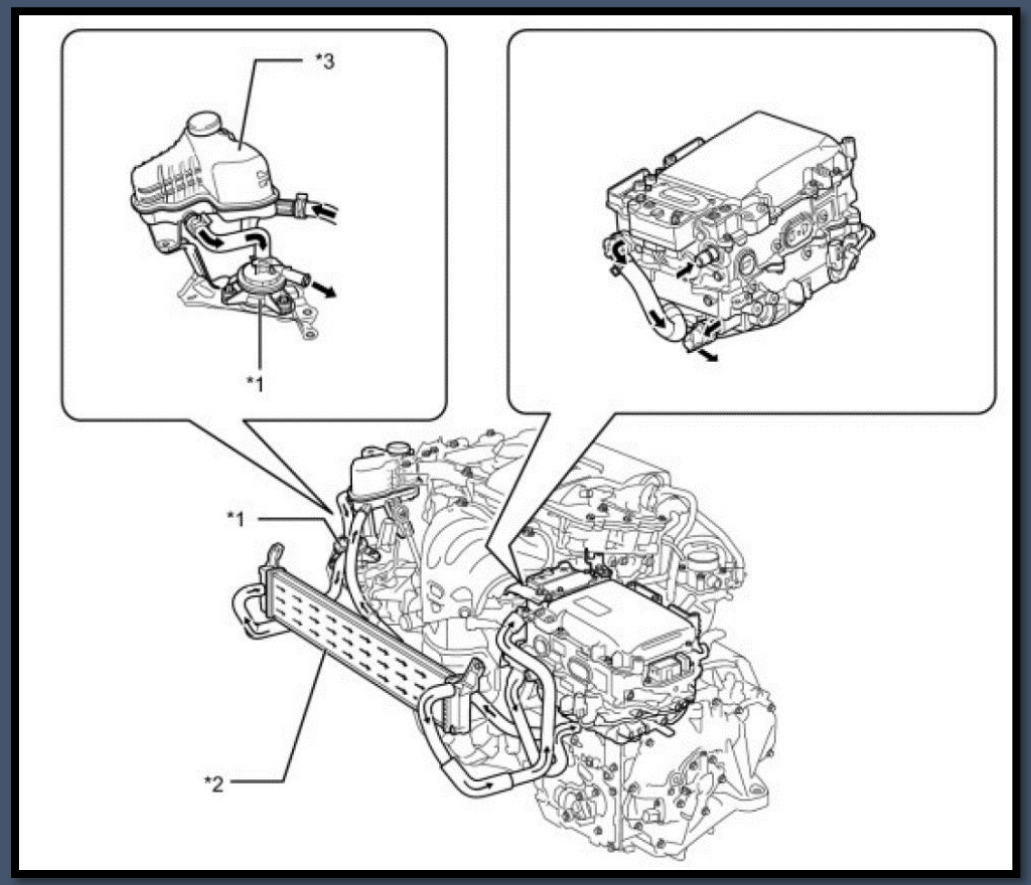
- The inverter will take DC battery voltage and convert it to AC voltage to operate the electric motors
- It will also convert AC voltage created during regeneration to DC voltage to store in the battery
- The inverter has its own cooling system
- The transistors will get hot from controlling the current

Inverter Technology



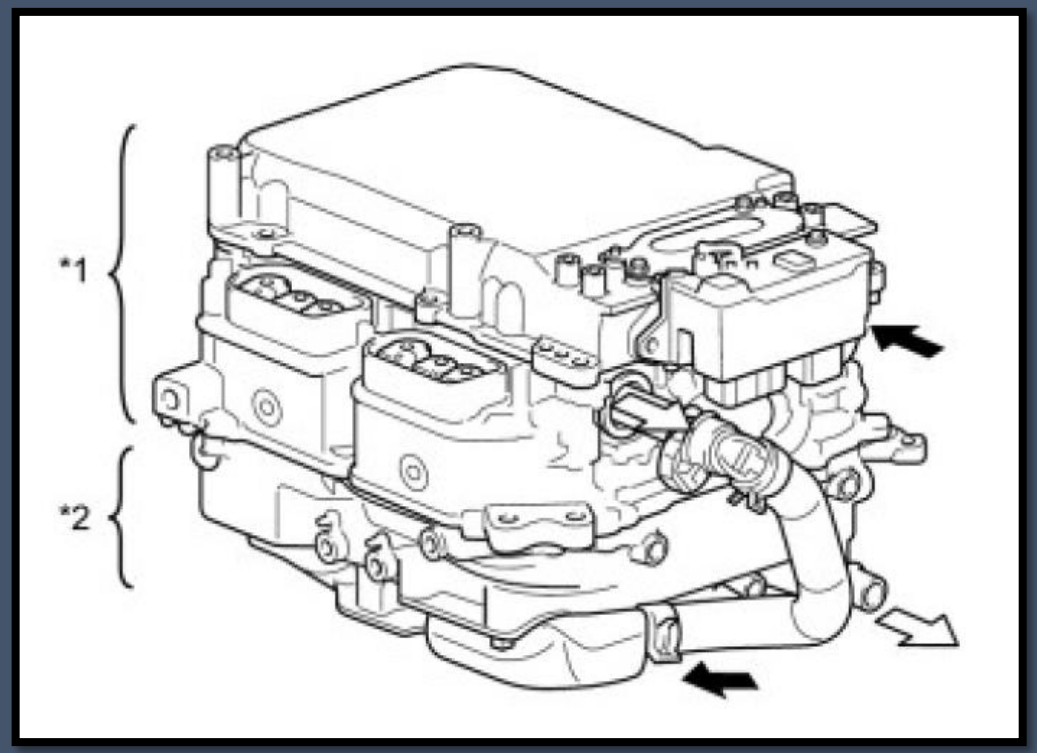
Inverter Technology

- Uses engine coolant
- Heat exchanger (radiator)
- Separate water pump



Inverter Technology

- Toyota Example:
  - Top half of the assembly is the Invertor
  - Bottom half is the convertor
    - Convertor will take power from the high voltage battery and convert it to low voltage for the vehicle's low voltage needs



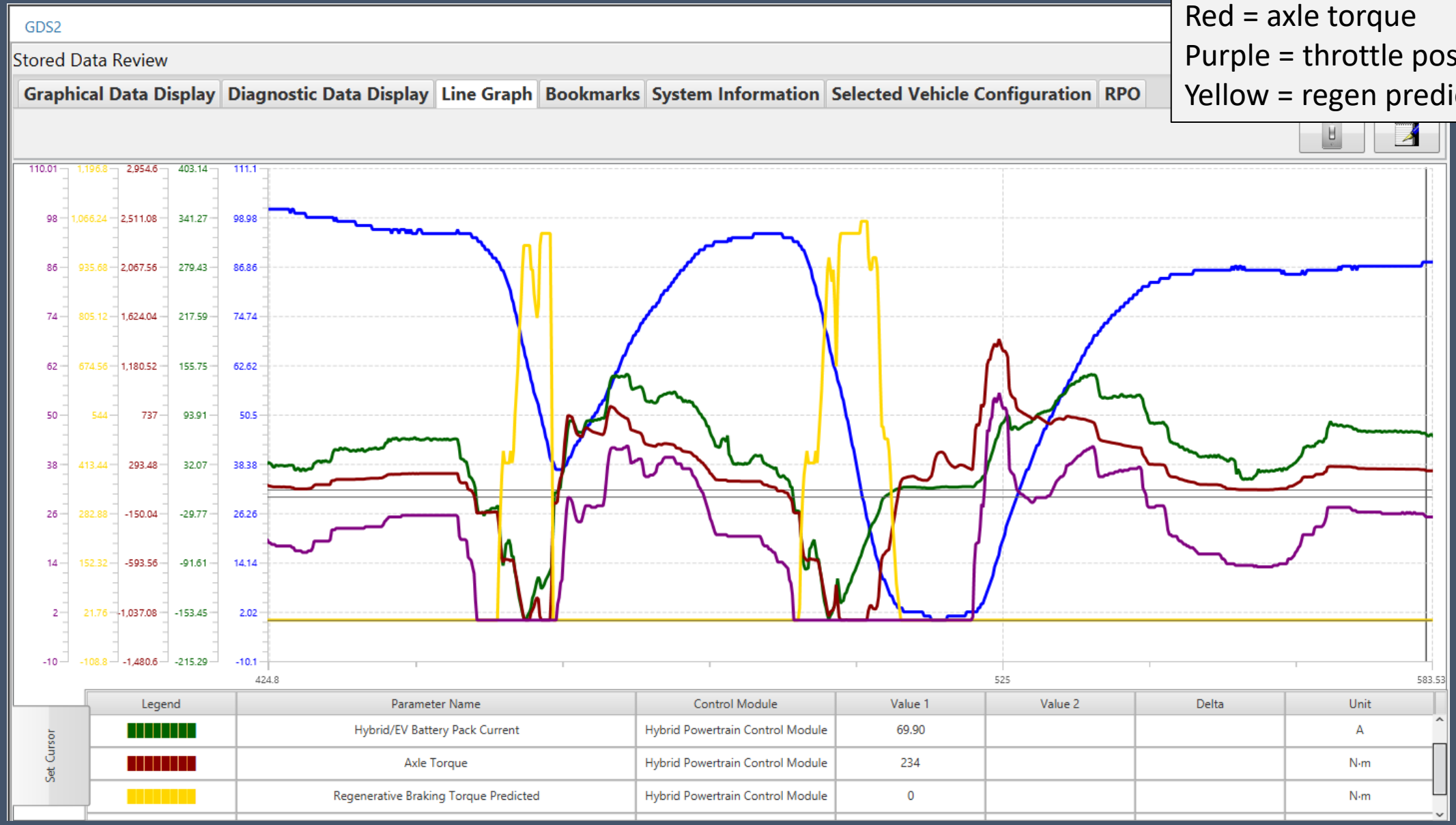
Inverter Technology

- Earlier hybrids had much bigger transaxles with large electric motors. The large motors had low max RPM, but had high torque output
- Newer hybrids use smaller (lower torque) motors, but they spin them fast and they handle higher voltages

Models	Inverter (DC⇔AC)	MG ECU	Boost Converter	DC-DC Converter
Gen 1 Prius	274V	N/A[1]	N/A[2]	✓
Gen 2 Prius	500V	N/A[1]	✓	✓
Gen 3 Prius, Prius V	650V	✓	✓	✓
Prius C	520V	✓	✓	✓
Prius PHV	650V	✓	✓	✓
Highlander Hybrid	650V	✓	✓	✓
Avalon Hybrid	650V	✓	✓	✓
Camry Hybrid ('07-'11)	650V	✓	✓	N/A[3]
Camry Hybrid ('12 & up)	650V	✓	✓	✓

Volt test drive

Blue = vehicle speed
Green = battery current
Red = axle torque
Purple = throttle position
Yellow = regen predicted



EV/PHEV Charging

[Electric Vehicle Fast Charging: Holistic Overview (onsemi.com)]

Vehicle Connections

- Plugs not only transfer power, but also provide communications between the vehicle and the charger
- Communications (via CP) include...
  - Maximum power output
  - Charging time
  - Fault conditions

Plug Configurations

- Standards are established globally to determine common...
  - Power & communication interfaces
  - Mechanical & electrical specifications for plug/socket assemblies
- North America uses the SAE J1772 standard for AC and DC charging
- CHAdeMo is a common global standard used for high-power DC charging

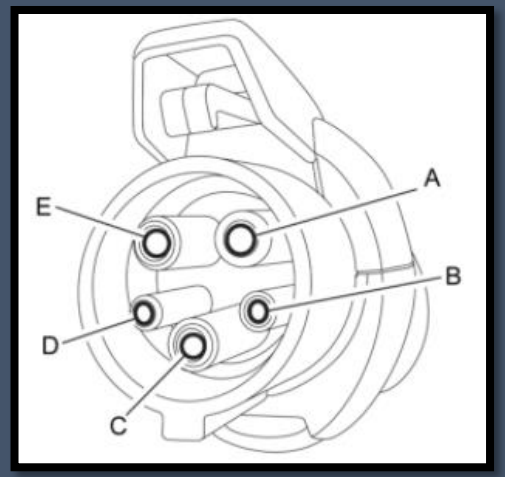

Type-1 Connector (1-ph AC)

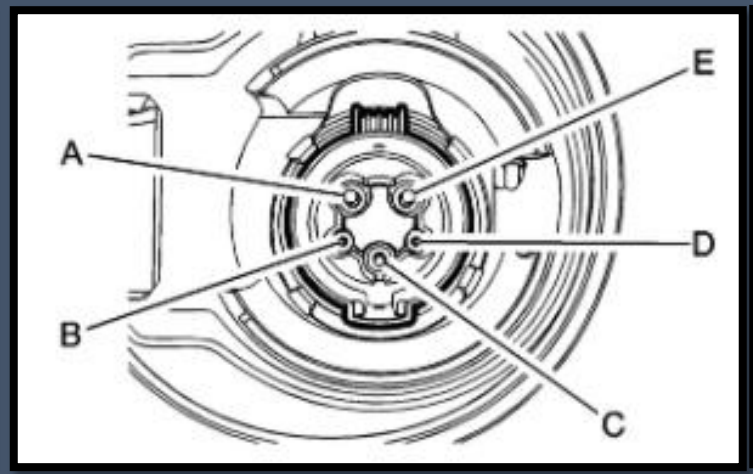

Combo Charging System (AC/DC)


CHAdeMO Connector (DC)

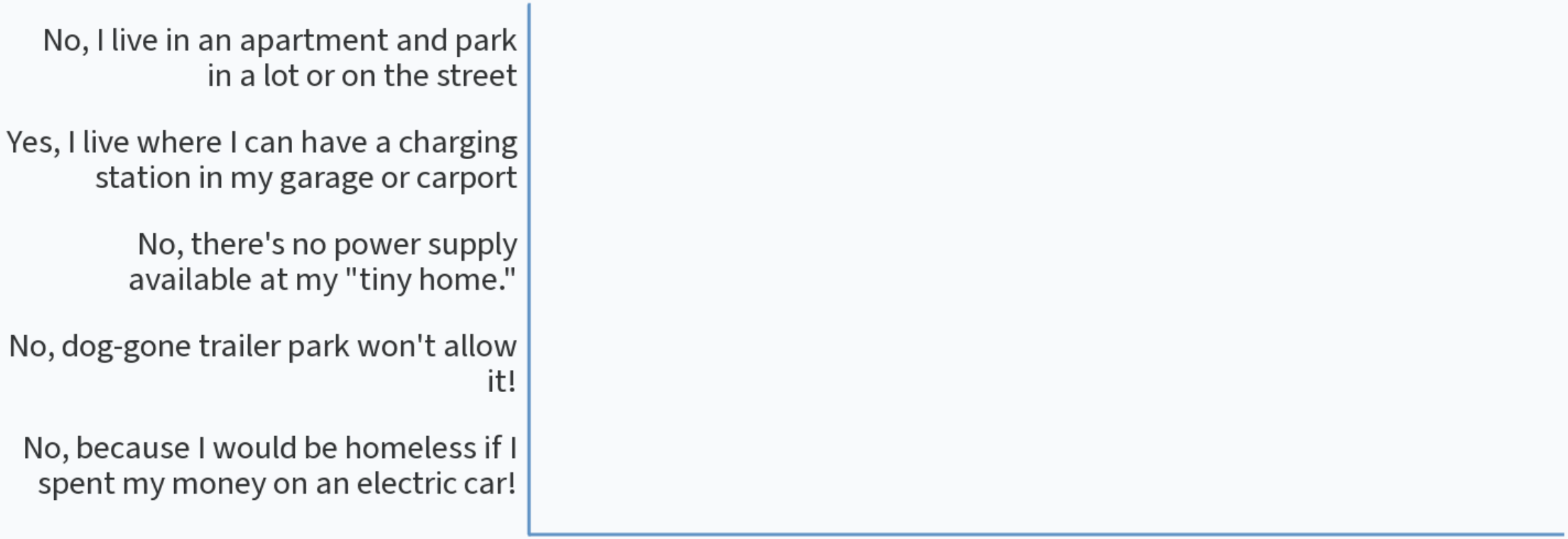
SAE J1772

- A - L1 terminal
- E - L2/Neutral terminal
- C - Chassis ground terminal
- D - Control pilot terminal - communicates charging needs/requirements
- B - Proximity terminal
  - Communicates if the charge port is plugged in or not
  - CS (control status): used in USA
    - Monitors release switch on handle
  - PP (proximity pilot): not used in USA
    - Detects connection status to vehicle

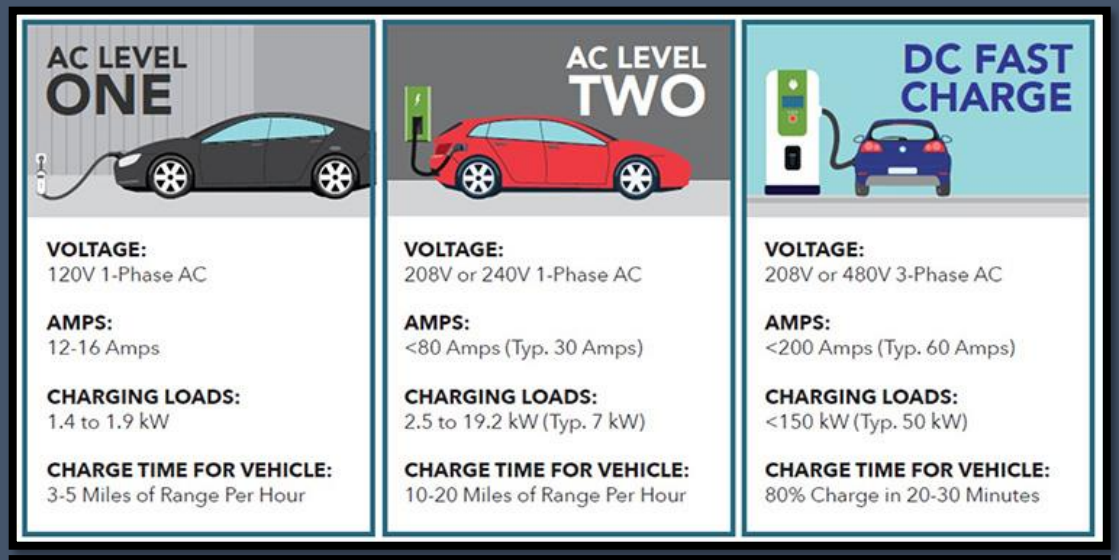


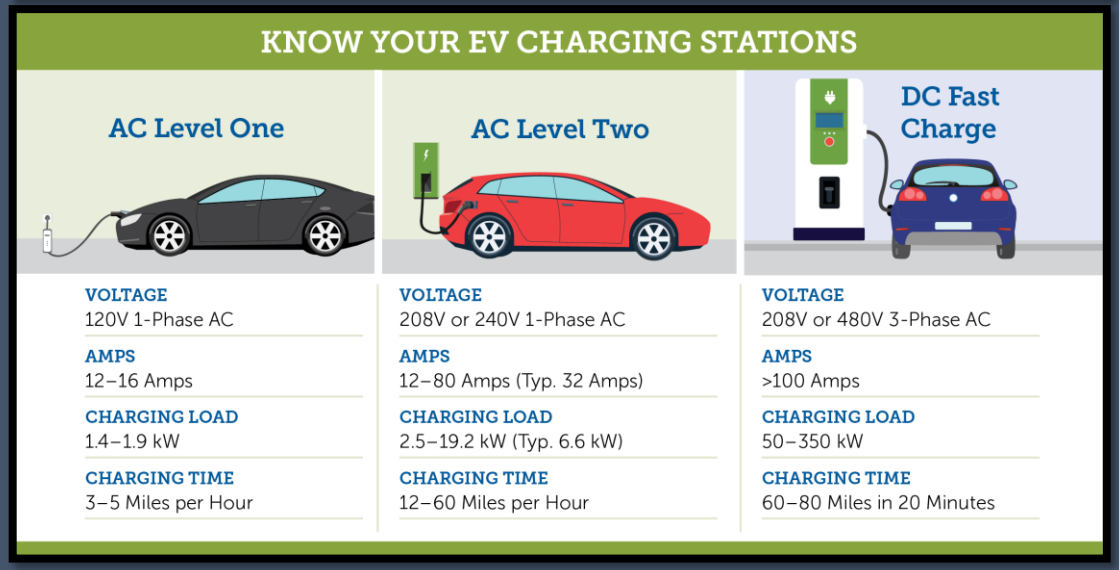


Do you live in a dwelling that would work well with at-home charging?



Charging Capabilities – info varies



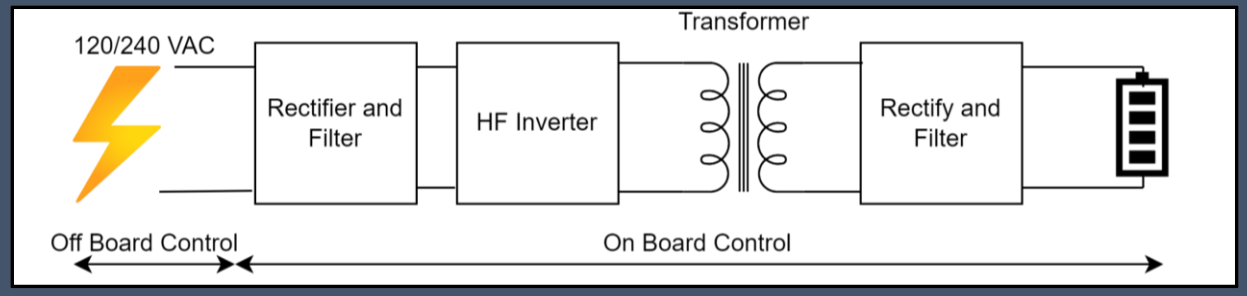


Charging level	Power setting	Electrical supply	Driving range (miles per hour of charge)	Application
AC Level 1	1.7 kW	120V ac / 20A	5 - 6 mi/hr	Residential
AC Level 2				
minimum	3.4 kW	240V ac / 20A	10 - 12 mi/hr	
typical	6.7 kW	240V ac / 40A	25 - 28 mi/hr	Residential
maximum	19.2 kW	240 V ac / 100A	60 - 70 mi/hr	
DC Level 1	40 kW	up to 500v dc / 80A	120 - 140 mi/hr	Commercial
DC Level 2	100 kW	up to 500v dc / 200A	up to 300 mi/hr	Commercial
Tesla (proprietary)	120 kW	480v ac / 250A	150 mi / 30 min	Supercharger

Level	Connector	AC/DC	Max. V & I	Power (kW)
Level 1	Type 1	1 phase AC	120 V/16 A	1.9
Level 2	Type 1	1/3 ph. AC	240 V/80 A	14 - 19
Level 3	Type 2	3 phase AC	480 V/63 A	43 - 52
Level 3	CHAdeMO	DC	500 V/125 A	63
Combo	Type 3	AC and DC	1 kV/400 A	36 - 200+

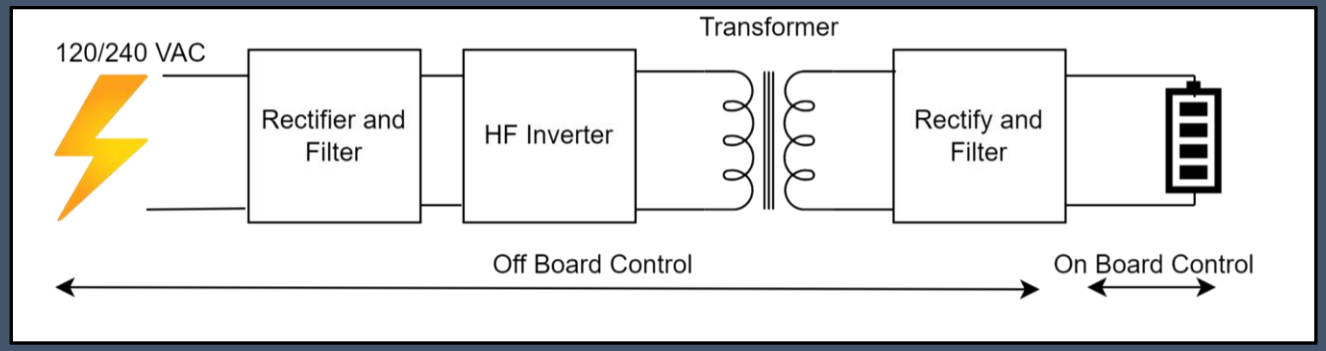
Charging configurations

- Level one and two chargers
- Household or commercial AC delivered to vehicle
  - Level one – 120V (up to 16 amps)
  - Level two – 240V (up to 80 amps, 32 or 50 typical)
- On board control
  - AC to DC rectification
  - DC back to AC for voltage control
  - AC Transformer to isolate the charger from the vehicle's HV
  - Rectify and filter to DC for the HV battery



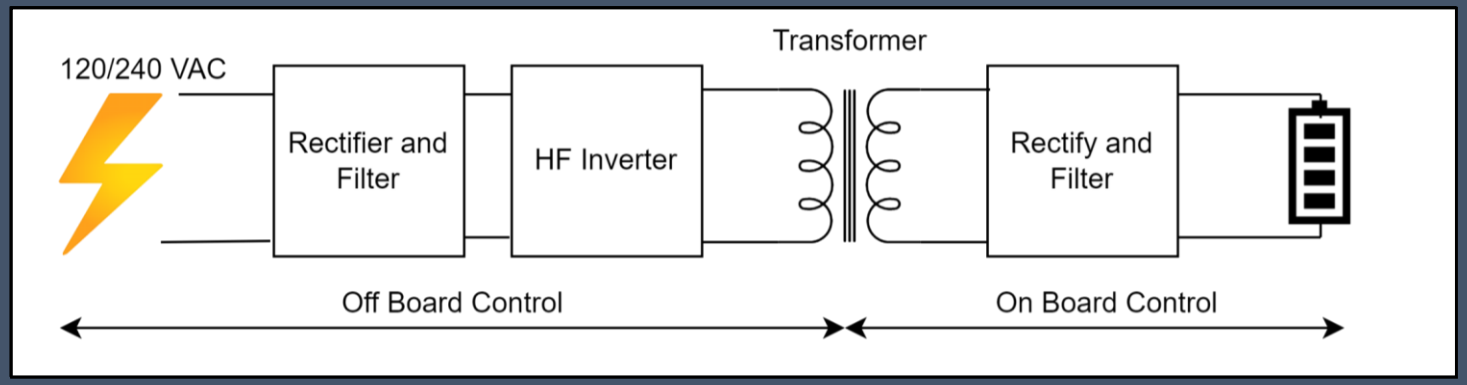
Charging Configurations

- Level 3 chargers
- Commercial DC delivered to vehicle
  - Class three – High voltage DC ready for the battery
- Off board control
  - AC to DC rectification
  - DC back to AC for voltage control
  - High frequency AC transformer for efficiency
  - Rectify and filter for the vehicle's HV battery

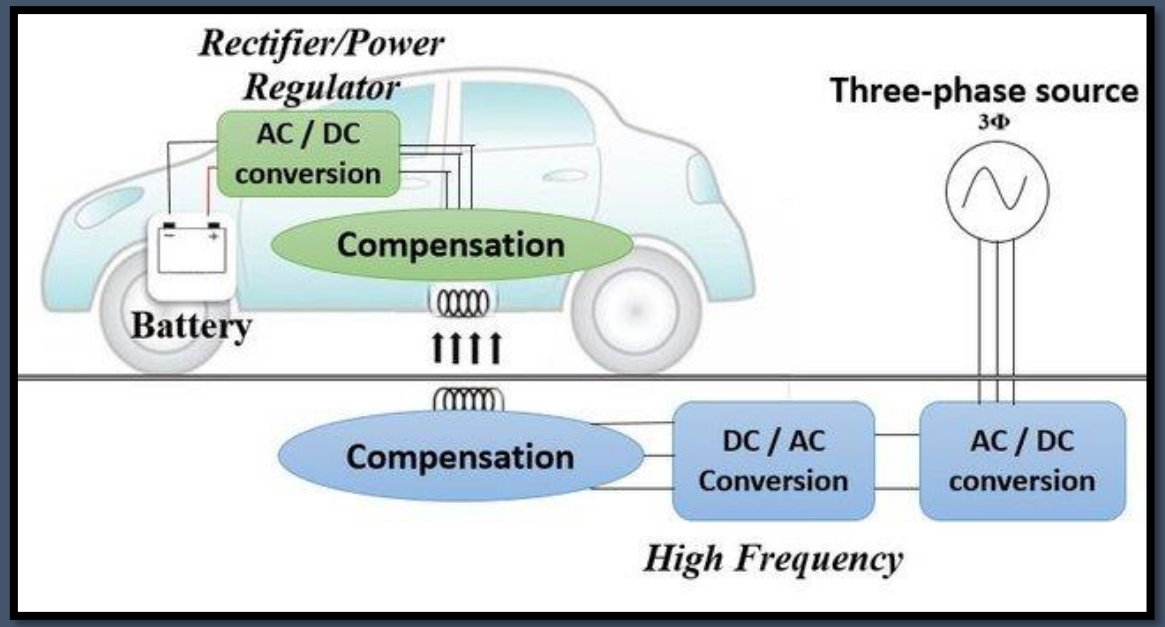


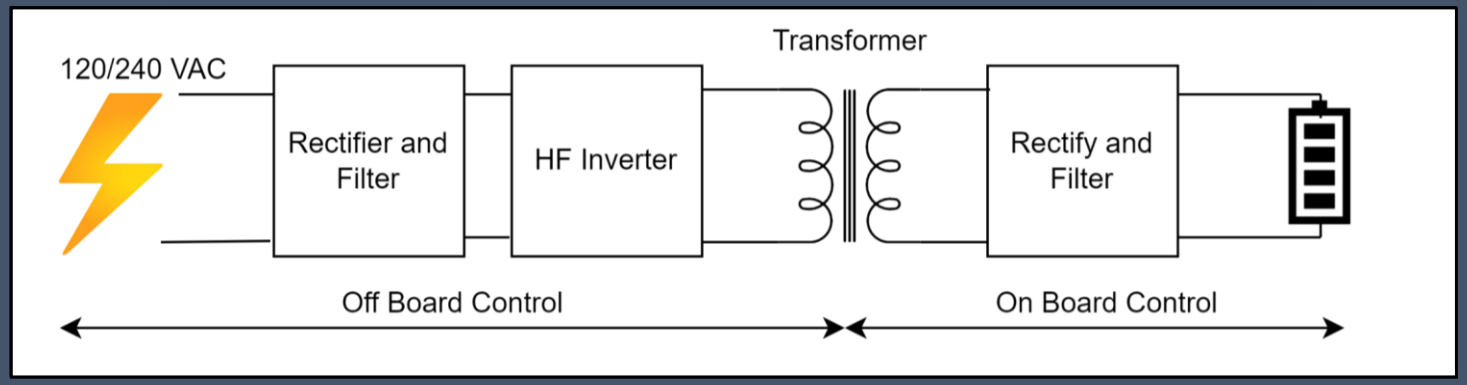
Charging configurations

- Wireless/Inductive
  - Vehicle is magnetically coupled (via transformer) to the off-board powering system (charger) without conductive contacts
  - Charging station performs the rectification/filtering and inversion, and the vehicle performs the final-stage rectification/filtering before the power is supplied to the vehicle's battery directly



Charging configurations





Miles per hour of charging

VEHICLE	ACCEPTANCE RATE (kW)	ACS-15 LEVEL 1 (12A,1.4kW) starting at $379	AmazingE LEVEL 2 (16A, 3.8kW) starting at $329	LCS-25 LEVEL 2 (20A, 4.8kW) starting at $469	LCS-30 LEVEL 2 (24A, 5.8kW) starting at $499	AmazingE *FAST* LEVEL 2 (32A, 7.7kW) starting at $469	HCS-50 LEVEL 2 (40A, 9.6kW) starting at $635	HCS-60 LEVEL 2 (48A, 11.5kW) starting at $899	HCS-80 LEVEL 2 (64A,15.4k) starting at $969
Nissan LEAF S 2016 (6.6kW onboard charger, S Upgrade) Nissan LEAF S 2016 (6.6kw onboard charger SL & SV Model) Nissan LEAF 2017 (6.6kW onboard, S Upgrade, SL & SV Model) Nissan LEAF 2018 (6.6kW onboard, S Upgrade, SL & SV Model) Nissan LEAF Plus (S, SL, SV Models) Nissan LEAF 2022 (All Models) Toyota RAV4 Prime XSE Premium	6.6	5.5	15	18.5	22.5	25.5*	25.5	25.5	25.5
BMW ActiveE Jaguar I-Pace Range Rover P400e	7	5.5	15	18.5	22.5	27.5	27.5	27.5	27.5
Chevy Bolt Chevy Volt LT 2019 Upgrade, Premier 2019 Hyundai Ioniq 2020 Hyundai Kona Jeep Wrangler 4xe Kia Niro EV Kia Soul 2019-2020 Porsche Cayenne S E-Hybrid Upgrade Porsche Panamera 4 E-Hybrid Upgrade Porsche Panamera S E-Hybrid Upgrade Smart Fortwo ED VW e-Golf (7.2kW onboard charger) VW e-Golf 2017-2019 (7.2kW onboard charger)	7.2	5.5	15	18.5	22.5	28*	28	28	28
BMW i3 2017 (60 Ah battery) BMW i3 2017-2018 (90 Ah battery) Mercedes GLC 350e 2020 MINI Cooper SE Polestar 2	7.4	5.5	15	18.5	22.5	29*	29	29	29

VEHICLE	ACCEPTANCE RATE (kW)	ACS-15 LEVEL 1 (12A,1.4kW) starting at $379	AmazingE LEVEL 2 (16A, 3.8kW) starting at $329	LCS-25 LEVEL 2 (20A, 4.8kW) starting at $469	LCS-30 LEVEL 2 (24A, 5.8kW) starting at $499	AmazingE *FAST* LEVEL 2 (32A, 7.7kW) starting at $469	HCS-50 LEVEL 2 (40A, 9.6kW) starting at $635	HCS-60 LEVEL 2 (48A, 11.5kW) starting at $899	HCS-80 LEVEL 2 (64A,15.4kW) starting at $969
BMW i3 2017 (60 Ah battery) BMW i3 2017-2018 (90 Ah battery) Mercedes GLC 350e 2020 MINI Cooper SE Polestar 2	7.4	5.5	15	18.5	22.5	29*	29	29	29
Audi Q5 Plug In Hybrid Tesla Model 3 Standard	7.7	2 5.5	5.5 15	6.5 18.5	8 22.5	11 30	11 30	11 30	11 30
Audi e-tron SUV Mercedes B Class B250e Porsche Taycan Tesla Model S 60 Single Tesla Model S 70 Single Tesla Model S 85 Single Tesla Model S 90 Single Toyota RAV4	9.6	5.5	15	18.5	22.5	30	37.5*	37.5	37.5
Ford Mustang Mach E	10.5	5.5	15	18.5	22.5	30	37.5	41	41
Chevy Bolt/Bolt EUV Hyundai Ioniq 5 VW ID.4	11	5.5	15	18.5	22.5	30	37.5	43	43
Tesla Model 3 Long Range Tesla Model S Performance, Long Range Tesla Model X Performance, Long Range Tesla Model Y Performance, Long Range Volvo XC40 Recharge	11.5	5.5	15	18.5	22.5	30	37.5	45*	45
Tesla Model S 100D & P100D Tesla Model X 60 Dual, 75 Dual, 90 Dual Tesla Model X 100D & P100D Tesla Roadster	17.2	5.5	15	18.5	22.5	30	37.5	45	60*
Cadillac Lyriq Lucid Air (all models: Dream Edition & Touring) Tesla Model S (60, 70, 85 and 90 Dual models)	19.2	5.5	15	18.5	22.5	30	37.5	45	60*

Miles per hour of charging

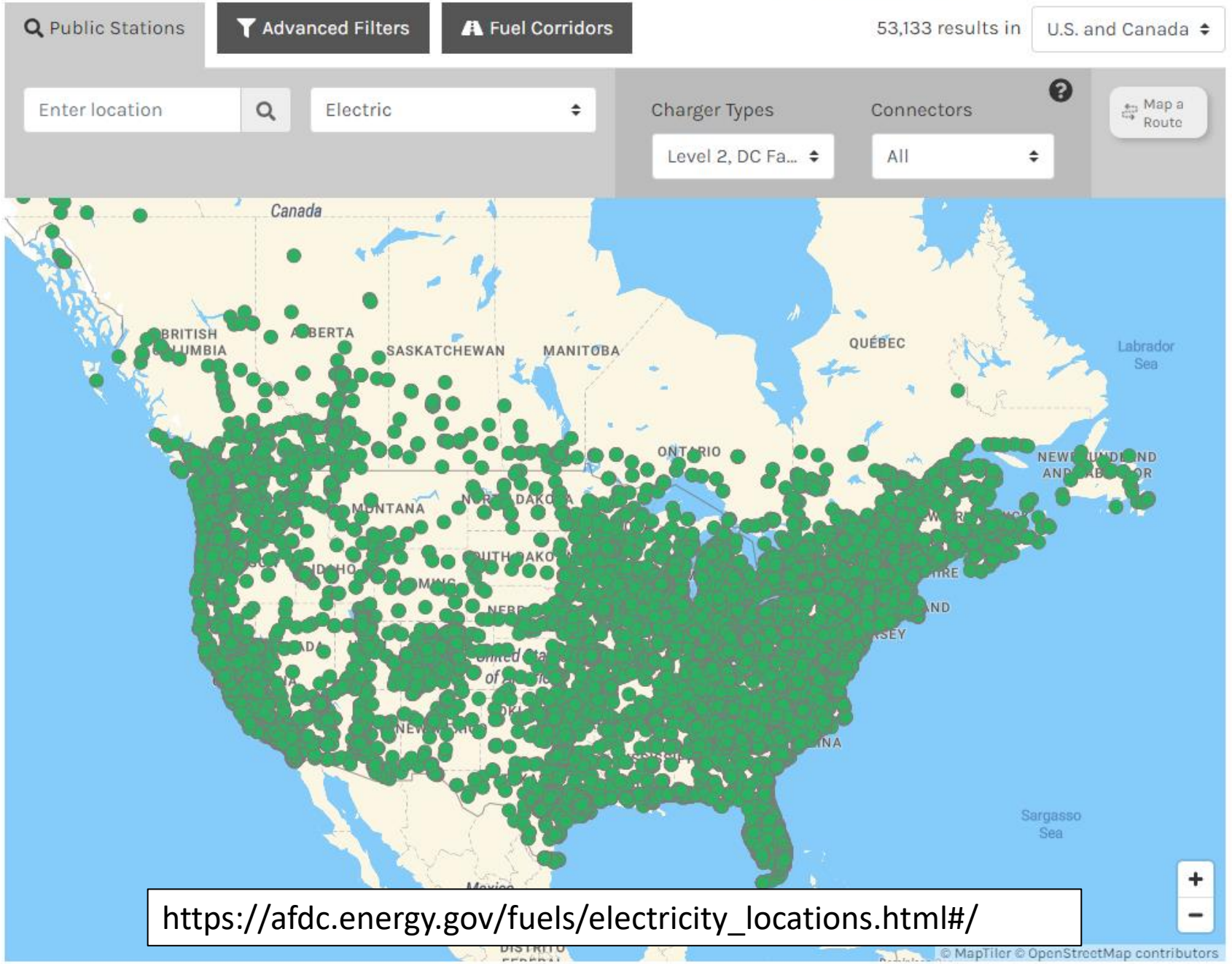
VEHICLE	ACCEPTANCE RATE (kW)	ACS-15 LEVEL 1 (12A,1.4kW) starting at $379	AmazingE LEVEL 2 (16A, 3.8kW) starting at $329	LCS-25 LEVEL 2 (20A, 4.8kW) starting at $469	LCS-30 LEVEL 2 (24A, 5.8kW) starting at $499	AmazingE *FAST* LEVEL 2 (32A, 7.7kW) starting at $469	HCS-50 LEVEL 2 (40A, 9.6kW) starting at $635	HCS-60 LEVEL 2 (48A, 11.5kW) starting at $899	HCS-80 LEVEL 2 (64A,15.4kW) starting at $969
Audi A3 E-Tron Cadillac ELR Chevy Volt Ford C Max Energi Ford Escape 2020 Ford Fusion Energi Hyundai Ioniq Plug-in Hyundai Santa Fe Plug-in Hybrid Hyundai Sonata Kia Niro PHEV Kia Optima Kia Sorento PHEV Mercedes C350 Hybrid Mercedes GLE 550e Mercedes S550 Hybrid MINI Cooper SE Countryman ALL4 Mitsubishi Outlander Nissan LEAF 2013-16 S (3.3 onboard charger) Nissan LEAF 2017 (3.3kW onboard charger S Model) Nissan LEAF 2018 (3.3kW onboard charger S Model) Smart Car Subaru Crosstrek Toyota Prius Toyota Prius Prime Toyota RAV4 Prime SE, XSE Volvo V60 Volvo XC90 T8	3.3	5.5	13*	13	13	13	13	13	13

Miles per hour of charging

VEHICLE	ACCEPTANCE RATE (kW)	ACS-15 LEVEL 1 (12A,1.4kW) starting at $379	AmazingE LEVEL 2 (16A, 3.8kW) starting at $329	LCS-25 LEVEL 2 (20A, 4.8kW) starting at $469	LCS-30 LEVEL 2 (24A, 5.8kW) starting at $499	AmazingE *FAST* LEVEL 2 (32A, 7.7kW) starting at $469	HCS-50 LEVEL 2 (40A, 9.6kW) starting at $635	HCS-60 LEVEL 2 (48A, 11.5kW) starting at $899	HCS-80 LEVEL 2 (64A,15.4kW starting at $969
BMW 330e BMW 530e BMW 740e BMW 745e BMW i8 BMW X3 xDrive30e BMW X5 xDrive40e BMW X5 XDrive45e Cadillac CT6 Chevy Volt 2016-2018 Chevy Volt LT 2019 Lincoln Aviator Grand Touring AWD Porsche Cayenne S E-Hybrid Porsche Panamera S E-Hybrid Porsche Panamera 4 E-Hybrid Porsche 918 Spyder Volvo S90 T8 Volvo XC60 T8 VW e-Golf (3.6kW onboard charger)	3.6	5.5	14*	14	14	14	14	14	14
Chrysler Pacifica Fiat 500E Ford Focus EV Ford Focus EV 2017 Honda Clarity EV Honda Clarity Plug-In Hyundai Ioniq Karma Revero Kia Soul	6.6	5.5	15	18.5	22.5	25.5*	25.5	25.5	25.5

Electric Vehicle Charging Station Locations

Find electric vehicle charging stations in the United States and Canada. For Canadian stations in French, see Natural Resources Canada.



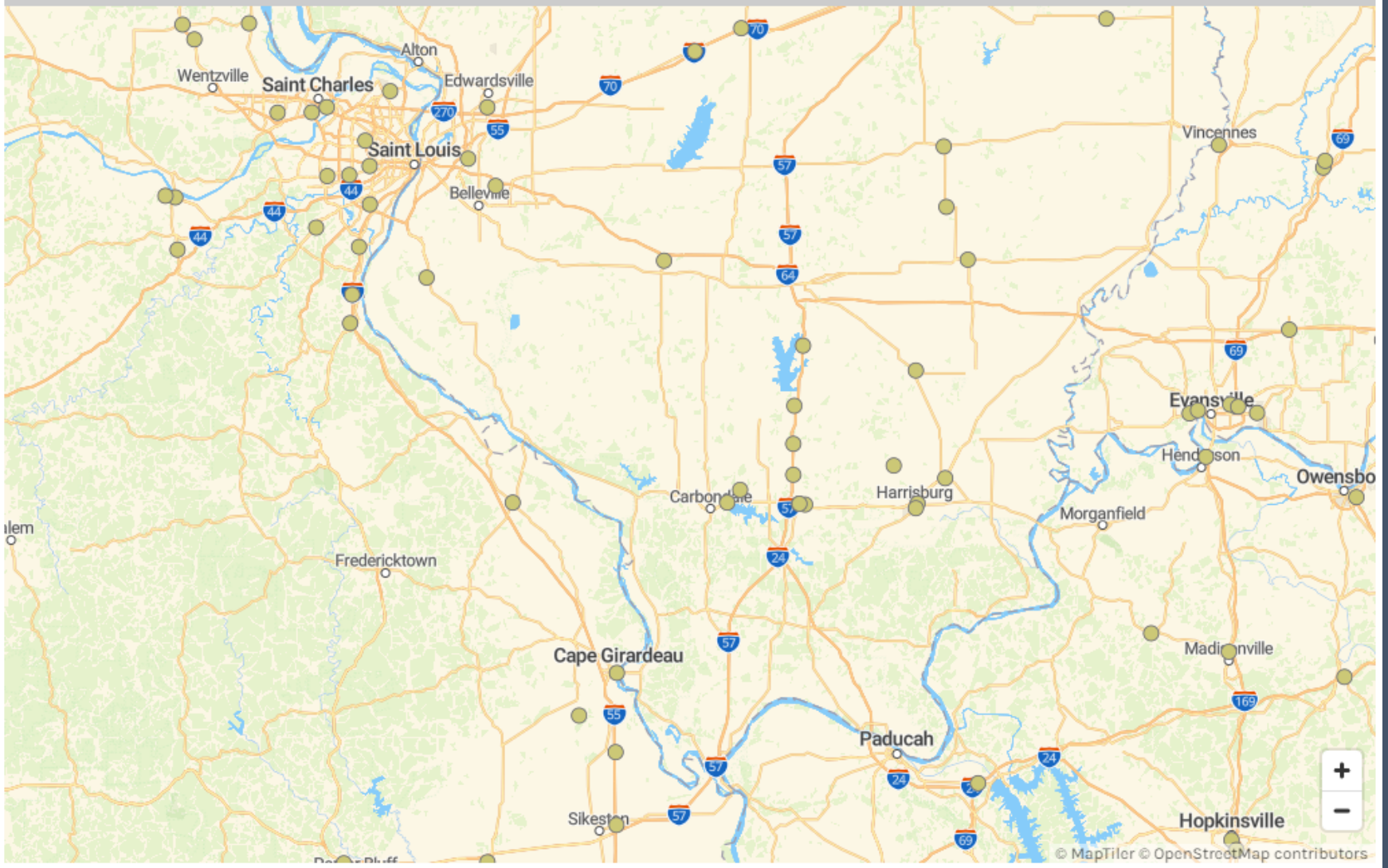
https://afdc.energy.gov/fuels/electricity_locations.html#/

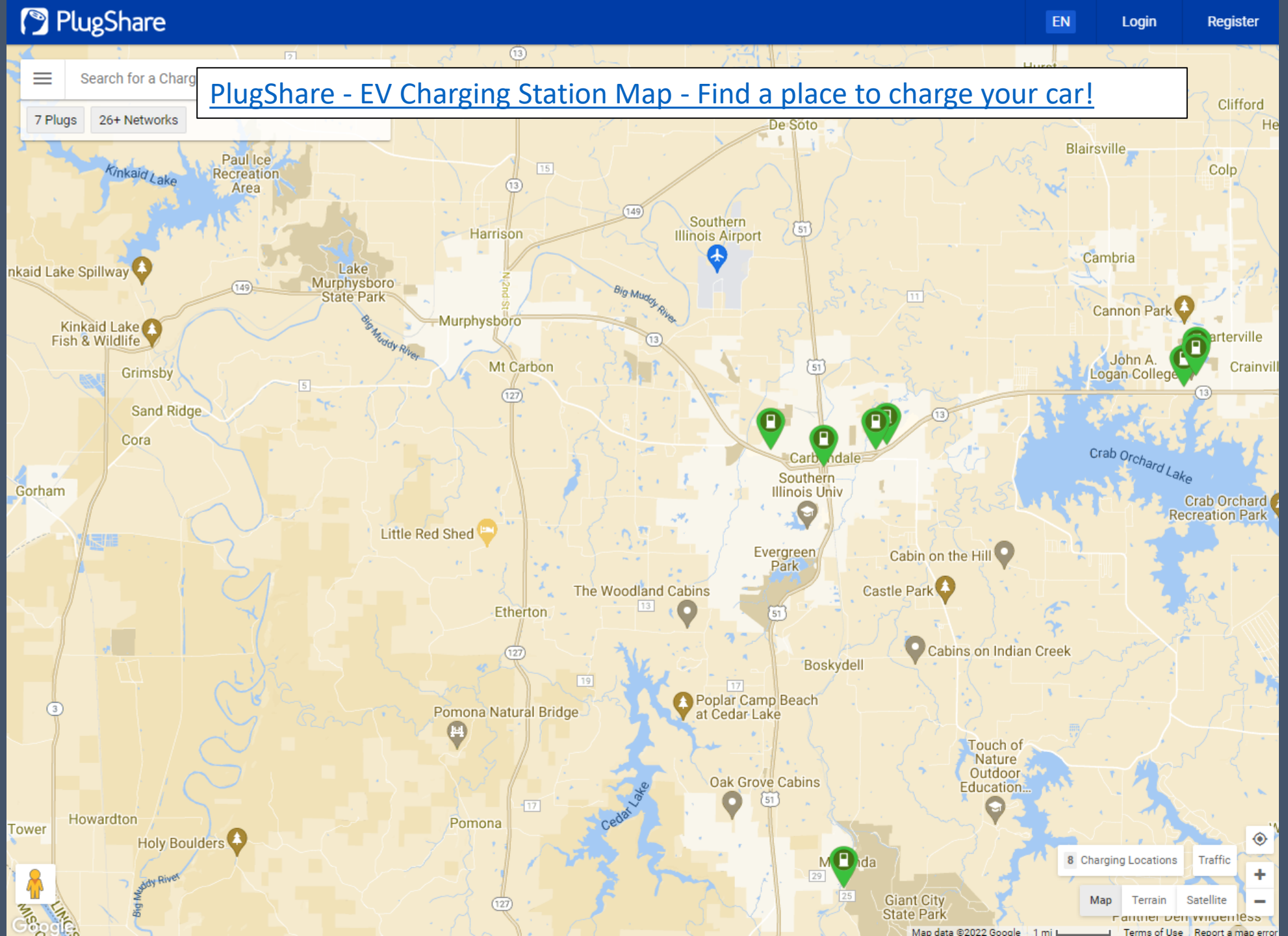
Electric Vehicle Charging Station Locations

Find electric vehicle charging stations in the United States and Canada. For Canadian stations in French, see Natural Resources Canada.

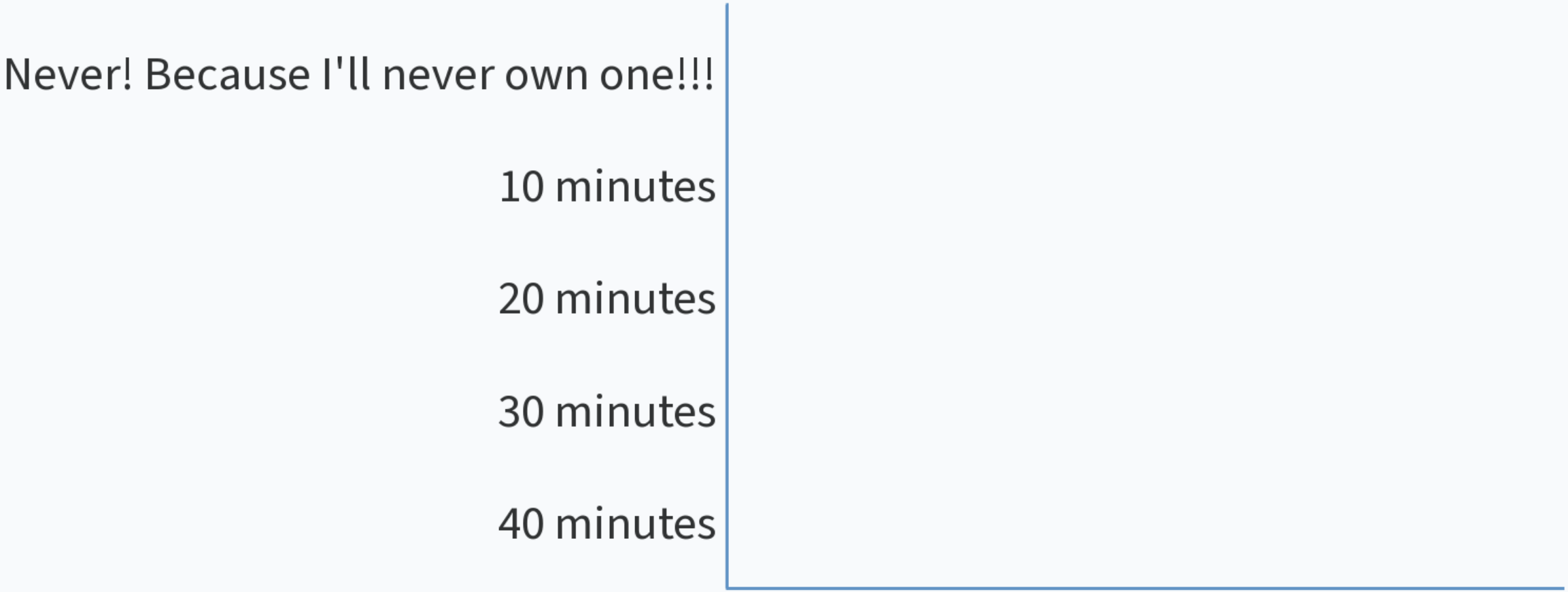
Public Stations | Advanced Filters | Fuel Corridors | 4,176 results in U.S. and Canada

Enter location | Ethanol (E85) | Map a Route



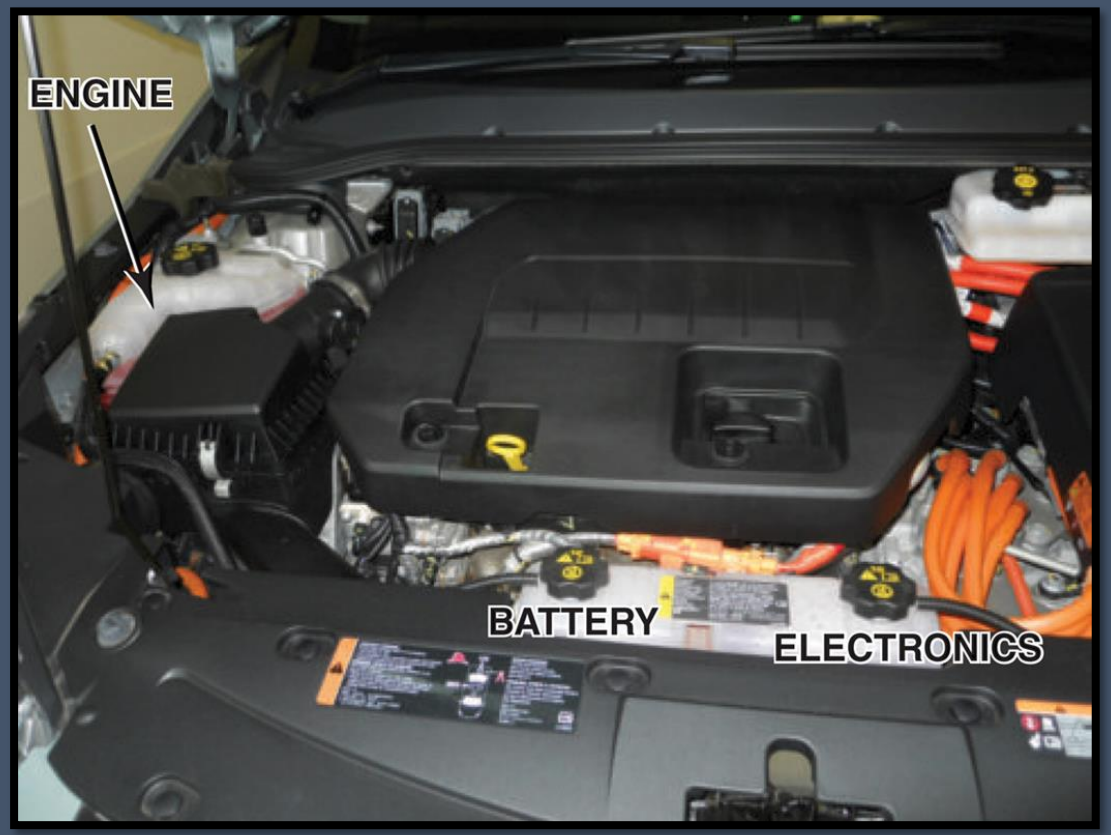

PlugShare
EN
Login
Register
Search for a Charg
7 Plugs
26+ Networks
PlugShare - EV Charging Station Map - Find a place to charge your car!
Kinkaid Lake
Paul Ice Recreation Area
Harrison
Southern Illinois Airport
De Soto
Blairsville
Colp
Clifford
Cambria
Lake Murphysboro State Park
Big Muddy River
Murphysboro
Kinkaid Lake Spillway
Kinkaid Lake Fish & Wildlife
Grimsby
Sand Ridge
Cora
Mt Carbon
Cannon Park
John A. Logan College
Crab Orchard Lake
Crab Orchard Recreation Park
Gorham
Little Red Shed
Southern Illinois Univ
Evergreen Park
Cabin on the Hill
Castle Park
The Woodland Cabins
Etherton
Cabins on Indian Creek
Boskydell
Poplar Camp Beach at Cedar Lake
Pomona Natural Bridge
Touch of Nature Outdoor Education...
Oak Grove Cabins
Cedar Lake
Howardton
Tower
Holy Boulders
Pomona
Giant City State Park
8 Charging Locations
Traffic
Map
Terrain
Satellite

How long are you willing to wait to charge your vehicle?



Volt charging system

- Battery Charger
  - Located behind passenger's headlamp assembly
    - Water cooled with the power inverter

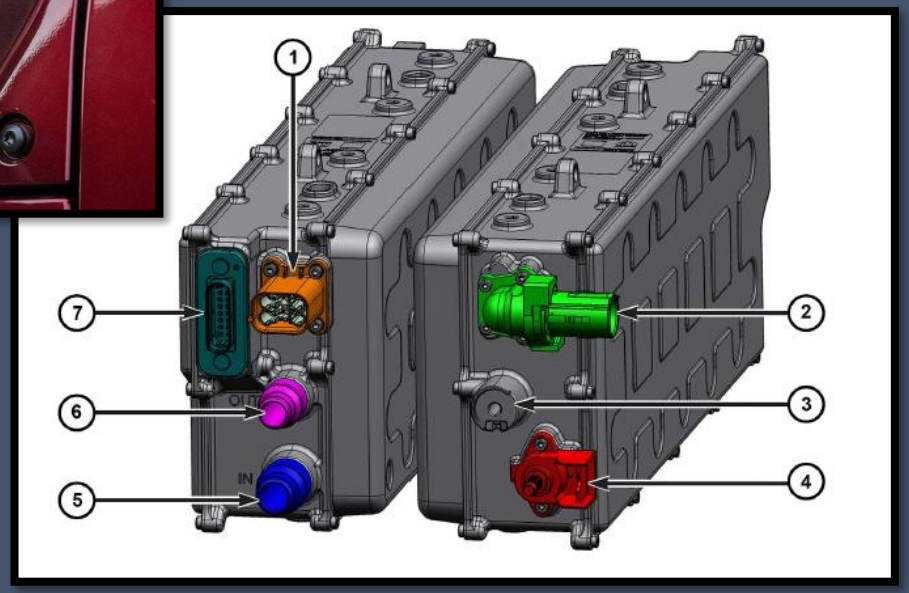


Charging cord failures/DTCs

Circuit	Short to Ground	Open/High Resistance	Short to Voltage	Signal Performance
Control Pilot Signal	P0CF4, P0CF5, P0CF6, P0CF9, P0D01, 1	P0CF4, P0CF5, P0CF6, 1	P0CF4, P0CF5, P0CF6, P0CF9,1	P0CF4, P0CF5, P0CF6, 1
Proximity Signal	P0D58, 1	P0D59, 1	P0D59, 1	—
110/120 A/C Line 1	1	P0D3F, P1EE6	1	—
110/120 A/C Line 2	1	P1EE6	1	—
110/120 A/C Ground	—	P0D59, 1	1	—
1. Plug In Charging Malfunction				

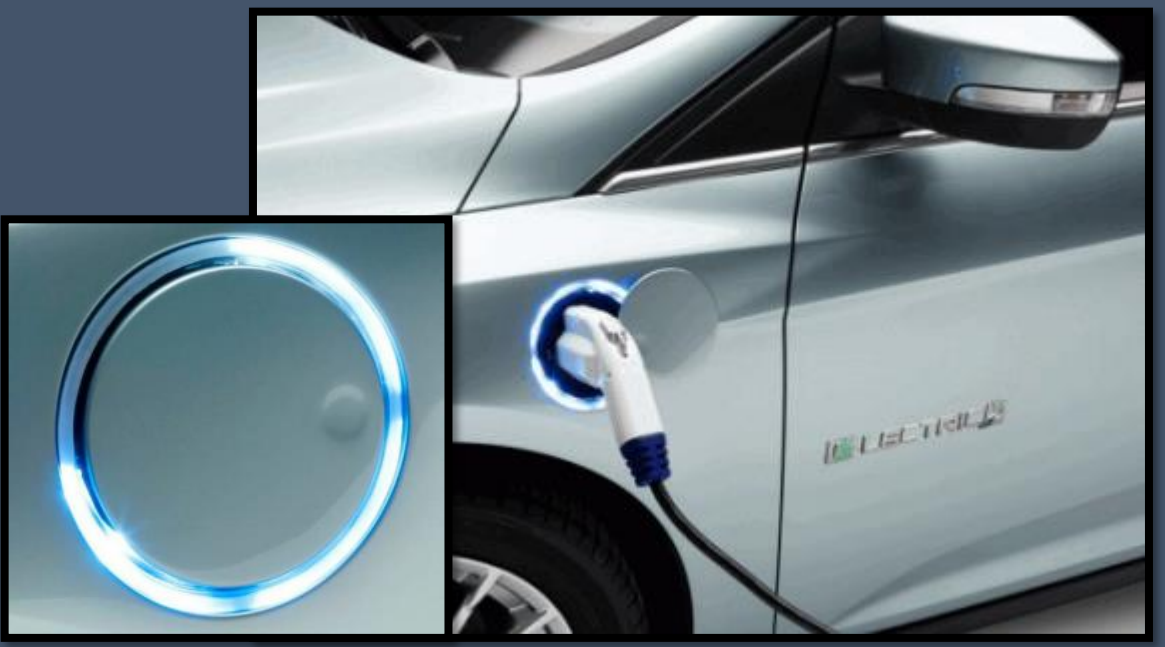
Jeep 4xe charging system

- Integrated Dual Charging Module
  - High voltage and low voltage
  - Water cooled through coolant loop
  - ESVE Locked until door unlock is requested

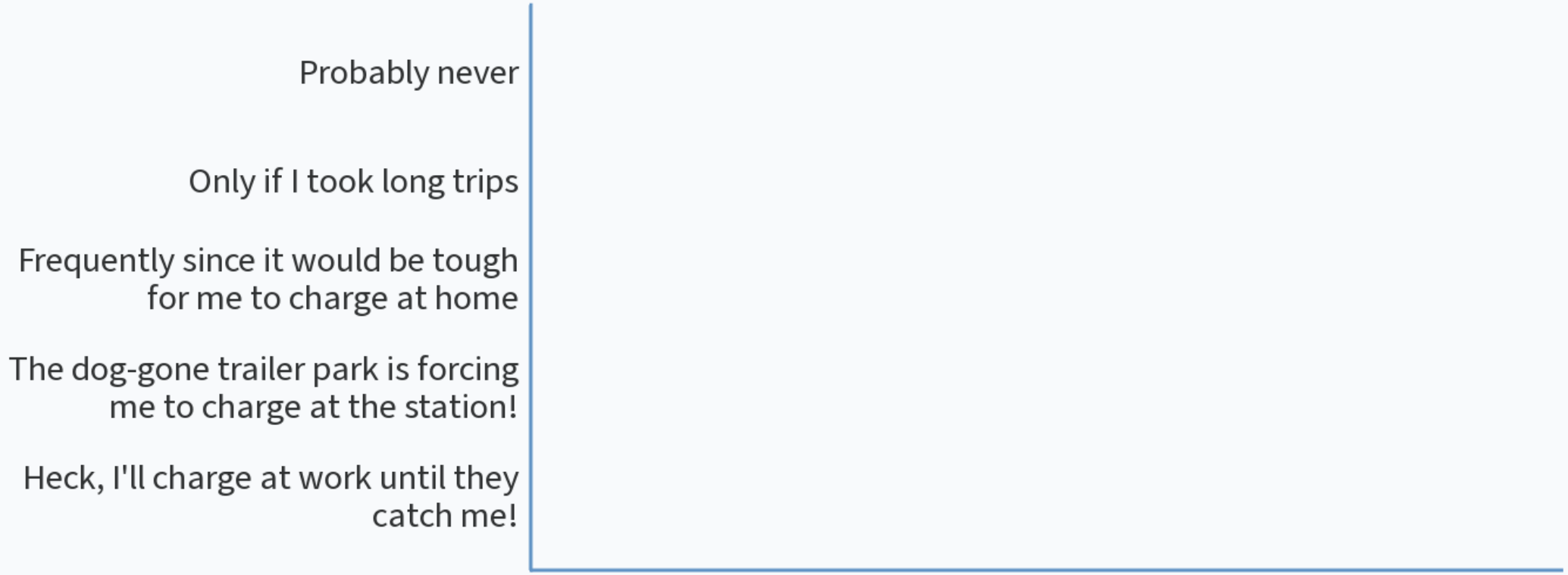


Ford charging system

- Charging port light ring (CPLR)
  - Current SOC
  - Light ring
    - Charging, faults, status
    - 25%, 50%, 75%, and full charge



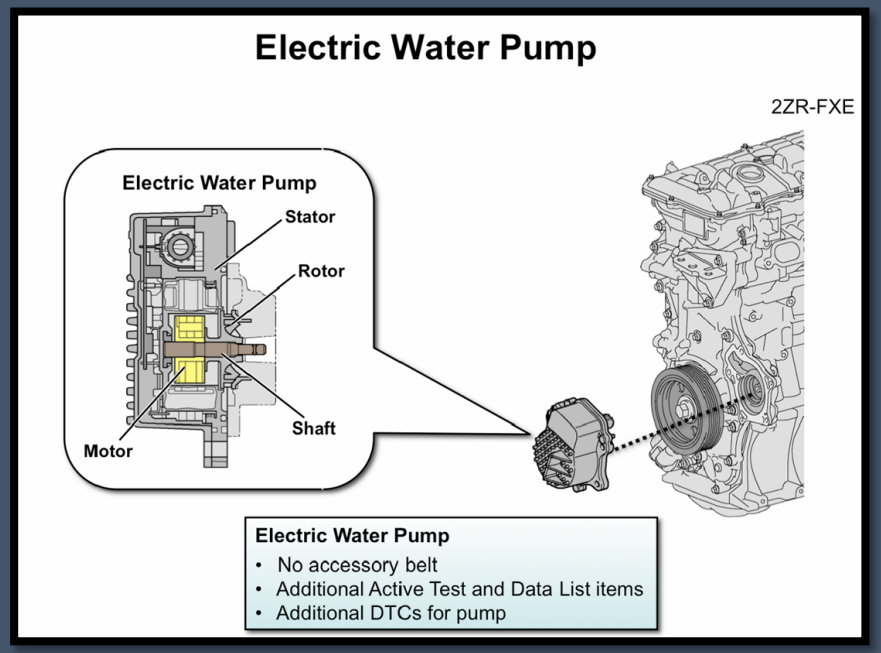
If you had an EV that had 250 miles of range, how often would you charge at a STATION and not at your home?



BREAK hour three

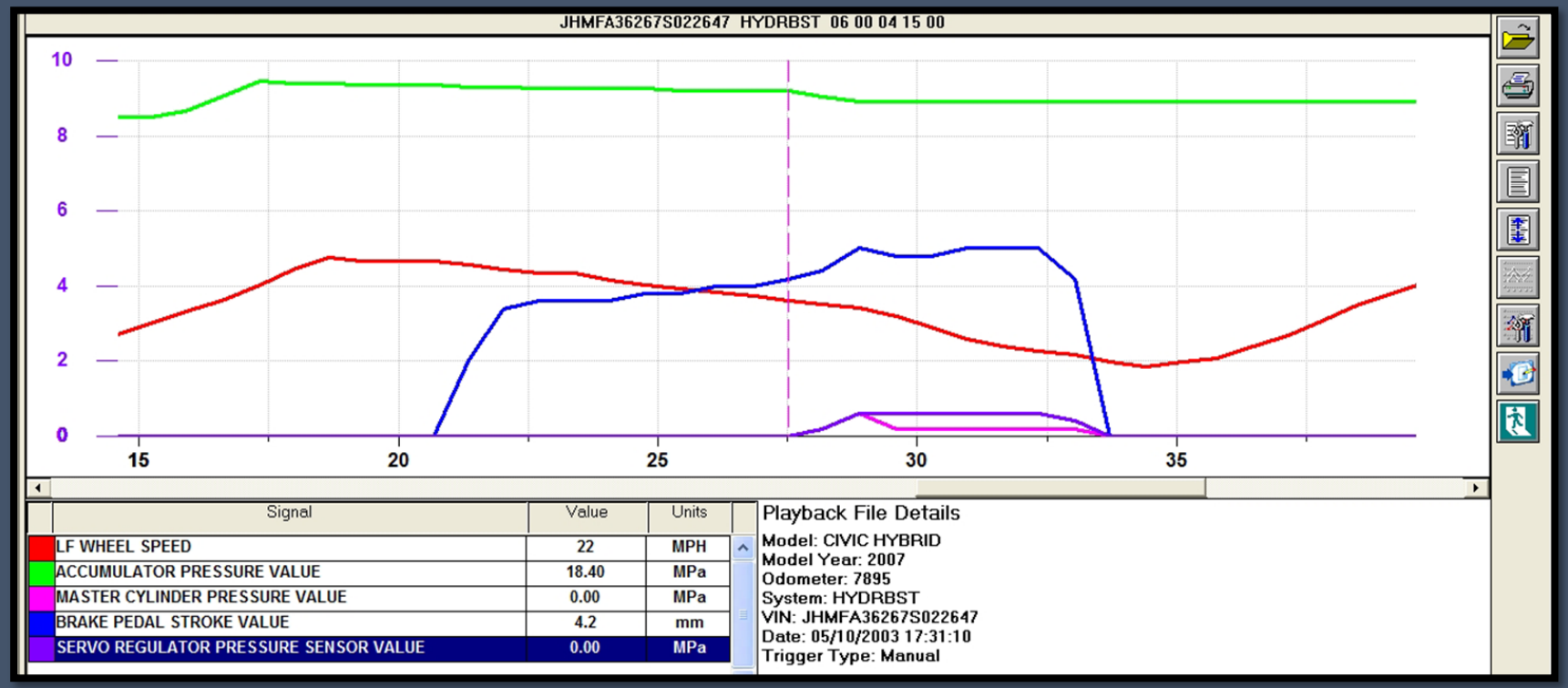
Cooling Systems

- Instead of engine driven accessories, use electric motors to serve the same function
- Separate pumps for multiple cooling systems



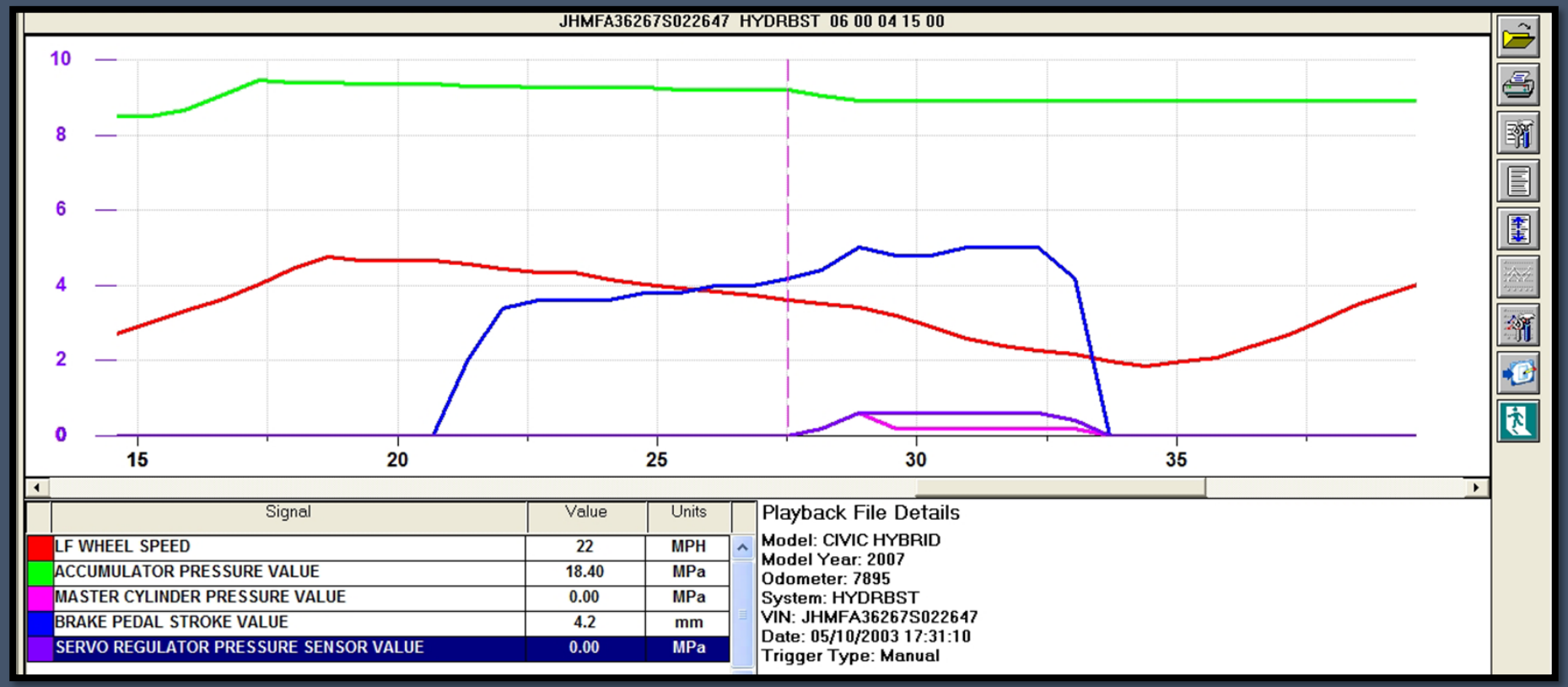
Braking System

- Brake by wire – pressing the brake pedal doesn't mean you are generating hydraulic pressure at the wheel-brakes

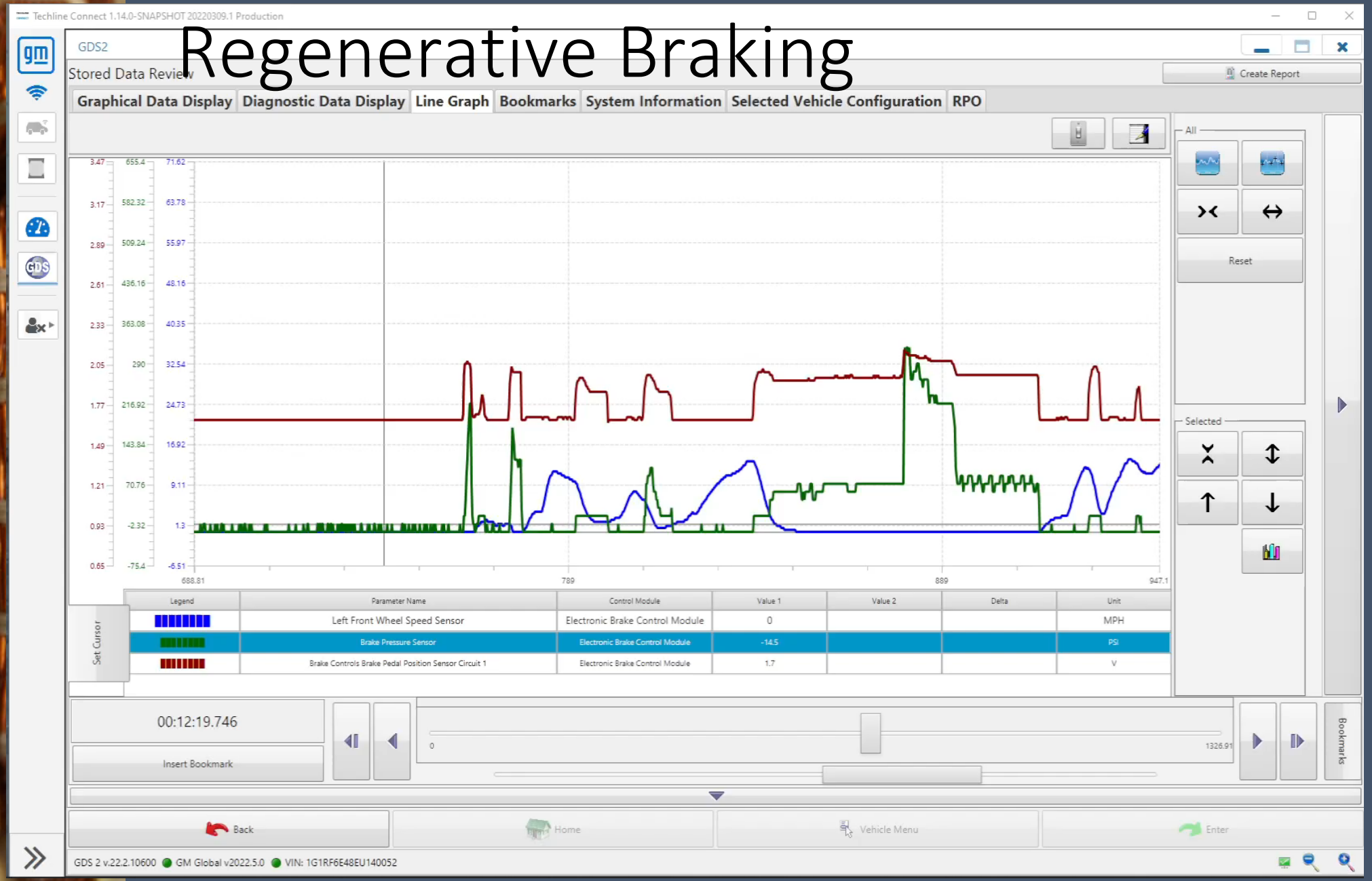


Braking System

- Brake controller will allow the motors to generate electricity (to charge the battery) to slow the vehicle down

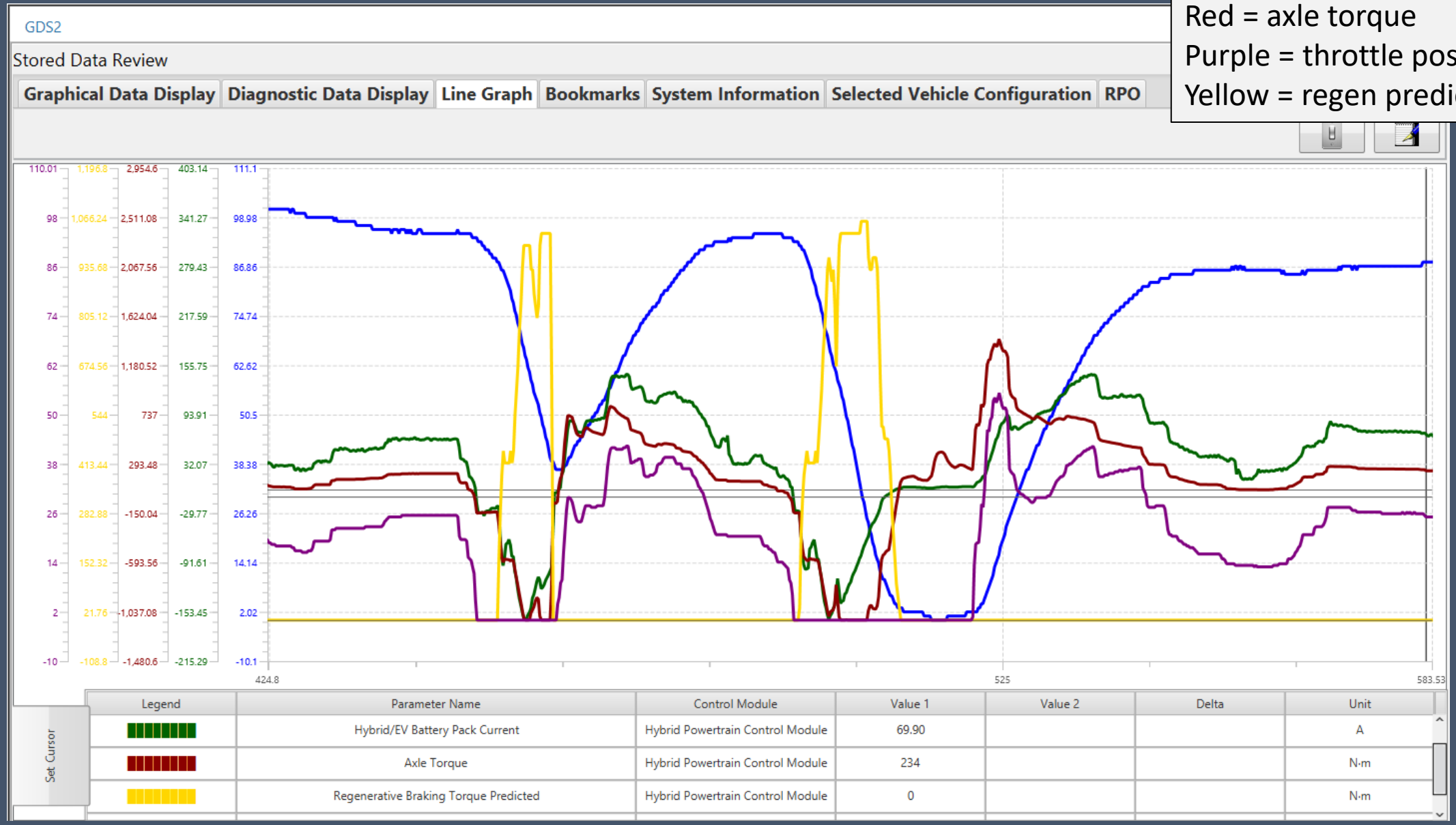


Regenerative Braking



Regenerative Braking

Blue = vehicle speed
Green = battery current
Red = axle torque
Purple = throttle position
Yellow = regen predicted

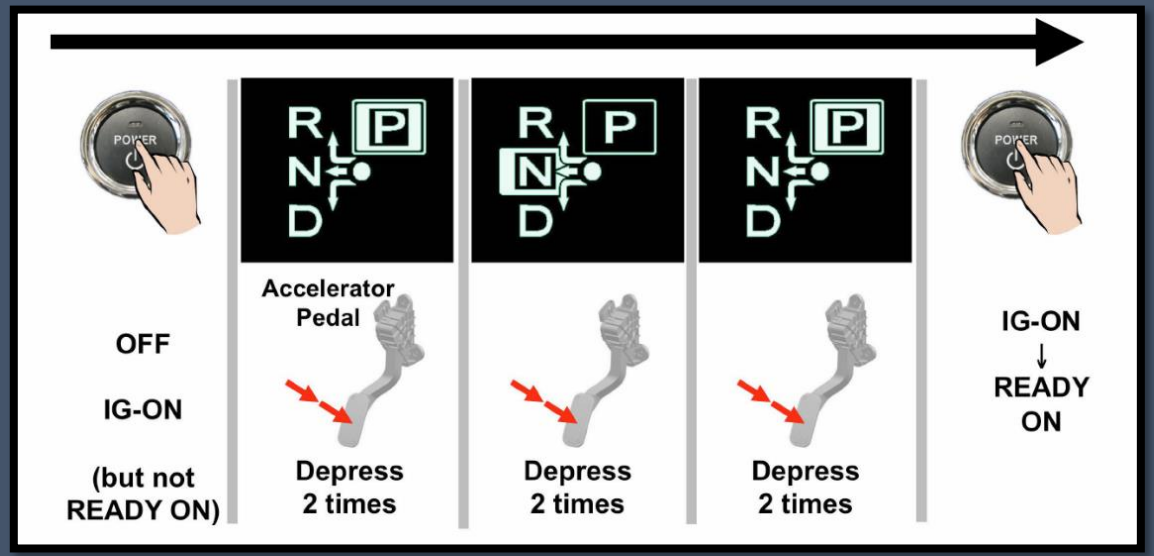


Servicing xEVs

- Maintenance mode:
  - Start/Stop engine considerations
  - Electronic brake system safety
- High voltage awareness

Maintenance Mode: Example - Toyota

- Place vehicle in maintenance/service mode
  - Prevents engine startup while ignition is “on”
  - Find and isolate vehicle keys and place them far enough away from the vehicle to avoid inadvertent starting
  - Raise the hood will prevent an engine start up on some vehicles
  - Attempt to start the engine when the keys are removed to see if there is a spare key hidden in the vehicle
- Brake system precautions
  - Every time the door is opened, the brake system energizes the hyd pump



Maintenance Mode: Ford Fusion

Start with the ignition off

1. Apply the parking brake
2. Keep gear shift in park position
3. Turn the ignition to the ON position with engine OFF
4. Within 5 seconds of ignition on, fully apply the accelerator pedal and hold for ten seconds
5. Within 5 seconds release the accelerator pedal and shift the transmission to drive (remember the engine should be off)
6. Hold the accelerator pedal fully applied for 10 seconds
7. Release the accelerator pedal and shift transmission to park
8. Start engine

Brake Maintenance Mode: Ford

- Set the ignition to ON.
- Press and hold the accelerator pedal and place the EPB switch to the RELEASE (downward) position. Continue to hold the accelerator pedal and EPB .
- Set the ignition to OFF then set the ignition to ON within 5 seconds . Continue to hold the accelerator pedal and the EPB switch.
- NOTE: The EPB system will be deactivated, preventing parking brake application until service has been completed and service (maintenance) mode has been deactivated. The yellow EPB indicator will be illuminated and Maintenance Mode will display on the message center.
- Set the ignition to OFF then release the accelerator pedal and EPB switch.

Brake Maintenance Mode: Toyota

- Turn the vehicle off and wait two minutes
- Disconnect the fluid reservoir switch connector with the parking brake applied
- Disconnect the 12V battery

Car wash mode: Bolt

- A specific procedure must be followed for taking the BEV through an automated car wash. To prevent the car from shifting into park, the following steps should be taken.

  1. Start the vehicle or switch the vehicle into service mode.

  2. Open the driver's side door while applying the brake.

  3. Shift the transmission into NEUTRAL.

  4. If the transmission indicator does not display neutral, start the process over from step one.

  Caution:
  This procedure allows the driver to exit the vehicle when the transmission is in neutral. However this condition will only last until the driver’s door is opened. When the driver’s door is opened with the transmission in neutral, the parking brake will engage and the transmission will immediately shift to park.

High Voltage Battery Disconnect

- Service plug
  - Pull service plug and wait 10 minutes before working on high voltage system (drain capacitors)
  - Review service info to learn about how to check for high voltage presence after disconnecting the service plug and 12v battery

High Voltage Battery Disconnect

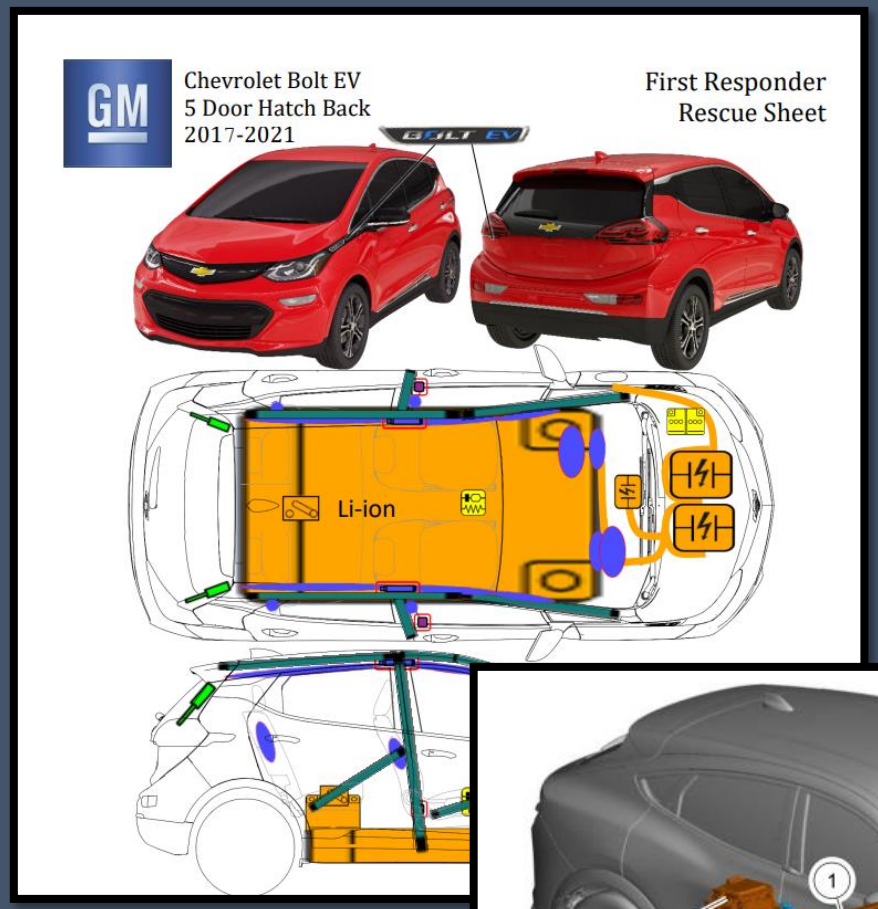
Loss of Isolation

- Demonstrate loss of isolation

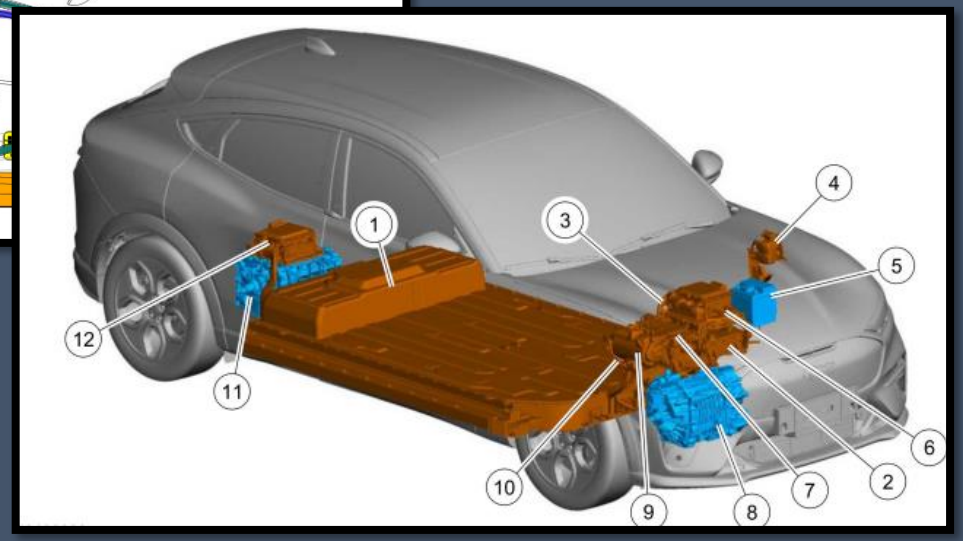
Motor resistance failures

- Demonstrate resistance diagnostics

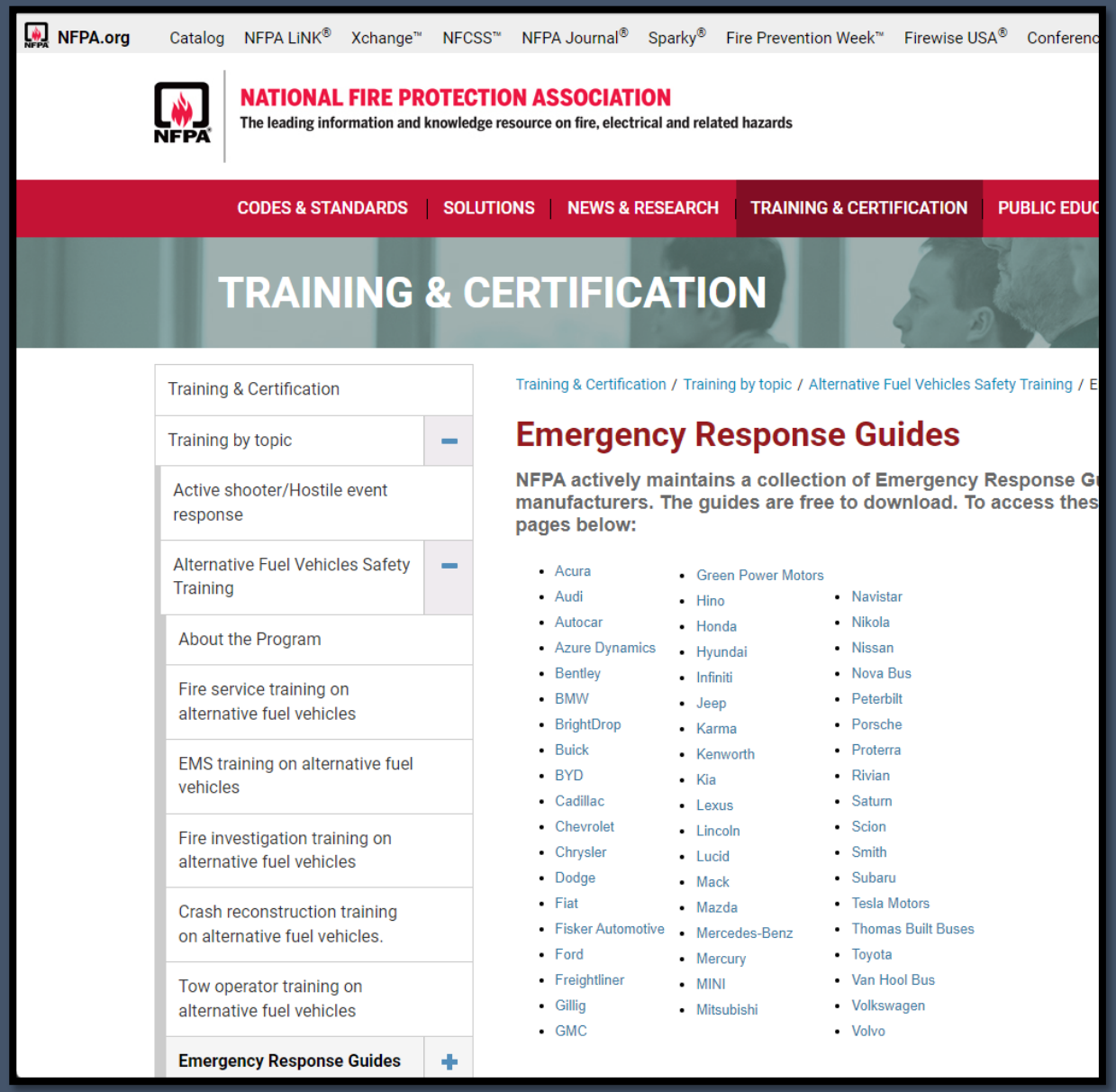
First Responder Guides



- www.nfpa.org
- www.motorcraftservice.com

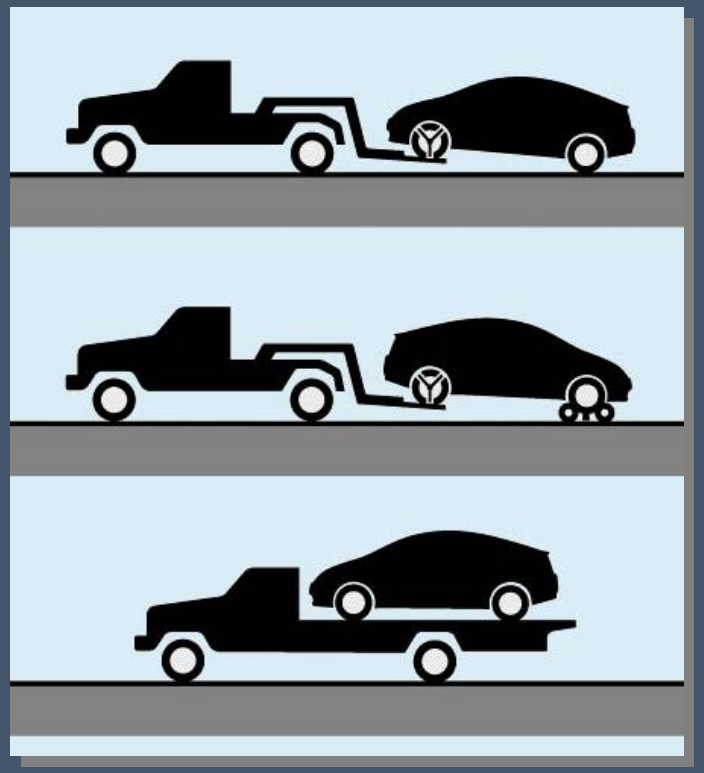


First Responder Guides

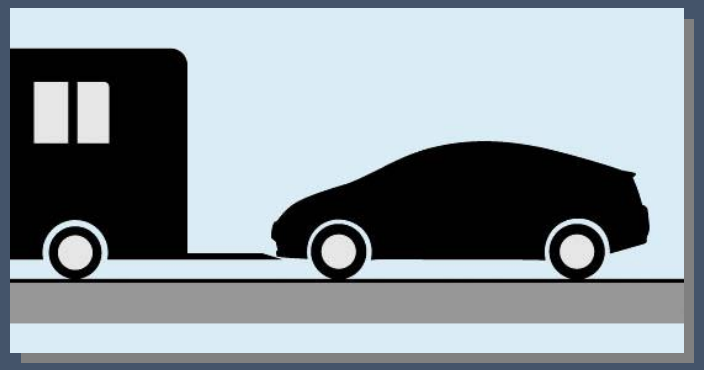


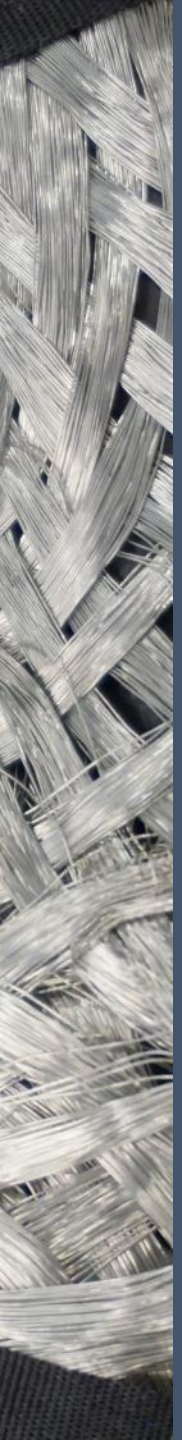
Towing

- OK



- Not OK

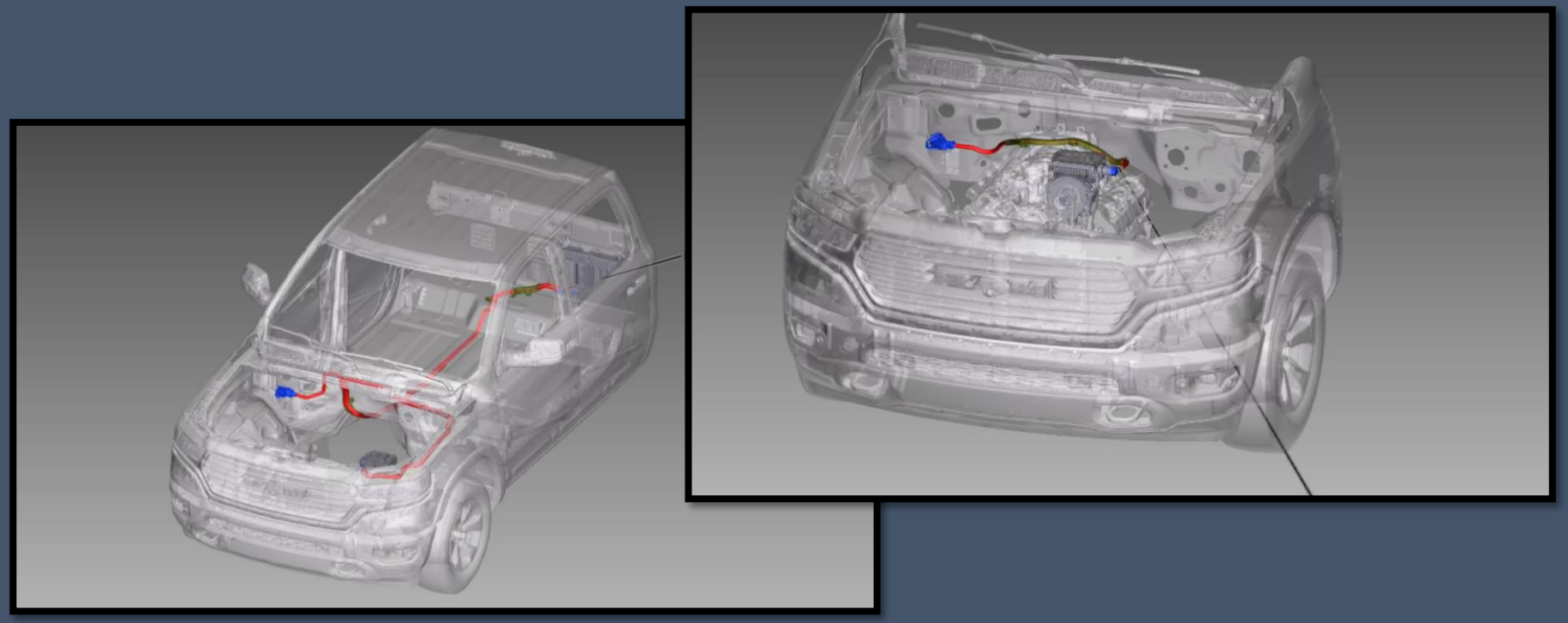




Ram eTorque

Ram eTorque Mild Hybrid System

- Belt Alternator System (BAS) style hybrid
- Replaces Alternator



eTorque

- Allows for better fuel economy
  - 4 Cylinder Mode
  - Stop Start Operation

eTorque

- Power Assist
  - Allows for an extra 130lbs/ft on the 5.7 Hemi
  - Allows for an extra 90lbs/ft on the 3.6 Pentastar

Motor Generator Unit

- Contains its own cooling system
  - 3.6l uses a liquid cooled system
  - 5.7l is an air-cooled system
- Controlled by the PCM

Motor Generator Unit

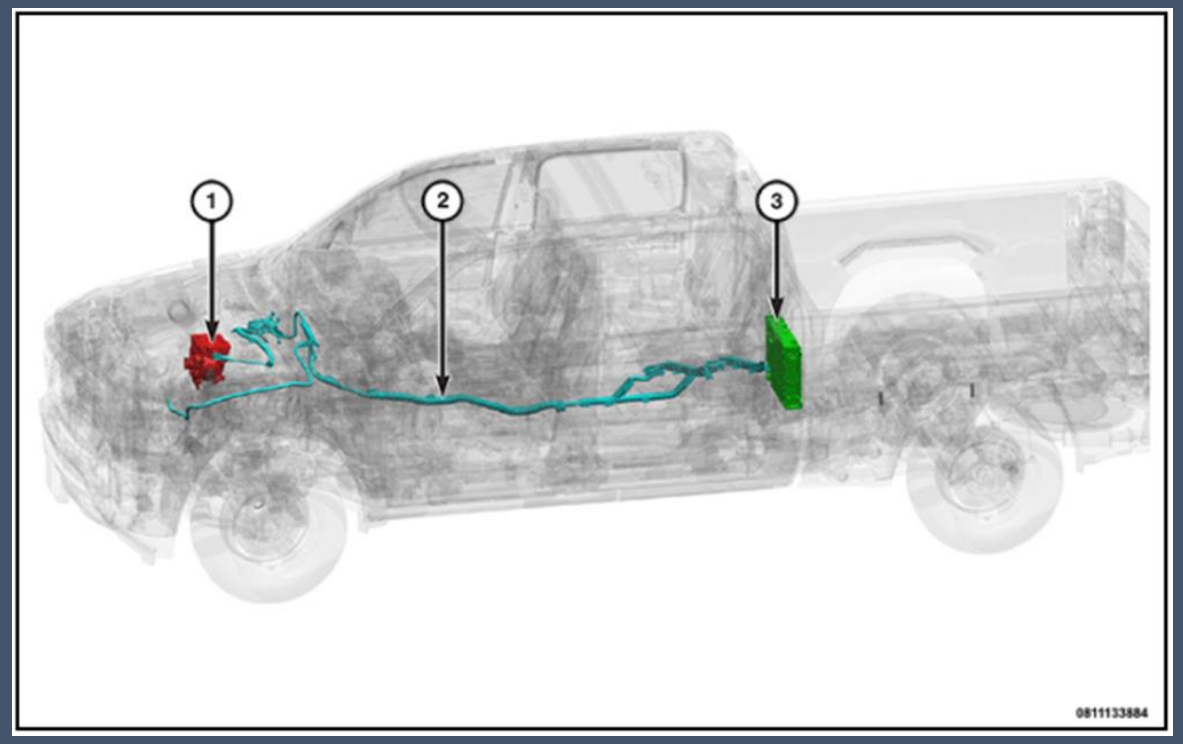
- Replaces the alternator and starter
- Large dedicated belt

Motor Generator Unit

- Contains its own cooling system
  - 3.6l uses a liquid cooled system
  - 5.7l is an air-cooled system
- Uses 48V power
- Controlled by the PCM

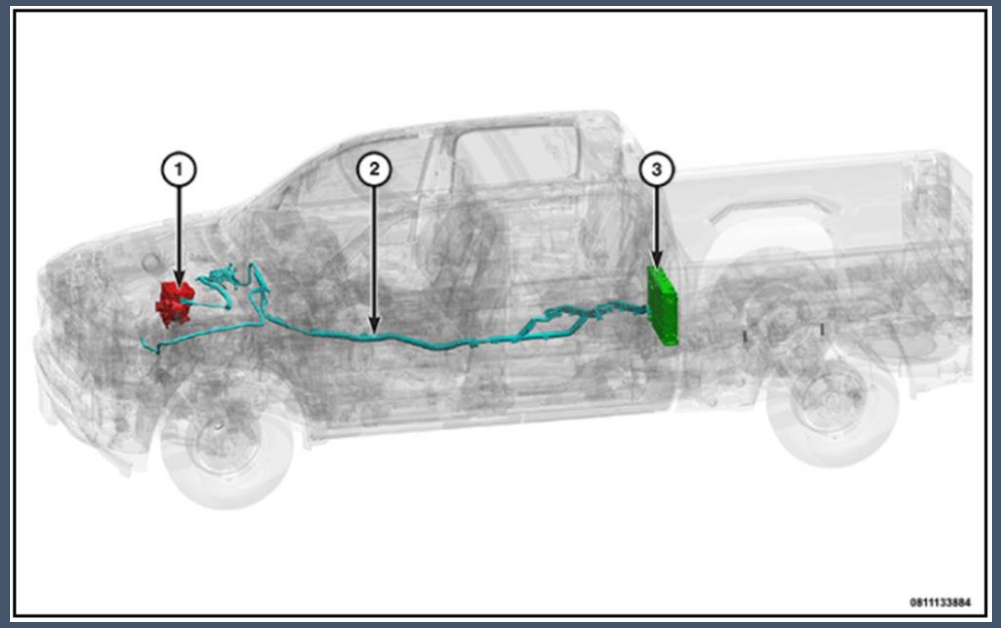
Power Pack Unit

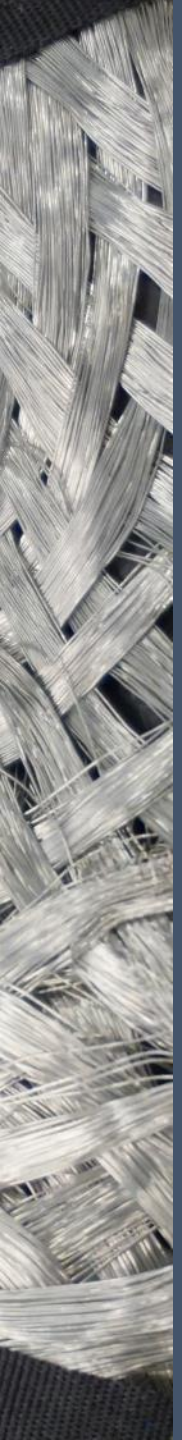
- Contains the 48V Nickel Manganese Cobalt-Graphite battery
- Sits behind the rear seats



Power Pack Unit

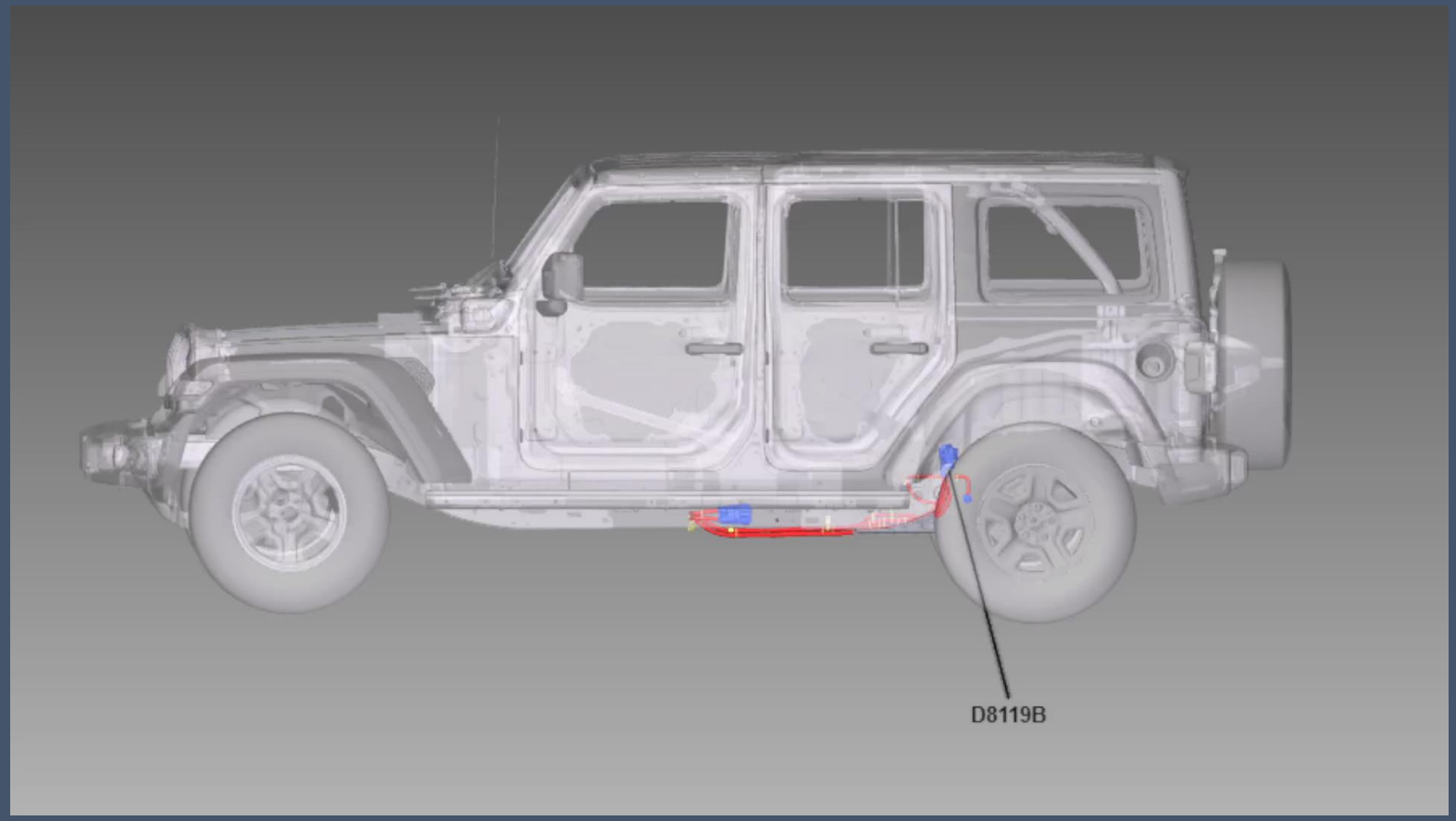
- Cooled by the cabin air
- Contains the Battery Pack Control Unit (BPCU)
- Includes a DC-DC converter that takes the 48V and turns it to 12V to charge the rest of the vehicle





Jeep 4xe

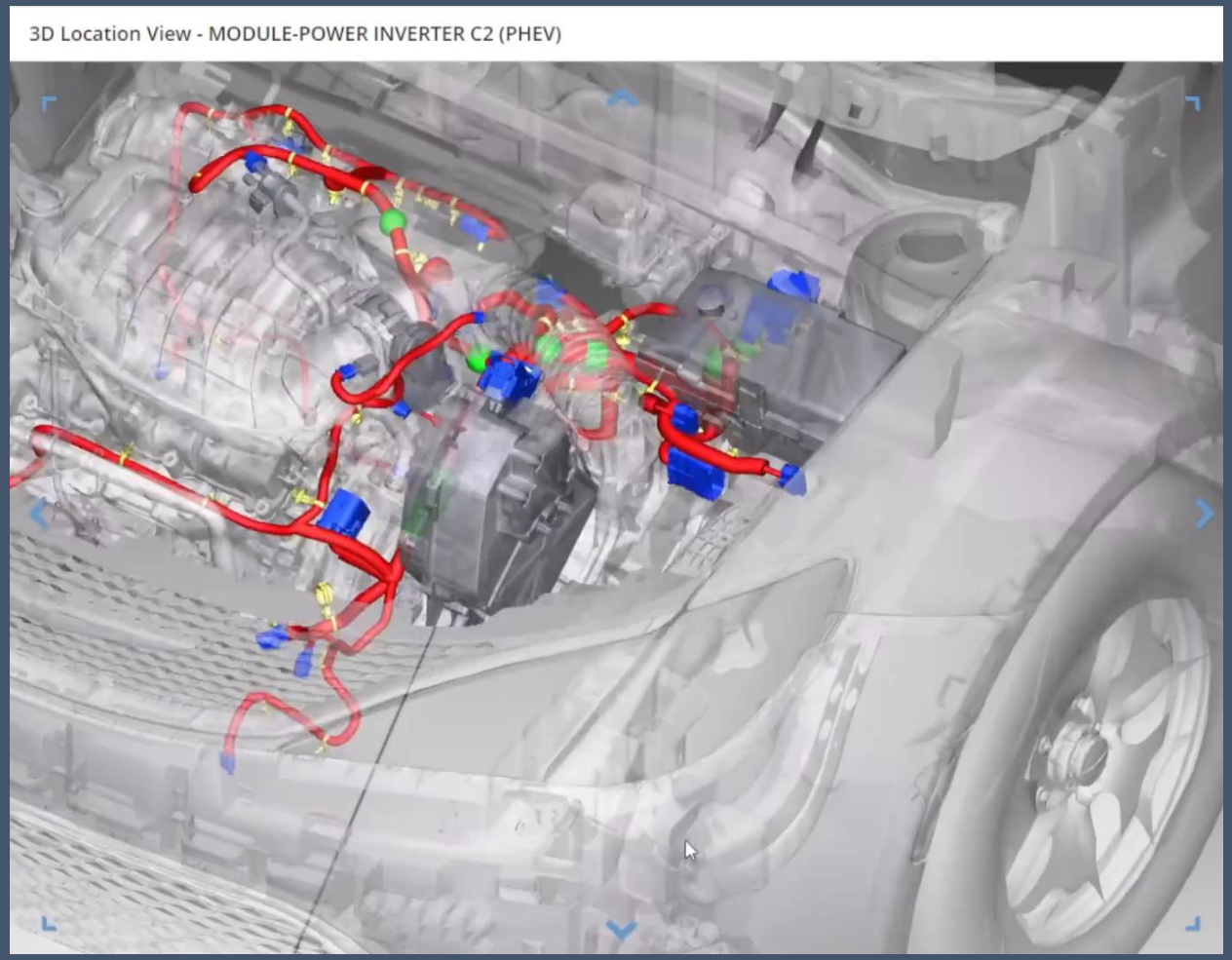
Jeep 4xe



Jeep 4xe

- ZF 8-speed transmission
- Parallel electric motor

Chrysler Pacifica Plug-in



Chrysler Pacifica Plug-in

Passive cooling

- Used during EVSE Charging
- Cycles engine coolant through battery

Active cooling - HV battery is too warm

- Low temp active pump cycles coolant past chiller
- Cabin coolant is bypassing battery

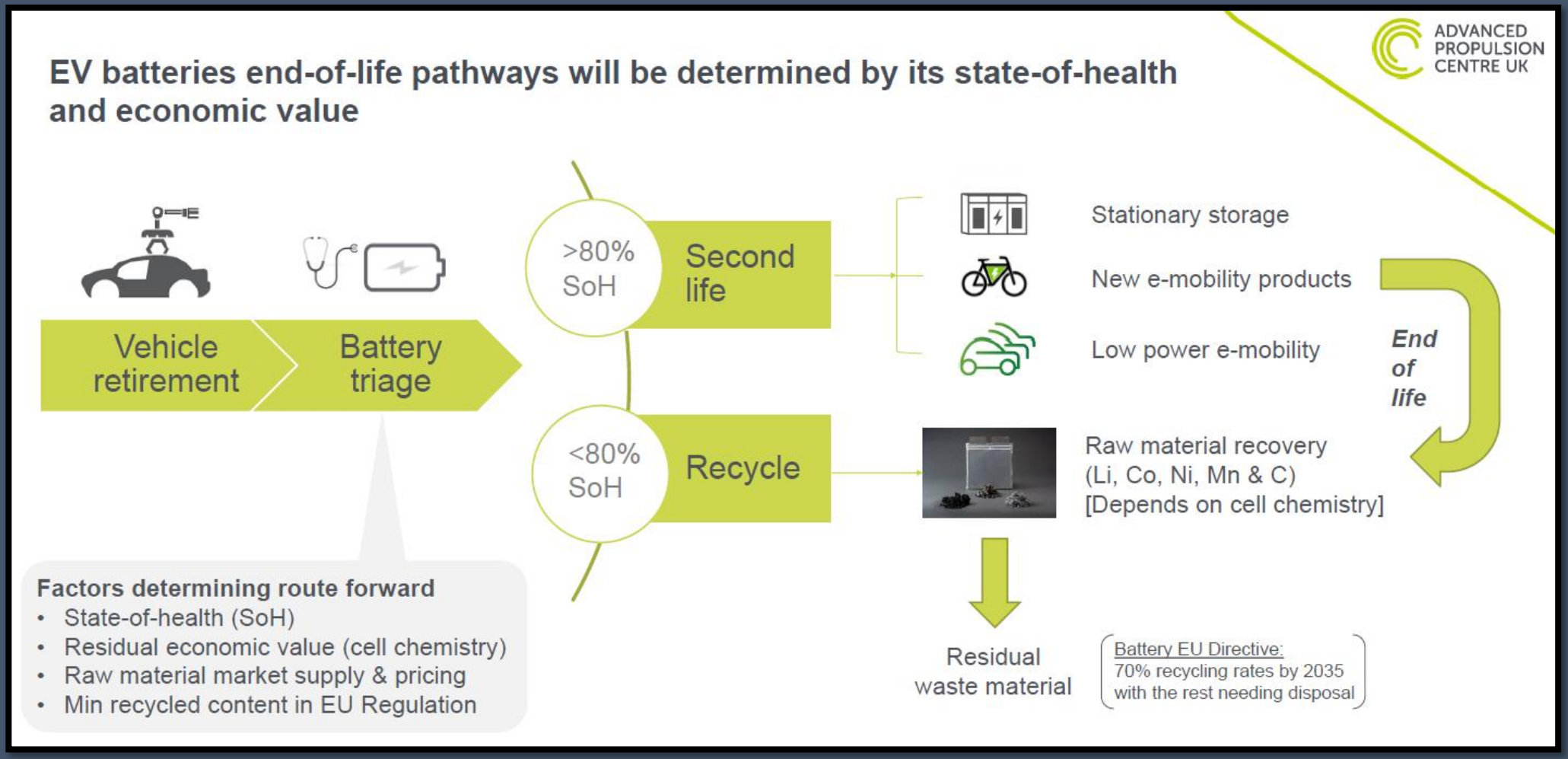
Active heating - HV battery pack is too cold

- Engine heat or electric heat cycles coolant through battery pack.
- Active and auxiliary pump is operating

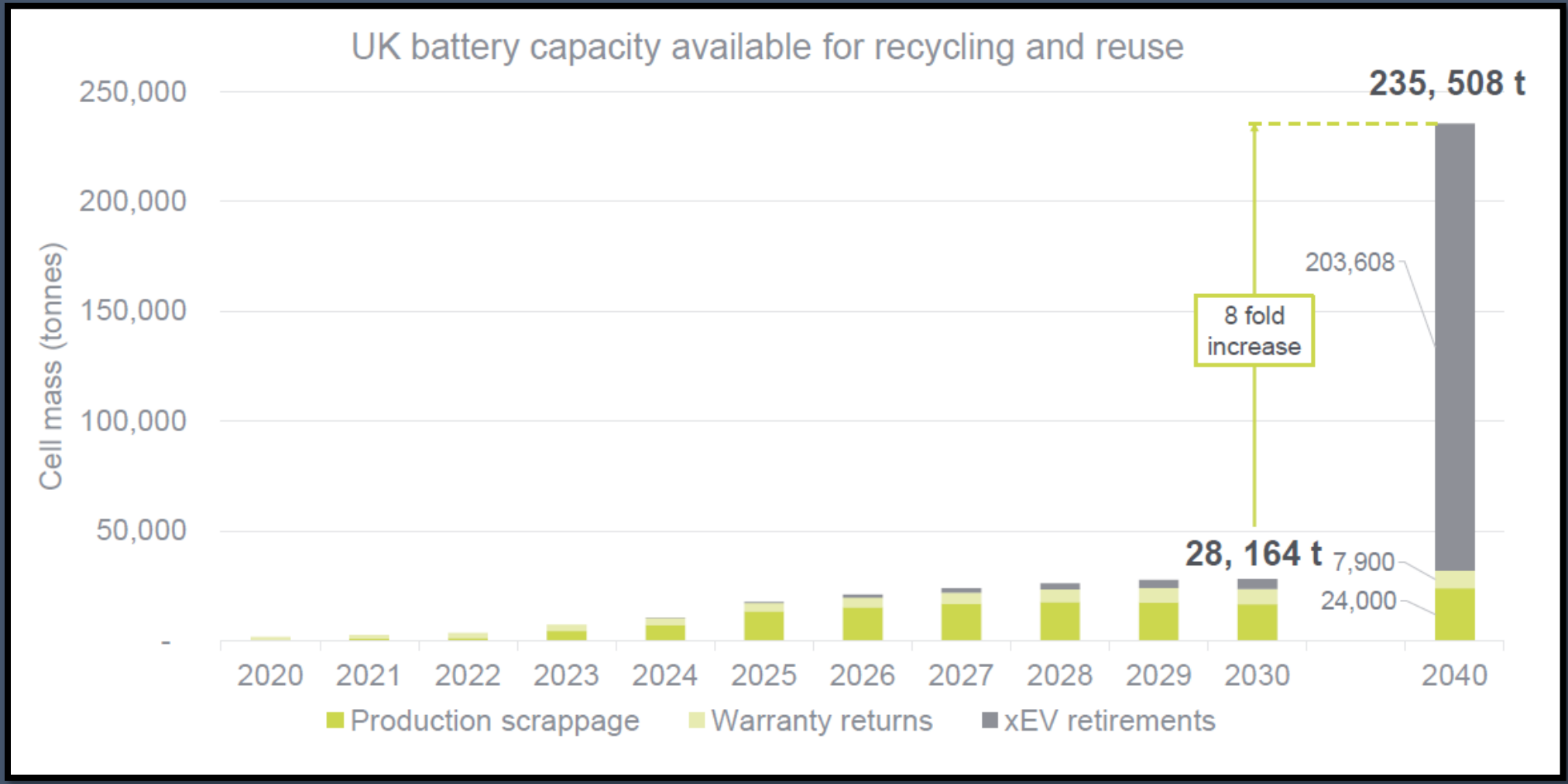
Environmental Concerns

- https://www.lithionrecycling.com/
- https://www.call2recycle.org/
- Battery Recycling - GlobalTech Environmental - Responsible Battery Recycling

Battery recycling



Battery recycling capacity



Pecan Street Project

Average energy use per day for each month. Notice what time of day EV's are charged.

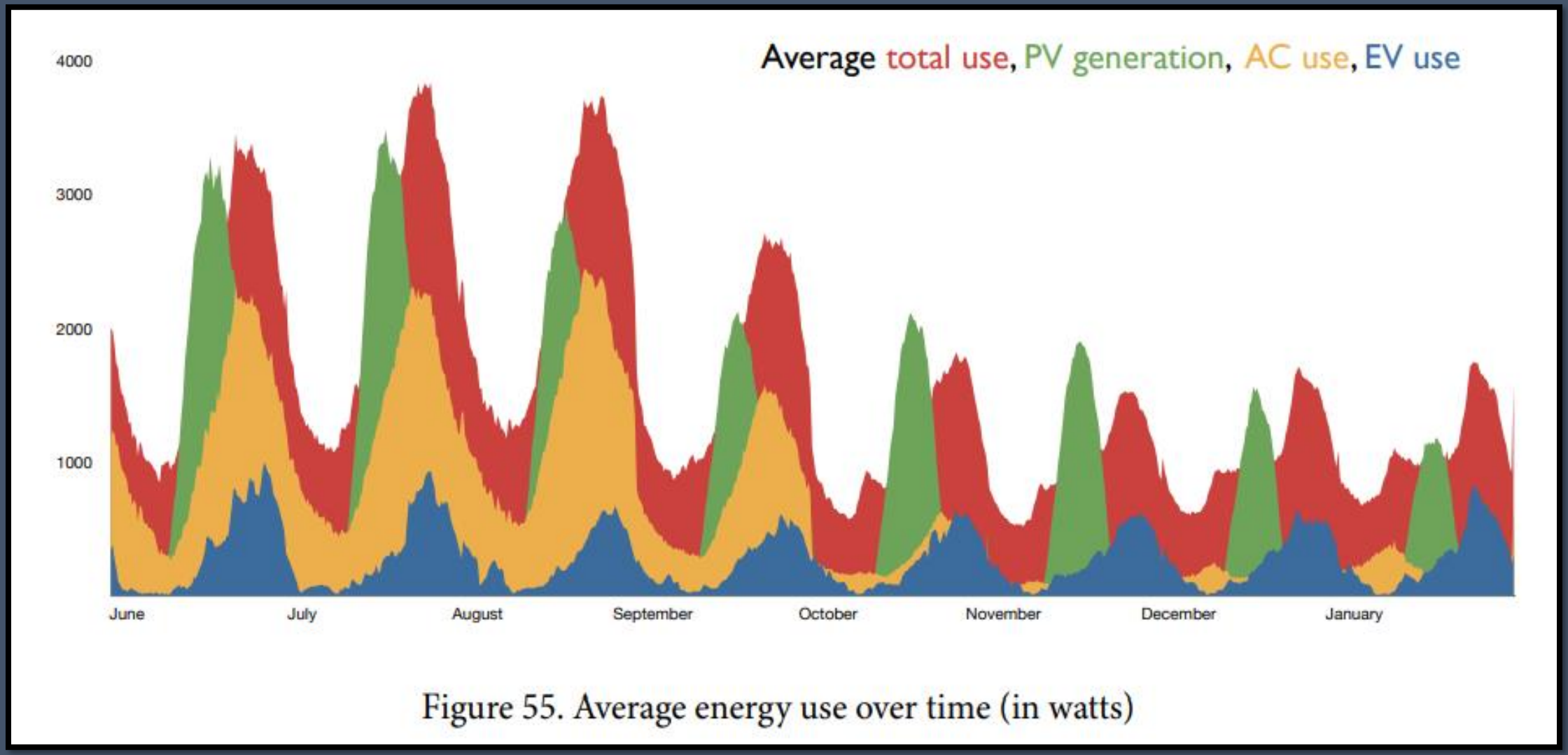


Figure 55. Average energy use over time (in watts)