The EV Battery Service Strategy Guide

MIDTRONICS

Advancing Battery Management


CHARGING
POINT

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Introduction

Over the next 10 years, the vehicle population will undergo a massive shift toward electric vehicles. As the world races toward new battery and vehicle technology, service providers are often left without a complete picture of what it will take to be service-ready for the transition.

Since 2010, Midtronics has been helping its customers become service-ready for high-voltage batteries in electric vehicles (EVs). In our garage, you can catch a glimpse of the entire evolution of high-voltage batteries as they exponentially grew in capacity. It is staggering to see just how far the battery has come in such a short time. Such rapid evolution makes it easy to understand why service providers feel they are faced with a daunting and seemingly impossible task in providing EV battery service.

Due to the high cost, size, and voltage of EV batteries, service is rife with challenges and questions. Does this service occur at normal service shops? What are the failure modes of EV batteries? What should my service strategy be across a network of dealers or service providers? What training is needed? What equipment is needed? What service applications are required? What do I need to know about the battery?

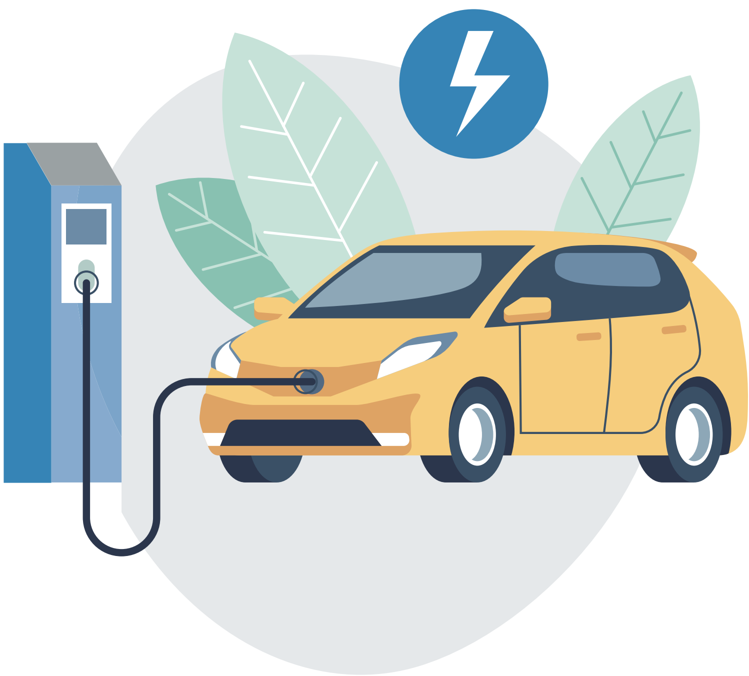
As the leading provider of EV battery service equipment across the globe, we have the expertise to be your trusted advisor. Our goal is to help you become and stay service-ready for EV batteries.

Chapter 1
Vehicle Electrification Overview

At the highest level, vehicle electrification is the process of powering the vehicle, both powertrain and auxiliary systems, via electricity.

In traditional internal combustion engines, electrification found its way into mainstream vehicles beginning as early as the 1920s, when traditional hand cranks were replaced by electric starter motors. Since then, vehicles have evolved to adopt a growing reliance on the battery for countless other components: power steering, traction control, variable load 12V alternators, airbag deployment systems, etc.

Vehicle electrification is also defined as the process of powering vehicles using energy produced from electricity instead of conventional sources such as petroleum and diesel. From micro-hybrid to fully electric vehicles, this evolution in vehicle technology is being driven by the global desire to reduce carbon emissions to slow climate change.



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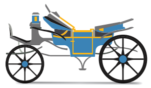
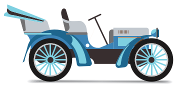
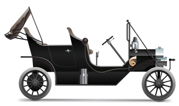
1.1. Brief history and overview of vehicle electrification



1889 – 1891 — The first successful electrical vehicle in the US is created. More electrified wagon than car, it sparks the initial interest in electric-powered vehicles.



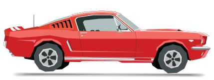
1900 – 1912 — Electric vehicle popularity peaks in the US with EVs accounting for a third of all vehicles on the road. Within this same time span, Edison innovates batteries for use in electric vehicles and the world's first hybrid electric car is invented.



1908 – 1912 — The mass-produced Model T makes gas-powered cars widely available and affordable, diminishing the popularity and demand for electric vehicles.

1920 – 1935 — Better roads and the discovery of cheap crude oil leads to a decline in electric vehicles. By 1935, they all but disappear from the roads.

1968 – 1973 — Gas prices rise dramatically, creating interest in electric vehicles once again. Many big and small automakers explore options for alternative fuel vehicles.



1979 — The interest in electric vehicles begins to fade again. Compared to gas-powered cars, electric vehicles have major drawbacks, including limited performance and range.

1990 – 1992 — New federal and state regulations create a renewed interest in electric vehicles. This causes automakers to begin modifying popular vehicle models into electric vehicles.

1996 — GM releases the EV1, an electric vehicle that was designed and developed from the ground up.

1997 – 2000 — Toyota introduces the first mass-produced hybrid, the Prius. By 2000, the Prius is released worldwide, becoming an instant success.

2006 — Tesla Motors, a Silicon Valley startup, announces it will produce a luxury electric sports car with a range of 200+ miles.

2010 — GM releases the Chevy Volt, making it the first commercially available plug-in hybrid. Nissan launches the LEAF, an all-electric, zero tailpipe emissions car.

2013 - Present — Innovations in vehicle and battery technology, combined with the global goal of reducing emissions, leads to a multitude of vehicle options across the vehicle electrification spectrum.

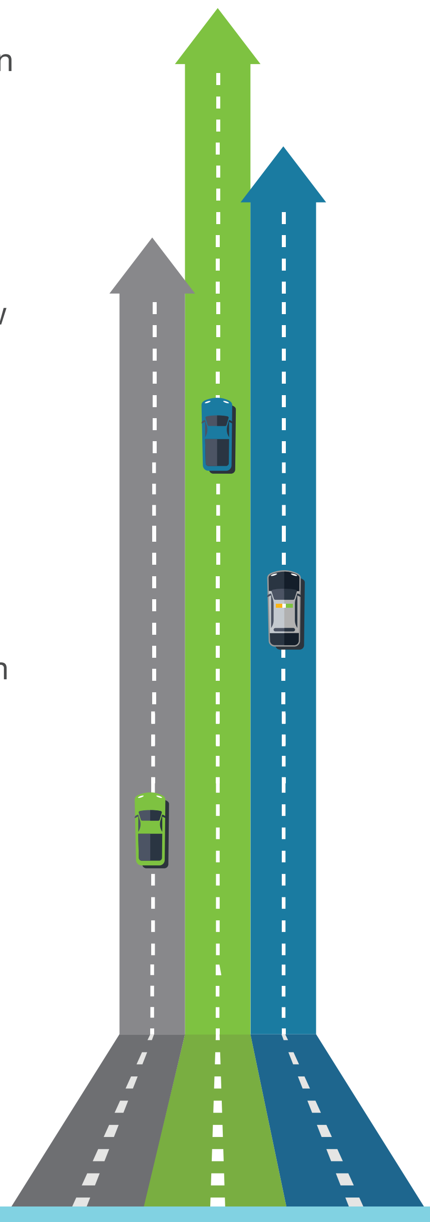
Source: https://www.energy.gov/articles/history-electric-car

1.2. Current state of vehicle electrification: Americas

Vehicle population statistics

In the United States, approximately 272 million car and light truck vehicles are on the road today. The average age of all cars on the road is 12.2 years, which shows the reliability and durability of the cars being manufactured today. Approximately 17 million new vehicles are sold every year. Of those 17 million new cars sold in 2021, only 2%, or 340,000, were electric vehicles (EVs) and another 2% were plug-in hybrid electric vehicles (PHEVs).

The 2030 predictions for EV sales as a percentage of all new vehicle sales vary between 19% and 45%. Many of the car manufacturers are publicly committing to an all-EV fleet by around 2030; for example, the Chrysler brand part of Stellantis stated it will sell only EVs starting in 2028. General Motors is said to follow by 2035 and Ford by 2040. Given the large car parc and age of vehicles, even the high end of the forecasts calculates that EVs will represent 9-19% of the total car parc by 2030. Midtronics believes this is a realistic estimate and shows that conventional internal combustion engine (ICE) vehicles will remain a significant powertrain in the United States into 2040.

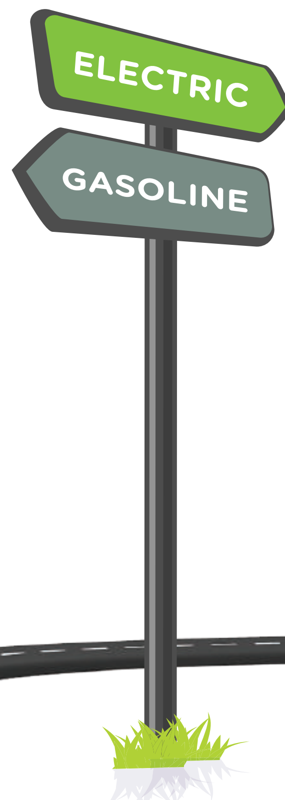


Policy and regulatory impacts

The National Highway Transportation Safety Administration (NHTSA) sets the Corporate Average Fuel Economy (CAFE) standards to regulate how far vehicles must travel on a gallon of fuel. In August 2021, NHTSA established a 49-mile-per-gallon industry-wide fleet average by the 2026 model year. These CAFE standards influenced car manufacturers to launch new EV options, which is increasing consumer adoption.

The more recent Federal tax credit has been phased out for most original equipment manufacturers (OEMs). US Congress has proposed new legislation in 2022 that rethinks how consumers qualify for the tax credit. The three major proposed qualifications include:

- How much of the battery was manufactured in a NAFTA country
- How expensive the vehicle was to purchase
- The income of the purchaser of the vehicle



Many original equipment manufacturers (OEMs) have already pushed back on these stricter requirements because they believe that they are unlikely to increase adoption.

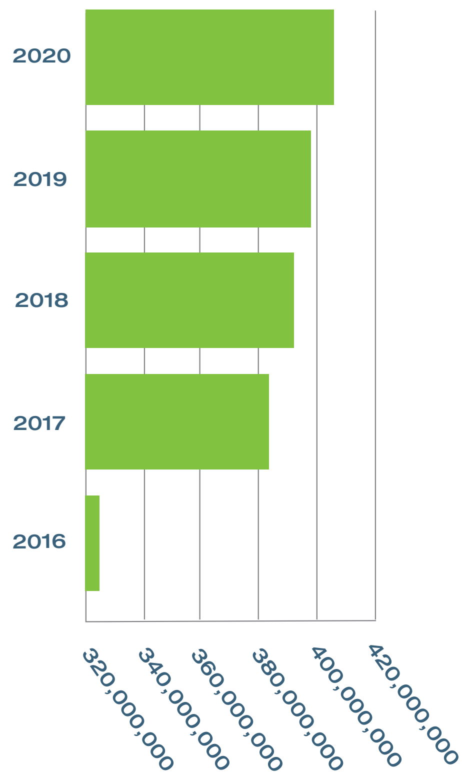
NHTSA

1.3. Current state of vehicle electrification: EMEA

Vehicle population statistics

Vehicles in Use in Europe

In Units: 2016 - 2020



Source: ACEA Vehicles in Use Report 2022

Fleet size

- In 2020, the European Union (EU) passenger car fleet grew by 1.2% compared to 2019, with 246.3 million cars on the road in total. The highest percent growth was seen in Romania (+5.4%), and Slovakia (+5.1%), while the French car fleet shrank slightly (-0.3%).
- Nearly 29 million vans are in circulation throughout the EU, half of which can be found in three countries: France (5.9 million vans), Italy (4.3 million), and Spain (3.9 million).
- There are more than 6.2 million medium and heavy commercial vehicles on EU roads, up 1.7% compared to 2019. With around 1.2 million trucks, Poland has the largest fleet by far.
- 684,285 buses are in operation across the EU, almost half of which can be found in three countries alone: Poland (124,526), Italy (99,883), and France (93,506).

Average age

- European Union cars are now on average 11.8 years old. Lithuania and Romania have the oldest car fleets, with vehicles almost 17 years old. The newest passenger cars can be found in Luxembourg (6.7 years old).
- The average age of light commercial vehicles in the EU is 11.9 years old. Of the EU's four major markets, Italy has the oldest van fleet (13.8 years old), followed closely by Spain (13.3 years old).
- Trucks are on average 13.9 years old in the EU. With an average age of 21.4 years old, Greece has the oldest truck fleet, while the newest ones can be found in Luxembourg (6.7 years old) and Austria (7 years old).
- Buses on EU roads are on average 12.8 years old. Aged more than 19 years, Greek buses are the oldest in the region. Only six countries in the EU have a bus fleet that is less than 10 years old.

Fuel type

- Despite the strong increase in sales seen in recent years, alternatively powered passenger cars still make up only 5.3% of the total European Union car fleet. Battery electric cars and plug-in hybrids account for just 0.5% and 0.6% of the fleet, while 1.2% of all cars on EU roads are hybrid electric.
- Diesel-powered light commercial vehicles are still dominant in all EU countries except for Greece: 91.2% of the EU van fleet runs on diesel and just 0.4% of vans in the EU are battery electric.
- Of all trucks in the EU, 96.3% run on diesel, while petrol fuels less than 1% of the fleet. A mere 0.24% of trucks on EU roads have a zero-emission powertrain, but that figure is up from 0.04% in 2019.
- Diesel buses account for 93.5% of the EU fleet, with only 0.9% being battery electric and 1.4% hybrid electric. However, significant shares of electric buses can be found in the Netherlands (12.4%) and Luxembourg (6.6%).

Policy and regulatory impacts

Nearly all European Union member states now offer some form of fiscal support to stimulate the market uptake of electric vehicles, but both the nature and the monetary value of such tax benefits and purchase incentives still differ widely across the EU:

- As of 2022, 17 EU member states (down from 20 in 2020) offer incentives for the purchase of electric vehicles.
- Ten (10) countries (four more than in 2021) do not provide any purchase incentives; most of them merely grant tax reductions or exemptions for electric vehicles.
    - Belgium
    - Bulgaria
    - Cyprus
    - Czech Republic
    - Denmark
    - Estonia
    - Latvia
    - Malta
    - Poland
    - Slovakia
- Estonia is the only member state without any fiscal stimuli at all.
    - Poland merely offers an exemption from acquisition tax.
    - Bulgaria exempts electric vehicles from ownership-related taxes.

1.4. Current state of vehicle electrification: China

Vehicle population statistics

In China, about 302 million vehicles are on the road today, of which 7.84 million are EVs, accounting for 2.6% of total vehicles. The number of BEVs is about 6.4 million, with a penetration rate among EVs of about 82%. In 2021, there were about 26.2 million new vehicles sold, of which about 3.5 million were EVs, accounting for about 13% of market share. The average vehicle age rose from 4.6 years in 2019 to 6.1 years in 2022, maintaining steady growth.

The Chinese government published the *Action Plan for Carbon Dioxide Peaking Before 2030*, which outlines clear instructions to increase the proportion of EV sales to about 40% by 2030. Based on current EV penetration progress, goals to achieve 20% by 2025 and 40% by 2030 are relatively achievable and could even be accelerated. At the same time, the government does not plan to issue a timetable or policy for stopping the sale of ICE vehicles nationwide.

Policy and regulatory impacts

In recent years, the Chinese government has continuously introduced policies and regulations to promote the popularization of EVs and the standardized development of the industry. The relevant initiatives include but are not limited to:

- Designed an innovative development strategy for intelligent vehicles, which set a specific timetable – By 2025, the basic industrial ecosystem, including technology innovation, industrial ecology, infrastructure, laws and standards, product supervision, and network security, will be established. By 2035–2050, the intelligent vehicle system will be completed and further refined.
- Implemented policies to promote EV sales – EV purchase subsidies and tax exemption will be extended until the end of 2022. The subsidies have been declining in the past two years, and the demand will gradually shift from policy-driven to market-driven.
- Established and improved the promotion mechanism of EV – Encourage public, municipal, and express delivery enterprises to adopt EV.
- Set up the standardization of EV – Optimize the standard system, accelerate the development of standards in the fields of EV, fuel cells, batteries, and electric charging.
- Strengthened the development of infrastructure – Increase number of charging poles and battery swap stations; expand 5G applications; build data centers.

Chapter 2
EV High-Voltage Battery Applications

There are three main types of electric vehicles:

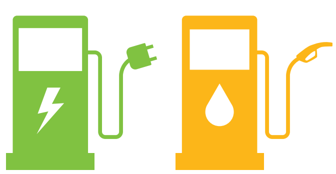
- Electric Vehicle (EV), also known as a Battery Electric Vehicle (BEV)
- Hybrid Electric Vehicle (HEV)
- Plug-in Hybrid Electric Vehicle (PHEV)

Each type has its own unique properties when it comes to battery application and how it is powered.

An Electric Vehicle (EV or BEV) is a fully electric vehicle that has rechargeable batteries. These batteries are recharged from the grid and are the only source of power for the vehicle, which does not have a tank for gasoline.

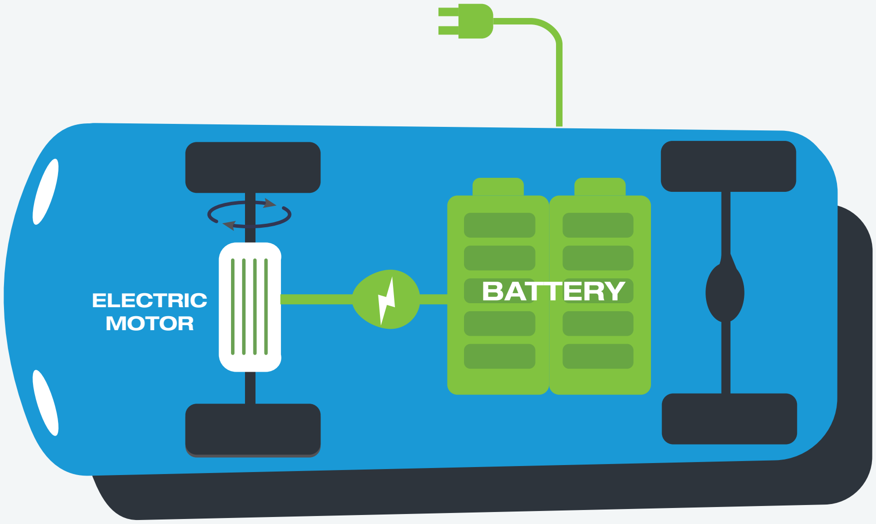
A Hybrid Electric Vehicle (HEV) is both electric and gas-powered. However, the grid cannot charge the batteries in this type of electric vehicle. The energy that powers its battery is gained through regenerative braking or while driving using the combustion engine. In a standard gas-powered car, the energy from braking is lost in the form of heat. This happens through the friction created between the brake pad and rotor to slow the vehicle.

A Plug-in Hybrid Electric Vehicle (PHEV) has an engine, battery, and electric motor. Like an HEV, a PHEV can recharge its batteries through regenerative braking or with the engine. The primary difference between an HEV and a PHEV is that the PHEV adds a charging port, allowing it to operate more like an EV, driving off the battery and recharging from the grid, and only using the combustion engine when the battery is depleted. PHEV batteries are higher capacity than HEV batteries. Once a PHEV battery is depleted, the internal combustion engine takes over.



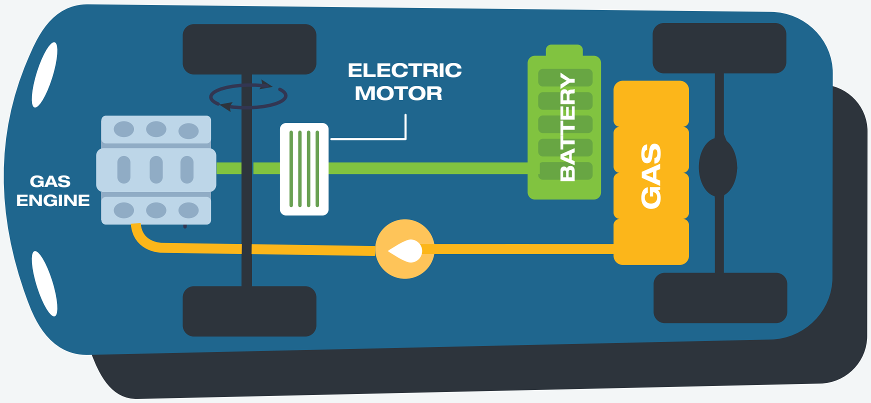
EV/BEV

Electric Vehicle or Battery Electric Vehicle



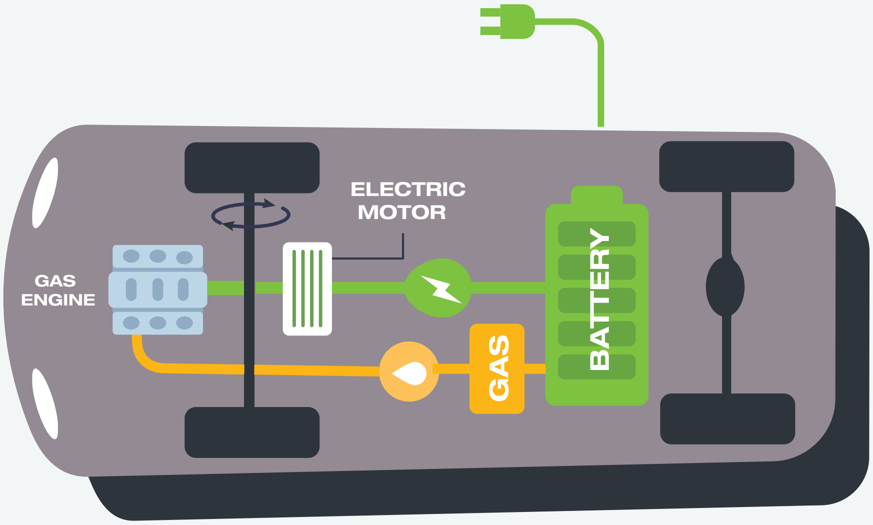
HEV

Hybrid Electric Vehicle



PHEV

Plug-in Hybrid Electric Vehicle

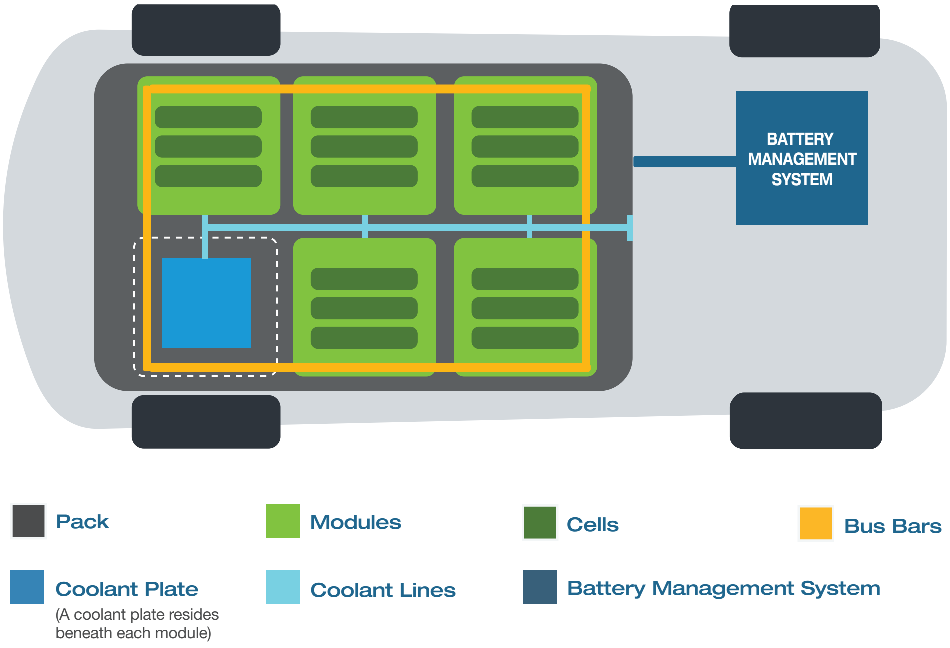


Chapter 3
EV High-Voltage Battery Technology

Besides the high-voltage battery, BEVs and PHEVs have a number of unique pieces of technology that set them apart from traditional ICE vehicles. These include the charge port and onboard charger, which enable an AC voltage from the grid to connect to the vehicle and transform it from a standard AC voltage into a DC voltage to charge the battery. In addition, these vehicles feature multiple-phase AC motors to transform the battery's DC voltage into the three phases typically used by these motors. BEVs and PHEVs also have a device called an inverter. The inverter handles a lot of energy within the vehicle and therefore produces a lot of heat. For this reason, many inverters connect directly to the car's cooling system.

Without question, the propulsion battery is the largest and most complex piece in this system, consisting of many expensive components of its own. Because battery technology is in a state of rapid innovation, differences in implementation abound. However, the core components are largely similar in form and function. These components are:

- Cells
- Bus Bars
- Coolant
- Battery Management System



Cells are the basic building block of a battery pack. Within newer packs, cells typically use a lithium chemistry base. There are three major types of cell architecture:

1. Cylindrical cells have a rigid structure so they do not need much structure within a pack and can provide the rigidity required. They are used within Tesla batteries (among others) and have a wide range of other uses.

2. Pouch cells are common in cell phone and EV batteries. Batteries with pouch cells do not have much structure to them but can be made in more form factors to better utilize space.

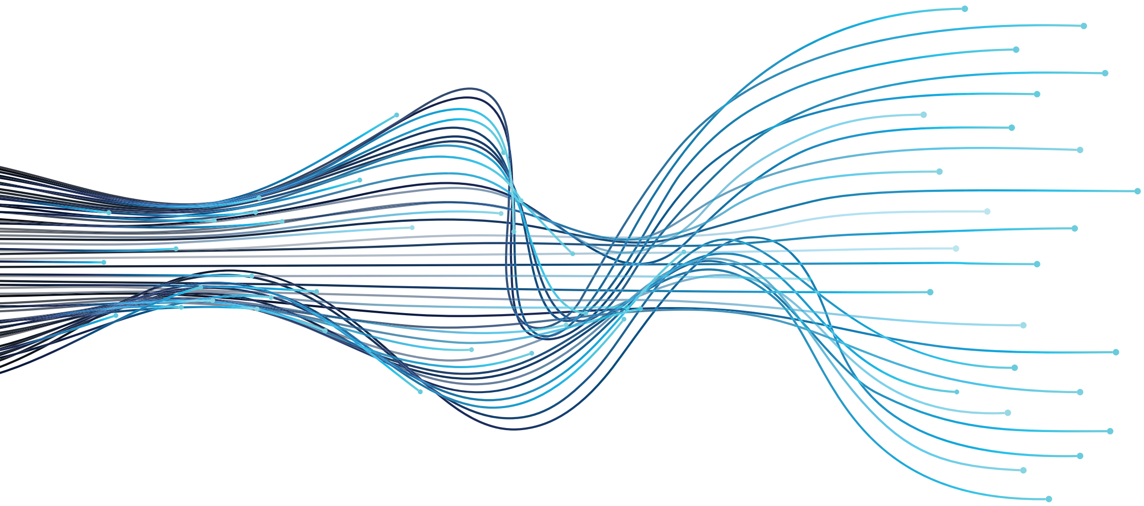
3. Prismatic cells are a cross between the cylindrical cell and the pouch cell, trying to pull the best from both: the increased rigidity of cylindrical cells alongside the space-saving quality of pouch cells.

Cells in these batteries are connected in series and in parallel. In many instances, the cells are combined to make serviceable modules, and these modules are combined to make a pack. Adding cells in parallel adds Ah capacity to the overall system while putting cells in series ups the pack voltage. Most packs start with a single cell before designers combine them in series and parallel to reach a stated voltage range and max capacity. Engineers design BEV packs to be within a 400V or 800V architecture. The 400V architecture came first as it was easier to understand and certify, and it made use of a lot of existing components on the market. It usually consisted of around 100 cells in series. The downfall was that to place this architecture within larger vehicles, the packs would have to be quite large in Ah capacity. A large Ah capacity hurts a vehicle's charge time and makes other circuits within the pack (like balancing circuits) less efficient. With slower charge times and other inefficiencies, it is more difficult to provide accurate state of charge (SOC). The 800V architecture typically has around 200 cells in series, which allows it to charge at a higher voltage while requiring less current, so long as the charger can handle it. The higher voltage also allows for other efficiencies with drivetrain components within the vehicle, like the inverter, motors, and cable harnesses.

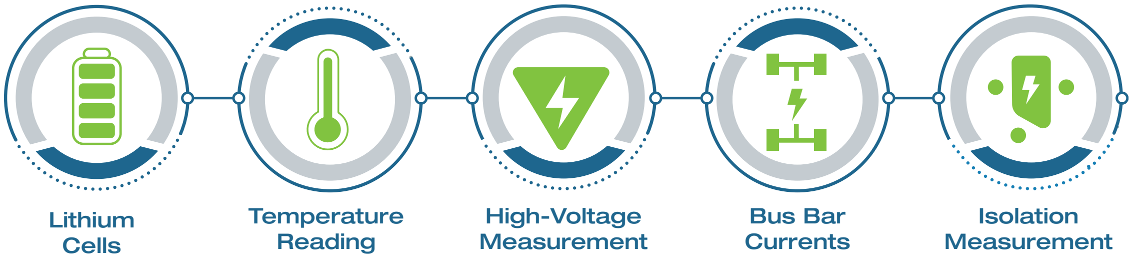
The trend with lithium cells is to pack a larger amount of potential energy in a smaller envelope. This creates a higher risk of fire or other safety hazard. Lithium cells use a liquid (gel) electrolyte to facilitate the movement of electrons between the cathode and anode. One major source of investment for many in the space is around solid-state batteries. This battery type promises even more increased capacity per area while lowering safety risks by replacing the liquid electrolyte with a solid electrolyte, which is firm and unlikely to break. A solid state rids the battery of its liquid component in favor of a more stable solid.

Bus bars are simply the interconnects between each cell or module. If the cells are all enclosed together, the bus bar is often a laser-welded piece of metal. If the bus bar is connecting a group of cells (i.e., a module) together, then it is often coated in copper. The copper bars are easier to manufacture and can be made custom for unique battery designs, all while carrying the same amount of current as standard copper wiring, if not more.

Cooling methods in current pack designs almost always consist of liquid being pushed through heatsinks near the cells. Older EV or hybrid packs often used forced air. These coolant lines flow back to a reservoir that has a small heater in it. One of the main goals of system designers is to maintain the pack within a reasonable temperature in order to keep the negative effects of cycling cells to a minimum.



The battery management system (BMS) is one of several dedicated electronic control units (ECUs) within a car. Its purpose is to read the battery's many sensors as well as control when the battery can connect to the rest of the vehicle. For safety reasons, to prevent high voltage from coursing through the entire vehicle at all times, the battery management system will close large relays within the pack (contactors) and allow the high-voltage battery energy to flow to the rest of the vehicle. The sensors that the battery management system reads vary with the application, but they typically provide a measurement of every series lithium cell, an array of temperature readings, a few high-voltage measurements at different points around the contactors, current readings on the bus bars, and an isolation measurement.



A high-voltage battery has a positive and a negative post – just as a 12V battery does. The difference is that the negative terminal of a 12V battery is connected to the chassis of the car. In a high-voltage battery, this is not the case; the negative terminal is not attached to the chassis due to safety concerns. With the negative terminal of a high-voltage battery connected to the chassis, the entire car would turn into a negative battery terminal. In this circumstance, the technician would be exposed to electrocution by lethal voltage if they physically touched the car and any part of the battery that has lethal voltage at the same time. Isolating the battery from the chassis makes it so the technician would have to touch two distinct points on the battery with lethal voltage between them. Additionally, most vehicle ECUs will perform an isolation test procedure to ensure that the battery is isolated from the vehicle. This isolation test procedure can also be performed using Midtronics battery service equipment.

Chapter 4
EV High-Voltage Battery Life

EV battery life is a large point of discussion as BEVs become increasingly prevalent. Unfortunately, the lack of historical data makes it difficult to accurately predict battery life. It is widely known that lithium ion batteries will degrade over time, but the rate of degradation can be affected by several factors, both controllable and uncontrollable. With the battery representing 25–40% of the overall vehicle cost, battery life becomes the most important factor in determining lasting value of the vehicle and particularly important in setting price during a change of ownership.

4.1. Lifespan

Degradation is defined as a reduction of the full capacity in a used battery when compared to the new or rated capacity. For the driver, this will manifest as a reduction of maximum range when a battery is charged to 100%, limiting the trips a driver can take and requiring more frequent charging. Battery manufacturers and original equipment manufacturers (OEMs) are working with data from their currently deployed BEVs to better understand the battery life and degradation to continually make improvements and understand warranty risks.

- Controllable factors:
  - Charging speed: Regularly using DC Fast Charging will negatively affect battery life. Level 2 charging is recommended to minimize degradation.
  - Extreme state of charge (SOC): Charging to 100% and discharging too close to 0% will affect battery life. The negative impact to battery life increases the more time the battery spends at fully charged and discharged states. Lithium ion batteries like to be closer to the middle of their SOC curve. Some OEMs mitigate this by limiting the available capacity at the top and bottom ends of the range. This results in a lower maximum capacity from the start but less degradation over time. Other OEMs recommend only charging to 80% unless a trip requires the full battery range.
  - Battery temperature control: Most batteries on newer vehicles are now actively cooled/heated to keep the battery in the optimal temperature range. Batteries perform best in the range that humans also like, so room temperature is a good target. Extreme hot or cold temperatures will affect the battery range at that moment and can cause long-term degradation.

- Uncontrollable factors:
    - External temperature: Vehicles in areas that have extreme temperatures will likely exhibit more severe degradation from the temperature swings in the battery.
    - Usage: The amount of time in operation, number of charge/discharge cycles, and long periods of no usage can all affect the overall battery life.
    - Manufacturing defects: Many battery issues and warranty claims are not due to battery life or degradation but rather to defects in the manufacturing process or design issues, often because of the complexity of the cells. Even the smallest tear or fold in the cell during manufacturing can cause serious issues. These issues can cause catastrophic failures or affect the overall performance of the vehicle.

4.2. Determining state of health (SOH)

State of health (SOH) is a figure used to note the capacity of the battery compared to the rated capacity of the battery, expressed as a calculated percentage comparing the battery capacity to its rated capacity. With regard to EV high-voltage batteries, SOH readings serve a variety of purposes. The main goal of determining SOH in an EV is to determine whether or not the battery can safely and effectively perform the job for which it is designed. However, “safe and effective” can mean different things in different circumstances; for example, a safe state of charge (SOC) for shipping is not going to be the same as an effective SOH for reliable driving range.

There are several ways to determine SOH in an EV high-voltage battery. First off, EVs have a sophisticated battery management system (BMS) that can calculate a battery SOH to some degree. Battery management systems generally use coulomb counting (tracking the energy in and out of the battery at measured SOC), calculated based on voltage compared to the ideal SOC curve, or estimated through internal resistance. Significant investments are being poured into researching new methods for determining SOH as well. For example, technologies like ultrasound and electrochemical impedance spectroscopy are being explored to find faster, independent ways to verify a battery’s SOH.

4.3. Warranty

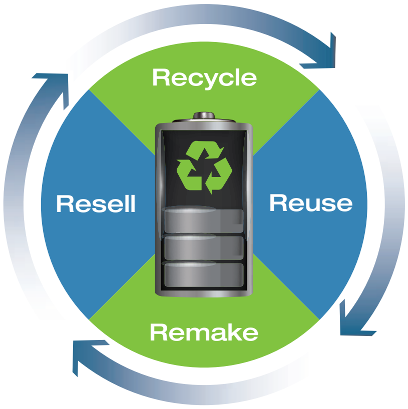
Warranty on an EV's high-voltage battery varies by manufacturer. In the US, federal law mandates at least an 8-year/100,000-mile warranty with several states extending this to 10 years/100,000 miles. OEMs are going even further as a selling feature, with some offering an unlimited/lifetime warranty on the battery. Important distinctions around the warranty revolve around SOH. While some OEMs warranty a battery against a reduction in overall capacity, others only warranty a battery against total failure.

4.4. Secondary life

BEV is a demanding application for batteries as the vehicle needs significant power during hard acceleration and must store enough energy to meet its range requirements. As the battery degrades, it can be reduced to thresholds that make it unsuitable for a vehicle application but still suitable for other stationary applications (such as energy storage systems, or ESS) prior to reaching end of life and being recycled. ESS applications can use a battery above 50% SOH to continue getting value out of it before it is sent to EOL/recycling, where it will be shredded for materials.

Finding secondary life applications for EV batteries can be challenging. The lack of standardization between packs, modules, and cells among EV batteries means that specific vehicle batteries may need to be paired together in order to be of renewed value in certain systems. Plus, the lack of SOH data in some cases can make it difficult to determine the usable life left in a battery for secondary life applications, which drives the value/price of the battery down.

4.5. End of life (EOL)/recycling



Once a battery pack has reached a 50% or lower SOH, it becomes a prime candidate for recycling. This process can be very intensive and may require information from the battery or vehicle manufacturer. At the start of the recycling process, the pack is discharged prior to disassembly. Then, the pack is disassembled and sorted into parts by hand or shredded and sorted through various automated processes. Depending on the chemistry of the pack, the cells may contain various high-value components, such as cobalt and nickel, or lower value components like iron. By the end of this process, the recycler will have sorted material into plastics, non-battery metals, and black mass (the recycled battery cells that can be put back in the battery cell manufacturing chain).

Chapter 5
EV High-Voltage Battery Service

The EV high-voltage battery is by far the heaviest, most costly, and most vital component in the vehicle. It alone represents 25–40% of the overall vehicle cost. An inadequate service plan can lead to drivers stuck without a vehicle, unscalable battery warranty exposure, unaffordable service, and even poor service quality. The following sections provide the essential information that must be understood in order to safely provide customers with high-quality EV battery service.

5.1. Safety

EV high-voltage batteries are complex systems that store energy in chemical form to use as electrical output. Most of the EV packs on the road today are at approximately 400 VDC. However, with the benefits of higher voltages, OEMs are targeting 800–1000 VDC for many of their vehicles that are currently in development. This increase in voltage hardly matters in terms of safety given that all EV packs are already well above the defined lethal level of 60 VDC. At these voltages, an electrical shock can kill you instantaneously. The battery pack is designed to isolate these voltages from the vehicle chassis and typically will have relays so voltage is not present without several safety systems in place and the protocols to operate the battery management system. However, the pack should always be treated as a lethal component when it is out of the vehicle due to possible damage or faults until it has been verified to be safe.

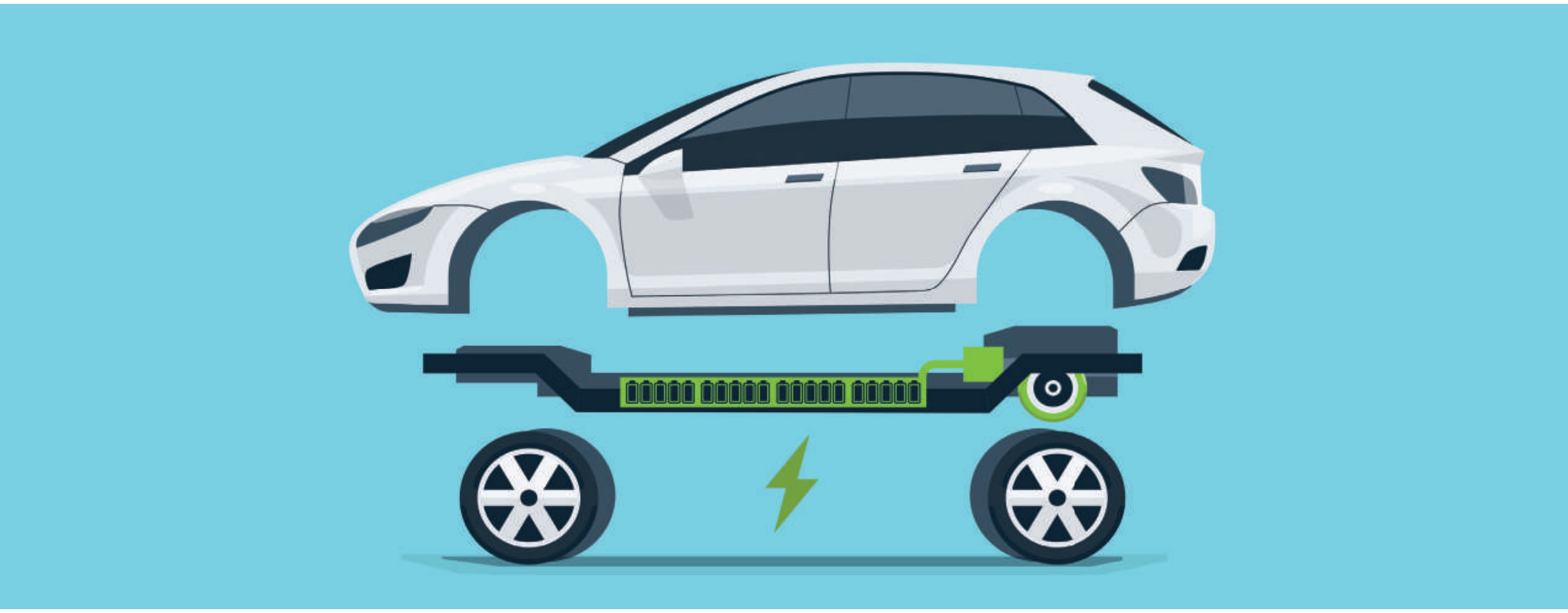
During many service applications, the battery pack must be opened to replace a component in the pack. In these instances, exposed high voltage is present. It is crucial to follow OEM service procedures and battery manufacturer instructions to remove electrical components and bring the pack to safe levels. Appropriate high-voltage personal protective equipment (PPE), including insulated gloves, arc flash suits, and insulated tools, should always be used when working inside the battery pack.

5.2. Training/certification required for servicing

High-voltage battery training is offered by several organizations. The training curriculum may be generalized to cover a variety of HV services, but there are also application-specific training programs for EV batteries.

Vehicle manufacturers have designed service procedures for their batteries. Typically, a technician will need certification to work on these vehicles. To earn this certification, candidates will be required to undergo safety training in high-voltage systems, as well as training around proper service and repair protocols for their specific systems.

It is important to understand if there are any safety standards in place in your country. Many countries have their own unique safety standards around high voltage and/or servicing EV batteries. For example, in the Netherlands, the standards *NEN 3140: Operation of electrical installations* and *NEN 9140: Safe working on EVs* describe different training levels that people can reach, allowing them to carry out different service jobs on electric vehicles.



5.3. Common battery service applications

The service requirements of EVs are drastically different than ICE vehicles. Most routine maintenance items for ICE vehicles do not apply to EVs.

Examples of routine maintenance needs on ICE vehicles that do not apply to EVs or are reduced:

- Oil changes
- Transmission fluid changes
- Spark plug changes
- Reduced frequency of brake service

Examples of significant maintenance needs on ICE vehicles that do not apply to EVs:

- Timing belts
- Water pump
- Catalytic converter
- Automatic transmission

Due to the rapid technological evolution of battery technology and lack of standardization, each electric vehicle has specific service needs and equipment.

The most common battery services at EV service centers / dealerships:

- Diagnosis and replacement of one or more faulty modules within a pack
- New module balancing after replacement
- Discharge of packs in the event of a collision
- Quick recharge (i.e., jumpstart) of hybrid batteries used to crank the vehicle

Other service applications include:

- Pack charge
- Pack service verification
- Warehouse monitoring and maintenance

Module balancing

Module balancing is one of the most common battery services performed today. To enable servicing of packs, the pack is split into serviceable modules. Therefore, if one module needs to be replaced, it is not necessary to replace the entire pack. Instead, the technician can identify the faulty module and replace it.

Module balancing is required after module replacement to charge or discharge the new module to match the SOC of the rest of the modules in the pack. If the modules are not balanced, battery performance and health issues may arise. Module balancing ensures optimized battery health, capacity, and performance.

Module balancing is currently performed at select dealerships and refurb centers and could apply to any type of vehicle with a high-voltage battery pack constructed with modules.

The equipment required depends on the vehicle and battery architecture. Some examples of commonly required equipment: battery lift (depending on vehicle/battery architecture), scan tool, personal protective equipment (PPE), pack adhesive, and pack service verification equipment.

High-level steps for performing a module balance service:

1. Vehicle comes into service center with a diagnostic trouble code (DTC); for example:
    a. Lost range.
    b. Service light on the dash.

2. Diagnostic information is pulled from the vehicle via OBD-2 scan tool (or wireless communication).
    a. Battery management system (BMS) on the pack monitors components within the pack (modules and cells).
    b. Some OEMs will have more diagnostic decision-making; others will provide streams of information and require the technician to make the diagnostic decisions (with flags on measurements outside of normal parameters).

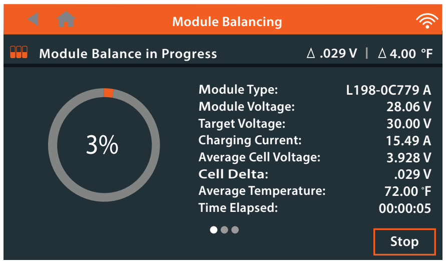
3. The pack is removed from the vehicle. Technician will:
    a. Place vehicle on lift.
    b. Place battery lift under vehicle.
    c. Disconnect battery.
    d. Lower battery onto battery lift.
    e. Move battery to wherever battery service will take place.

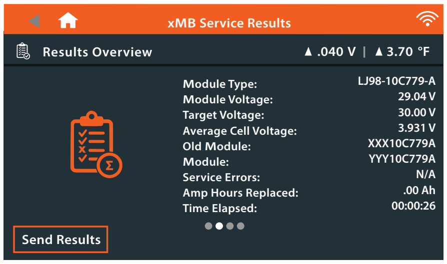
4. The pack is opened, which can take more than 2 hours. Many packs require wedges to open; some may require specific tools.
    a. Remove bolts and cut adhesive.
    b. Clean off adhesive ahead of regluing.

5. The potential defective module is removed.
    a. This may require the removal of other modules.
    b. Connect to the sense leads (disconnect communication harness-low voltage from battery, and connect module balancer cables to battery).
    c. Measure cell voltage and acquire thermistor readings directly from battery with module balancer. Compare with scan tool readings.
        i. If consistent, then replace module.
        ii. If inconsistent, then diagnose BECM or harness.

6. Order a module (if it hasn't been ordered already).

7. Balance the new module.
    a. Connect module balancer to the module terminal and the cell connection.
    b. Set the target voltage based on the scan tool assessment or from the module balancer.
    c. Using the module balancer, charge/discharge the module to match the SOC of the other modules on the pack.





8. Install the new module and close the pack.
    a. Connect the bus bar.
    b. Test the pack.
    c. Bolt the lid/top of the battery.
    d. Re-apply adhesive.
    e. Test to ensure seal is made.

9. Re-install the pack into the vehicle.

Pack discharge

Another common battery service application is pack discharge. This service removes the charge from the entire pack at one time for safe shipment, handling, or storage. In collision events, it is vital to remove the power from the battery as quickly as possible to prevent unintended energy leakage. Additionally, some OEMs and heavy duty fleets have implemented centralized battery pack service models. These service models require the battery pack to be shipped out. Due to regulatory restrictions (which vary by country), as well as general safety guidance, the battery pack should be discharged prior to shipment.

Pack discharge is currently performed at select dealerships as well as roadside, refurb, pack fulfillment, and storage centers. Like module balancing, the pack discharge process and required equipment can vary depending on the vehicle and battery architecture. Equipment requirements include a pack discharger, cabling for HV connection, a battery lift, personal protective equipment (PPE), and pack service verification equipment.

Pack service verification

After any service is performed, it is vital to verify the service was performed correctly. Pack service verification ensures the pack is fully assembled and functional. It typically consists of a suite of tests that includes some of the following:

- Communication with a pack ECU
- Receiving all cell voltages and verifying against limits
- Receiving all temperature sensors and verifying against limits
- High-voltage relay check
- Discharge of pack to verify energy out and current sensor measurements
- Charge of pack to verify energy in and current sensor measurements
- Test of pack seal
- Test of coolant lines
- Isolation measurements within the pack
- Bus bar torque tests
- Pack-level AC-IR test
- Pack-level DC-IR test

Pack service verification ensures a safe high-voltage battery pack and hazard-free performance. It is performed at any battery pack service locations, including dealerships, refurb centers, pack fulfillment and storage centers, and on product lines.

The equipment required depends on the vehicle and battery architecture. Common equipment required includes a diagnostic tool, pressure tester, pack charger/discharger, module balancer, battery lift, and personal protective equipment (PPE).

BATTERY PACK
Service Verification

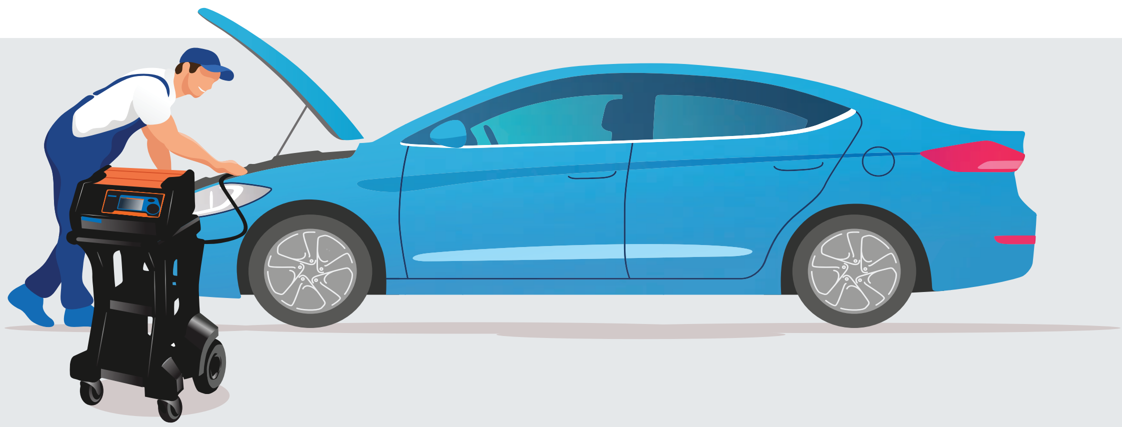
Hybrid rescue charge

Many hybrid electric vehicles (HEVs) do not have an external alternator and starter motor like traditional ICE vehicles. These two components have been replaced by a single generator/starter that is used to start the combustion engine, generate current, and charge the high-voltage battery. The high-voltage battery pack feeds the inverters that then send power to the electric motors, and the pack is recharged by the engine-driven generator and through regenerative braking.

If the high-voltage battery depletes below a certain state of charge (SOC), there is no way to start the vehicle until the battery is charged to a minimum level. Unlike a 12V battery, there are no posts so it can't be charged by connecting to it externally. Due to the amount of energy required to crank the combustion engine, the high-voltage battery can quickly deplete if the driver makes multiple attempts to start the engine. Example scenarios that can cause the high-voltage battery to run out of energy include use of the wrong fuel, a fuel injector issue, a depleted gas tank, or any other scenario that might cause the driver to repeatedly attempt to start the vehicle.

Once this occurs, specific HEV rescue charging equipment is required to resolve the issue. This equipment allows the technician to convince the battery that it is being charged so that the battery won't further deplete if it closes contactors. Then, the high-voltage battery charger charges the high-voltage battery pack to an acceptable threshold for the vehicle to start on its own.

This service is currently performed at select EV service centers and dealerships.



Pack charging

Refurb centers, pack fulfillment and storage centers, product lines, and even select service environments need to charge a full pack to a configured SOC. Pack charging allows for an entire pack to be brought up to a particular SOC (instead of individually balancing modules) before installing the pack into the vehicle.

Since the vehicle is often not present in these service environments, a pack charger that connects to the high-voltage terminal and communicates with the battery to monitor safe charging (e.g., proper cell voltage or temperatures) is required.

Warehouse monitoring and maintenance

When storing high-voltage batteries, it is important to ensure packs/modules are maintained at a healthy state of charge. If proper storage practices aren't followed, degradation and capacity reduction may result. See the "State of Health" section (4.2.) for more details on ideal temperatures and state of charge of high-voltage batteries in storage.

The equipment required for battery pack monitoring and maintenance can vary depending on the specific battery, but it often includes a pack charger/discharger, module charger/discharger, monitoring equipment, lifts, tables, and monitoring software. Common places that require warehouse monitoring and maintenance include refurb, pack fulfillment, and storage centers.

Isolation testing

Isolation testing is required to make sure the pack is not grounded in any way, and that there is no leakage to the vehicle. This is to prevent exposure to a lethal voltage. These types of measurements are continuously performed by the vehicle. The OEM-approved diagnostic tool can also command the vehicle to provide isolation reporting.

5.4. Most common service strategies in use

The battery pack's size, cost, and high voltage creates some serious service challenges. Consequently, different service strategies are employed across the globe.

Enlist "flying doctors": These battery service specialists travel to the stranded electric vehicle with the goal of getting it back on the road. This strategy can be an extremely costly affair. The costs add up very quickly with each service event: one or two technicians, repair tools, food, housing, transportation, a replacement vehicle for the customer. And the customer may not always be happy relinquishing their vehicle for a prolonged period of service time. It may be an option for OEMs with a small presence in the EV space, but it is not scalable for OEMs with plans to release many electric vehicle models in their product and service lineup.

Replace the pack: Another option is to simply replace and return the entire high-voltage pack. This strategy avoids pack-level service at dealer locations. However, the pack is the most expensive component on the vehicle and it is costly and difficult to ship due to its weight, which makes this option extremely expensive and time-consuming for the customer. It is also important to consider local regulations around shipping electric vehicle batteries. Many countries have strict laws around shipping hybrid and electric vehicle batteries. Like the "flying doctor" approach, this option can seem like a reasonable first step; however, it is not scalable for OEMs with goals to transition their product lineup to electric vehicle models.

Return the car: The "nuclear" option is to return the entire vehicle to a specialized OEM workshop where it can be serviced. This is by far the most expensive and time-consuming solution, and simply not practical for OEMs with long-term electric vehicle plans.

Service the pack: The most cost-effective and easily scalable service strategy takes place right in the dealership or service center. When talking about servicing the pack, there are four primary service applications: 1) Diagnose and replace pack and/or module issues within the pack; 2) Balance new modules after replacement; 3) Discharge packs in the event of a collision; 4) Quickly recharge (i.e., jumpstart) hybrid electric batteries used to crank the vehicle. With training and the right equipment, this option is a viable solution to many OEMs as owners are searching for a fast, safe, cost-effective, and scalable service strategy.

Chapter 6
The 12V Battery in All EVs

In EVs, all electrical vehicle systems outside of propulsion operate on a 12V system powered by an auxiliary battery. The 12V battery system powers numerous critical components, including door locks, ECUs, power steering, braking, and any other electrical function not related to propulsion. Therefore, if issues are detected with the 12V battery, the EV often will not allow the vehicle to be driven. Like ICE vehicles, the most common cause for roadside events with EVs is an issue with the 12V battery.

The 12V system is separate from the high-voltage system. One reason this system exists is for safety. Maintaining low voltage through consumer-facing features limits the possibility of human exposure to lethal voltage levels. Another reason is that legacy 12V vehicle systems and componentry have been accumulating throughout the evolution of vehicle electrical systems/functions and electrified components in both EVs and ICE vehicles. In short, the existing supply for the parts needed is high.

The functions of the 12V battery in EVs depend on the vehicle. For example, many HEVs rely on the 12V battery for support when starting the internal combustion engine and powering all other 12V systems within the vehicle. In BEVs, the 12V battery supports all non-propulsion loads, including safety and emergency components (as well as peak loads).

Traditional 12V battery diagnostic methods identify whether the battery can start an internal combustion engine. Since the function of the 12V battery in a BEV is different and the battery must have a minimum SOC for the vehicle to operate, the service required differs.

Depending on the vehicle architecture for how the batteries are used and charged in operation, there may be a need for regular maintenance charging of the battery. Diagnosing and servicing the 12V battery requires equipment capable of assessing the battery's ability to support the vehicle-specific function that the battery was designed to perform. For BEVs, it means testing for a different SOH function, not cranking capability. For HEVs and PHEVs, it means testing for both cranking and the capability to provide power for the other functions, including safety and computer systems. It is also vital that the battery exhibits a strong ability to accept charge so that it can maintain sufficient capacity to perform its critical functions.

Chapter 7
Impact of Vehicle Electrification in the Aftermarket

Over the last few years, the number of electric vehicles on the road in the US has nearly tripled to almost 1.8 million vehicles.* With this increase in electric vehicles comes the challenge of vehicle maintenance on a unique type of vehicle. While this is a hurdle for all service technicians and shops in the dealer and aftermarket sectors, the aftermarket has a larger disadvantage in that it must overcome product and safety training, cost of diagnostic equipment, and reduced preventative maintenance opportunities.

Service of traditional ICE vehicles has been a relatively even playing field between the OEMs and the aftermarket for many years. In general, maintenance is the same at both OE and aftermarket shops with under-hood components, electrical systems, brakes, tires, fluids, and 12V batteries. OE shops have the advantage in terms of equipment and technician skill level due to larger budgets, but the aftermarket makes up for this by offering lower pricing to consumers. With the move toward electric vehicles, the challenges for the aftermarket will accumulate faster than at the dealerships. First, in terms of training, the dealer technicians will get trained on their specific vehicles directly from the OEM. The OEM will also provide the shop with any specialized equipment needed for their electric vehicles. And lastly, warranty will keep maintenance almost exclusive to the dealerships for many years due to the longer guarantees on the high-voltage EV batteries.

* Desilver, Drew. "Today's electric vehicle market: Slow growth in U.S., faster in China, Europe." Pew Research. June 7, 2021. https://www.pewresearch.org/fact-tank/2021/06/07/todays-electric-vehicle-market-slow-growth-in-u-s-faster-in-china-europe/

In the aftermarket, training will have to be more widespread as shops must be prepared for any vehicle type that drives up to its bays. Specialized equipment will be more costly, as the aftermarket will need to service a wide array of vehicles as opposed to a single OEM. Some of this equipment might not exist yet, so aftermarket shops may need to improvise or wait to service these types of issues. Most aftermarket shops also rely on preventative maintenance activities to increase revenues. With electric vehicles, preventative maintenance opportunities are far less frequent. Electric vehicles require fewer fluid changes and have larger intervals between mechanical parts and 12V battery replacements.

The largest area of concern regarding electric vehicles is the battery due to its status as a significant safety hazard. Batteries in electric vehicles are normally lithium ion with voltages between 400V and 800V. These batteries can cause not only significant injuries to technicians but can also be substantial fire hazards at any time if not serviced correctly. Proper care must be taken not only when servicing the batteries but also when dealing with service near or around the battery. Aftermarket shops must invest time and effort into safety training and equipment not normally needed for servicing standard ICE vehicles.

Over the last several decades the aftermarket has continued to evolve itself within the vehicle market. Turning wrenches has turned into digital diagnostics. Now it's time for the aftermarket to change again as the world pushes toward electric vehicles.

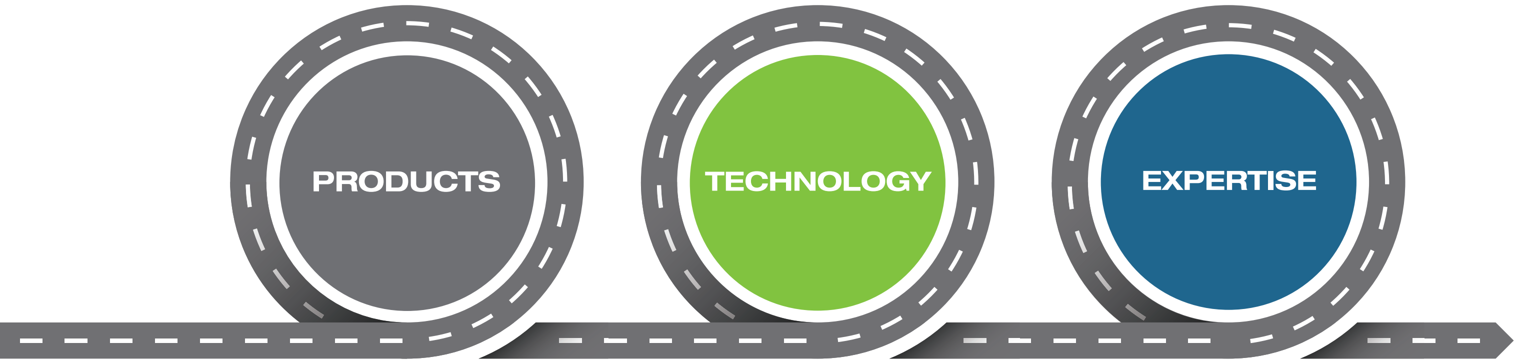
Conclusion

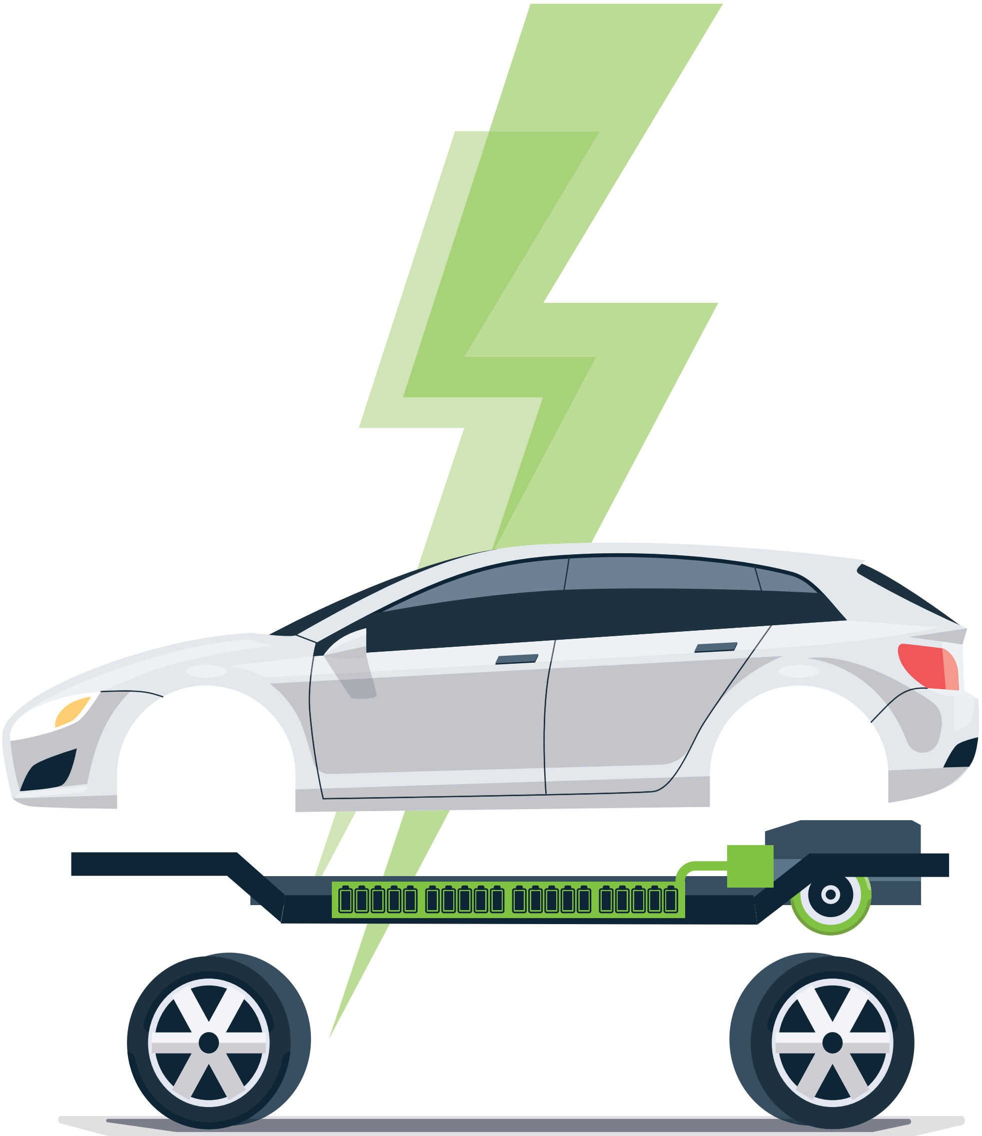
Anyone who deals directly with high-voltage EV batteries needs to be well trained in their service, maintenance, and safety. Whether you service, sell, or manufacture electric vehicles or the batteries that power them, you face an uphill battle before you can be fully equipped for the challenges ahead. Even if you only store or recycle EV batteries, you need a plan to get technicians up to speed. The transition to EV takes a lot of work, but you'll be helping to future-proof your business in a rapidly changing industry.

Fortunately, Midtronics is here to help. Over the past decade, Midtronics has rolled out dealer-level programs around the world, enabling technicians to perform services at the pack and module levels. Our module balancing, pack discharging, and rescue charging equipment is used in over 70% of EV battery service locations worldwide. And we have helped countless partners form strategies for their EV battery service, equipping their technicians with the tools and knowledge needed for exemplary service across the EV landscape.

You don't need to travel the EV road alone. Midtronics knows the path to EV battery service readiness. As global leaders in EV battery service, we have the products, technology, and expertise to partner with you along the journey.

Partner with Midtronics today and provide world-class EV service to your customers.





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