ELECTRIC AND HYBRID VEHICLE TECHNOLOGY

AUTOMOTIVE RECYCLERS ASSOCIATION®
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ROE – Recycled Original Equipment®

ARA UNIVERSITY

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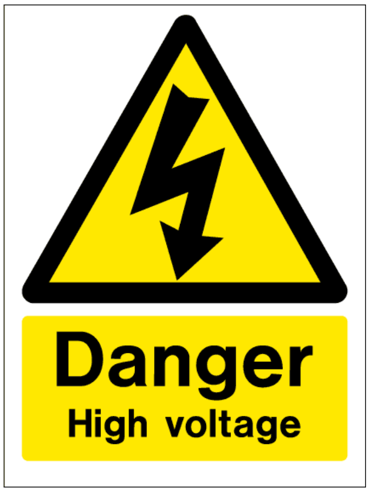
Forward

This guide for automotive recyclers has been developed to aid in the proper handling, storage and shipping of hybrid electric vehicles and their components, including high voltage battery packs. A valuable overview of hybrid and electric vehicle technology along with examples of various technologies and safe working practices are contained in this manual. In addition, various hybrid/electric vehicle dismantling topics such as hybrid high voltage battery disabling, battery removal and disassembly are included throughout this guide.

The selections and examples are intended to be additional resources for the auto recycler and NOT a replacement for Original Equipment Manufacturer (OEM) factory service information, official OEM safety procedures and accredited technician training. Hybrid and electric vehicles contain some of the most complex systems ever used in the automotive field.



Hybrid and electric vehicles have components and wiring containing hundreds of volts and hundreds of amps of current in both DC and AC forms. For that reason, these vehicles can be hazardous or even lethal for service and recycling technicians who do not follow prescribed safety procedures.

Due to the importance of safety, the unabridged service documents and official safety procedures found in factory OEM service information always take precedence over aftermarket service information such as contained in this guide. Therefore, if you cannot locate the information you are looking for regarding hybrid electric and electric vehicles or have any doubts about a service or safety procedure, always consult the official factory OEM information. OEM service information is readily available on-line for reasonable subscription fees on a variety of sites.

Another challenge experienced by auto recyclers is the need to keep up and comply with various local, national, and international regulations concerning workplace safety, environmental issues, and proper shipping procedures. For this reason, always consult with the proper governmental organizations to ensure your recycling operation is up to date regarding the unique concerns presented by hybrid and electric vehicles.

Common EV Acronyms and other Acronyms used in this guide

Acronym	Meaning	Acronym	Meaning
A	Amps	LED	Light Emitting Diode
AC	Alternating Current	LEV	Low Emissions Vehicle
AGM	Absorbent Glass Material (12v battery design)	Li-Ion	Lithium-Ion
BAS	Belt Alternator Starter	mA	Milliamp
BCM	Body Control Module	MCB	Miniature Circuit breaker
BEV	Battery Electric Vehicle	MG	Motor Generator
Co SHH	Control of Substances Hazardous to Health	MIL	Malfunction Indicator Light
CPD	Continual Professional Development	mV	Millivolt
CVT	Continuously Variable Transmission	NiMH	Nickel metal Hydride
DC	Direct Current	OBD	On Board Diagnostics
DLC	Diagnostic Link Connector	OEM	Original Equipment Manufacturer
DMM	Digital Multi Meter	PAS	Power Assisted Steering
DSG	Direct Shift Gearbox	PEV	Pure Electric Vehicle
DTC	Diagnostic Trouble Code	PHEV	Plug-In Hybrid Electric Vehicle
ECU	Electronic Control Unit	PPE	Personal Protective Equipment
EPA	Environmental Protection Agency	PTC	Positive Temperature Coefficient
E-REV	Extended Range Electric Vehicle	R	Resistance (ohms)
EV	Electric Vehicle	RCD	Residual Current Device
FCV	Fuel Cell Vehicle	RCBO	Residual Current Breaker with Overcurrent
FWD	Front Wheel Drive	RMS	Root Mean Square
HAS	Hydraulic Actuation System	RPM	Revolutions Per Minute
HEV	Hybrid Electric Vehicle	RWD	Rear Wheel Drive
HSE	Health and Safety Executive	SOC	State of Charge
IATA	International Air Transport Association	SOH	State of Health
ICE	Internal Combustion Engine	UN	United Nations
IDIS	International Dismantling Information System	ULEV	Ultra-Low Emissions Vehicle
IMI	Institute of the Motor Industry	V	Volts
IGBT	Insulated Gate Bi-Polar transistor	VIN	Vehicle Identification number
IMA	Integrated Motor Assist (Honda)	ZEV	Zero Emissions Vehicle
ISG	Integrated Starter Generator	4x4	Four Wheel Drive
ISO	International Standards Organization	4WD	Four Wheel Drive
KERS	Kinetic Energy Recovery System		

Contents

1. Introduction

1.1. Disclaimer

This information is a training package to make you aware of the technologies and issues associated with high voltage vehicles. The information presented here is to the best of our knowledge correct and appropriate for technicians who may need to work on high voltage vehicles. However, the authors of the materials cannot be held responsible for actions of individuals or changes in design and methods. The following guidance **MUST** therefore be always followed:

NEVER ATTEMPT TO SERVICE OR DISMANTLE A HYBRID OR ELECTRIC VEHICLE (HEV/ EV) WITHOUT THE PROPER TRAINING AND SAFETY EQUIPMENT

ALWAYS REFER TO MANUFACTURER'S INFORMATION BEFORE CARRYING OUT ANY WORK

Working on high voltage vehicles is not dangerous if you are trained and follow the correct procedures. EVs have a range of sophisticated systems designed to keep the passengers and technicians safe, even in the event of a serious crash or during complex work.

1.2. How to use this material

1.2.1. Introduction

This resource is designed to help you learn about electric and hybrid vehicles in general, and the issues associated with dismantling. We recommend that you study it in sections and only move on to the next when you understand what you have covered so far.

It is an exciting change to our industry so you should find it interesting. However, even more important is that learning about how to work with high voltage vehicles safely – could save your life!

Figure 1 Third generation Prius battery pack (Source: Toyota Media)

1.3. Overview

1.3.1. Dismantling and recycling

Hybrid and electric vehicles are now mainstream. This means that high voltage battery packs, inverters, converters, special cooling systems, complex braking systems and electric motor generators are now common technologies. This learning resource will help technicians in the recycling trade, both those with limited experience in handling and disassembling hybrid vehicles, and those who have yet to work on a hybrid, gain essential knowledge on safety, theory of operation and practical procedures.

In the USA, the figure is around 3% but this is growing rapidly, particularly in areas where there is strong ‘green’ legislation. In the UK (United Kingdom) vehicles with high voltage components now make up about 8% of the total (2020) and this is climbing as new legislation comes into force. This means automotive recyclers will be seeing more and more hybrids in their yards over the next several years.

From a standpoint of safety, automotive recyclers are accustomed to various hazards associated with internal combustion engine (ICE) vehicles. Chemicals, flammable liquids, pressurized hydraulic systems, and compressed coil springs are just a few of those hazards recyclers already safely encounter on a daily basis.

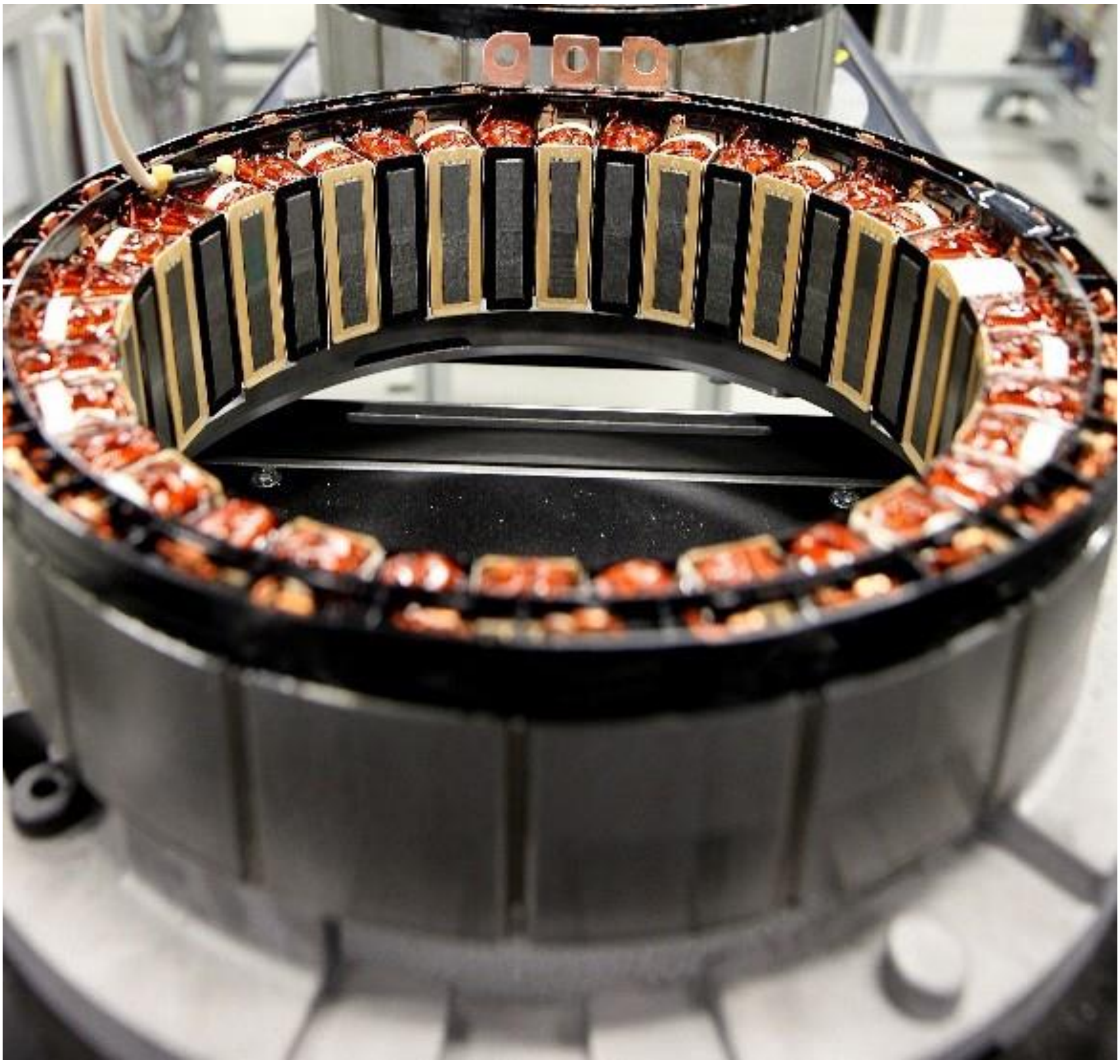


Figure 2 EV motors under construction

All hybrid and electric vehicles use components and systems that contain high voltages, which can injure or even kill an inexperienced and untrained technician. This guide will help dismantlers learn how to stay safe when working on or around hybrid and electric vehicles and their associated components. Hybrid and electric vehicles are not just another new challenge; they are a potential source of new revenue for the recycling industry.

1.3.2. Types of electric vehicle

Electric Vehicle (EV) usually refers to any vehicle that is powered, in part or in full, by a battery that can be directly plugged into the mains. Strictly speaking it refers to a vehicle only powered by a battery but take care as many tend to use EV as the 'catch all' phrase.

Pure-Electric Vehicles (PEVs) are electric vehicles powered only by a battery. Sometimes BEV is used meaning battery electric vehicle. Currently most manufacturers, of standard performance cars, offer pure-electric vehicles with a range in excess of 100 miles.

Figure 3 Tesla Model S charging – pure EV

Plug-In Hybrid Electric Vehicles (PHEVs) have an internal combustion engine (ICE) but also a battery range in excess of 15 miles. After the battery range is utilized, the vehicle reverts to the benefits of full hybrid capability (utilizing both battery and ICE power) without compromising the range.

Figure 4 Volkswagen Golf GTE – PHEV

Extended-Range Electric Vehicles (E-REVs) are similar to PEVs. However, range is extended by an ICE driven generator providing many additional miles of mobility. With an E-REV, the propulsion is always electric, unlike a PHEV where the propulsion can be electric or full hybrid.

Figure 5 BMW i3 – E-REV Option

Hybrid Electric Vehicles (HEVs) where it is not possible to charge the battery externally, were the first high voltage cars in common use.

Figure 6 Toyota Prius – HEV (Source: Toyota Media)

A phrase used in connection with pure EVs is 'range anxiety.' This refers to the fear about the distance a pure EV can drive, and the worry that the battery charge may not be enough to reach the destination.

An interesting point to note, however, is that the average individual journeys are as follows:

- UK is less than 10 miles, with the average total daily distance travelled about 25 miles
- Europe, more than 80% of drivers cover less than 63 miles in a typical day
- USA the average journey length is in the region of 40 miles.

All these distances can therefore be achieved using pure-electric cars and many journeys can be made with plug-in hybrid or extended-range electric cars without using the internal combustion engine.

Figure 7 London electric taxi on charge

Table 1 Summary of EVs and HEVs and their alternative names

Electric Vehicle/Car (EV), Electrically Chargeable Vehicle/Car	Generic terms for a vehicle powered, in part or in full, by a battery that can be plugged into the mains
Pure-EV, Pure-Electric Car, Vehicle, All Electric, Ba9ery Electric Vehicle (BEV), Fully Electric	A vehicle powered only by a battery charged from mains electricity. Currently, typical pure-electric cars have a range of 100-200 miles
Plug-In Hybrid Electric Vehicle (PHEV), Plug-In Hybrid Vehicle (PHV)	A vehicle with a plug-in battery and an internal combustion engine (ICE). Typical PHEVs will have a pure-electric range of 10 to 30 miles. After the pure-electric range is used up, the vehicle reverts to the benefits of full hybrid capability
Extended-Range Electric Vehicle (E-REV), Range Extended Electric Vehicle (RE-EV)	A vehicle powered by a battery with an ICE powered generator on board. E-REVs are like pure-EVs, but range is extended by an on-board generator. With an E-REV the vehicle is still always electrically driven and is known as a series hybrid
Hybrid Electric Vehicles (HEV), Full/ Normal/Parallel/Standard hybrid	A hybrid vehicle is powered by a battery and/or an ICE. The power source is selected automatically by the vehicle, depending on speed, engine load and battery charge. This battery cannot be plugged in so charge is maintained by regenerative braking supplemented by ICE generated power
Mild Hybrid	A mild hybrid vehicle cannot be plugged in or driven solely on battery power. However, it does harvest power during regenerative braking and uses this during acceleration. Some mild hybrids now use 48V technology
Micro Hybrid	A micro hybrid normally employs a stop-start system and regenerative braking which charges the 12V battery
Stop-start Hybrid	A stop-start system shuts off the engine when the vehicle is stationary. An enhanced starter motor is used to support the increased number of engine starts
Alternatively, Fueled Vehicle (AFV)	Any vehicle which is not solely powered by traditional fuels (i.e. petrol/gasoline or diesel) is referred to as alternative fuel
Internal Combustion Engine (ICE)	Petrol/gasoline or diesel engine, as well as those adapted to operate on alternative fuels
Electric quadricycles	This is a four-wheeled vehicle that is categorized in a similar way to a moped or three-wheeled motorcycle
Electric motorcycles	Battery only, so full electric drive

2. Safe working, tools, and hazard management

2.1. General safety precautions

2.1.1. Introduction

Safe working practices in relation to all automotive systems are essential, for your safety as well as that of others. It does not matter if you are repairing, tuning, dismantling, restoring, painting, servicing, I could go on! Unless you take precautions, and are trained to know what you are doing, there are serious risks.

When working on high voltage systems, it is even more important to be trained and know what you are doing. However, you only must follow three simple rules to be safe.

- Use your common sense – do not fool around
- Only work unsupervised on high voltage vehicles if you are fully trained
- If in doubt – ask for help.

The following section lists some particular risks when working with electricity or electrical systems, together with example methods for reducing them. This is known as risk assessment.

2.1.2. High energy safety

Electric vehicles (pure or hybrid) use high voltage batteries so that energy can be delivered to a drive motor or returned to a battery pack in a very short time. The Honda Insight system, for example, used a 144V battery module to store re-generated energy. The Toyota Prius originally used a 273.6V battery pack but this was changed in 2004 to a 201.6V pack. Voltages of 400V are now common and some are up to 800V so clearly, there are electrical safety issues when working with these vehicles.

Figure 8 High voltage (HV) battery pack under the floor (Source: Volkswagen Media)

EV batteries and motors have high electrical and/or magnetic potential that can severely injure or kill. It is essential that you take note of all the warnings and recommended safety measures outlined by manufacturers and in this and other sources of information. Any person with a heart pacemaker or any other electronic medical devices such as an insulin pump, should not work on an EV motor since the magnetic effects could be dangerous.

An additional danger of the very high strength magnets used in EV motors is trapping (and possibly losing!) fingers, for example, when stripping down or rebuilding the drive motor. The strong magnets in the rotor can snap into place inside the stator without warning and at great force and speed. Special clamps and pullers should be used to prevent this.

Most of the high voltage components are combined in separate units. These are located behind the rear seats, under the bonnet/hood or under the luggage compartment floor (or the whole floor on some cars). The battery unit is usually a metal box that is completely closed with bolts. A battery module switch, if used, may be located under a small secure cover on the power unit. The electric motor is located between the engine and the transmission or as part of the transmission on a hybrid. On a pure-EV, it is the main driving component. A few vehicles use wheel motors.

Figure 9 Volvo hybrid car (Source: Volvo Media)

The electrical energy is conducted to or from the motor via thick orange wires. If these wires have to be disconnected, you must SWITCH OFF or DE-ENERGIZE the high voltage system. This will reduce the risk of electric shock or short circuit of the high voltage system. More about how to do this later.

Figure 10 Hybrid engine (Source: Nissan Media)

2.1.3. IMI TechSafe™

The IMI TechSafe™ professional registration scheme is designed to ensure complex automotive technologies are repaired safely and that technicians work safely – particularly in the UK, but it is just as effective internationally. To be added to the register, a technician must: successfully meet specified standards, join the IMI Professional Register, and complete specified annual CPD to ensure current competency is maintained.

Figure 11 IMI TechSafe process

There are several parts of the Electricity at Work Regulations 1989[1] (UK) that apply to working on high voltage vehicles.[2] However, the following are key:

> *Regulation 3(1)(a) states that: "it shall be the duty of every– (a)employer and self-employed person to comply with the provisions of these Regulations as far as they relate to matters which are within his[/her] control. 3(2)(b) reiterates the duty for employees.*
>
> *Regulation 16 states that: "No person shall be engaged in any work activity where technical knowledge or experience is necessary to prevent danger or, where appropriate, injury, unless he possesses such knowledge or experience, or is under such degree of supervision as may be appropriate having regard to the nature of the work."*
>
> *Regulation 29 states that: "In any proceedings for an offence consisting of a contravention of regulations 4(4), 5, 8, 9, 10, 11, 12, 13, 14, 15, 16 or 25, it shall be a defense for any person to prove that he took all reasonable steps and exercised all due diligence to avoid the commission of that offence."*

For EVs this will fully meet the requirements that anyone working on high voltages must be competent (Electricity at Work Regulations 1989). ADAS, and other areas will be covered in a similar way. Technology safe, means technician safe means customer safe.[3]

Figure 12 IMI TechSafe logo

2.1.4. General safety guidance

Working on high voltage vehicles is perfectly safe if you are trained and you follow instructions. The processes are usually split into these four areas:

- Before maintenance
- During work

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[1] HSE Guidance: www.hse.gov.uk/pubns/books/hsr25.htm

[2] The definition of high voltage can be confusing, when comparing vehicles to national grid powerlines for example. For vehicle use, any figure in excess of 30V AC and 60V DC is considered to be high voltage, www.hse.gov.uk/mvr/topics/electric-hybrid.htm

[3] www.theimi.org.uk

- Interruptions to work
- After work

More on these stages later.

Figure 13 High voltage battery connections (Source: Toyota Media)

I repeat, because it is important: Working on hybrid and electric vehicles is **not** dangerous **IF** the previous guidelines and **manufacturers' procedures** are followed. Before starting work, check the latest information – DON'T take chances. Dying from an electrical shock is not funny.

Figure 14 High voltage cables are always orange

Crash safety: Electric vehicles are tested to the same high standards as other vehicles currently on our roads.

Figure 15 Crash test (Source: Marcel Langthim, Pixabay)

Pedestrian safety: The quietness of EVs is a benefit but can pose a threat to sight and hearing-impaired people, particularly at low speeds.

2.1.5. General risks and their reduction

The following table lists some identified risks involved with working on ALL vehicles. The table is by no means exhaustive but serves as a good guide.

Table 2 Risks and their reduction

Identified risk	Reducing the risk
Electric shock 1	Voltages and the potential for electric shock when working on an EV mean a high-risk level – see later sections for more details.
Electric shock 2	Ignition HT is the most likely place to suffer a shock when working on an ICE vehicle; up to 40 000 Volts is quite normal. Use insulated tools if it is necessary to work on HT circuits with the engine running. Note that high voltages are also present on circuits containing windings due to back emf as they are switched off, a few hundred volts is common. Mains supplied power tools and their leads should be in good condition and using an earth leakage trip is highly recommended. Only work on HEV and EVs if trained in the high voltage systems.
Battery electrolyte	In lead-acid batteries, the sulphuric acid is corrosive so always use good PPE. In this case, overalls and if necessary, rubber gloves. A rubber apron is ideal, as are goggles if working with this type of battery on a regular basis. Electrolytes used in high voltage lithium or nickel-based batteries can be toxic. Wear suitable PPE for dismantling.
Raising or lifting vehicles	Apply brakes and/or chock the wheels and when raising a vehicle on a jack or drive-on lift. Only jack under substantial chassis and suspension structures. Use axle stands in case the jack fails
Running engines	Do not wear loose clothing, good overalls are ideal. Keep the keys in your possession when working on an engine to prevent others starting it. Take extra care if working near running drive belts
Exhaust gases	Suitable extraction must be used if the engine is running indoors. Remember it is not just the CO that might make you ill or even kill you; other exhaust components could cause asthma or even cancer

Moving loads	Only lift what is comfortable for you; ask for help if necessary and/or use lifting equipment. As a general guide, do not lift on your own if it feels too heavy!
Short circuits	Use a jump lead with an in-line fuse to prevent damage due to a short when testing. Disconnect the battery (earth lead off first and back on last) if any danger of a short exists. A very high current can flow from a vehicle battery, it will burn you as well as the vehicle
Fire	Do not smoke when working on a vehicle. Fuel leaks must be attended to immediately. Remember the triangle of fire – (Heat / Fuel / Oxygen) – do not let the three sides come together
Skin problems	Use a good barrier-cream and/or latex gloves. Wash skin and clothes regularly

2.2. High voltage safety precautions

2.2.1. Introduction

There are a number of different specifications for low and high voltage, and this can become confusing! For this reason, allow me to state the obvious:

The voltages (AC or DC) used on electric vehicles can kill, have killed, and will kill again.

2.2.2. High energy cables and components

Electric vehicles use high voltage batteries so that energy can be delivered to a drive motor or returned to a battery pack efficiently in a very short time. It is important to be able to correctly identify high energy cabling and associated components. This is done by:

- coloring
- warning symbols
- warning signs.

The following pictures shows some typical warning labels:

Figure 16 Danger sticker Figure 17 Warning labels

2.2.3. High voltages

The United Nations (UN) document: Addendum 99: Regulation No. 100[4] Revision 2, is called: Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train. It is a large document but the specific regulation of interest here is this one:

[4] http://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2013/R100r2e.pdf

- **2.17. "High Voltage" means the classification of an electric component or circuit if its working voltage is > 60 V and ≤ 1500 V DC or > 30 V and ≤ 1000 V AC root mean square (rms).**

Figure 18 United Nations (UN) logo

Low or high voltage is a relative term, the definition varies by context. Different definitions are used in electric power transmission and distribution, and in the electronics industry. Electrical safety codes define low voltage circuits that are exempt from the protection required at higher voltages. Therefore, it becomes confusing! For this reason, allow me to state the obvious: **The voltages (AC or DC) used on electric vehicles can kill, have killed, and will kill again.**

To reiterate, for the purpose of the work we do on vehicles (DC):

- **Low voltage means the 12 or 24V** (or even 48V) systems
- **High voltage is 60V or more** and refers to the drive battery, motor, and other associated components.

Figure 19 Caution!

2.2.4. Electric shock

The three basic factors that determine what kind of shock you experience when current passes through the body are:

- size of the current
- duration
- frequency.

Direct currents (DC) have zero frequency, as the current is constant. DC causes a single continuous contraction of the muscles compared with AC current, which will make a series of contractions depending on the frequency. In terms of fatalities, both kill but more milliamps are required of DC than AC current at the same voltage. Either AC or DC currents can cause fibrillation of the heart at high enough levels. This typically takes place at 30 mA of AC (rms, 50–60 Hz) or 300–500 mA of DC.

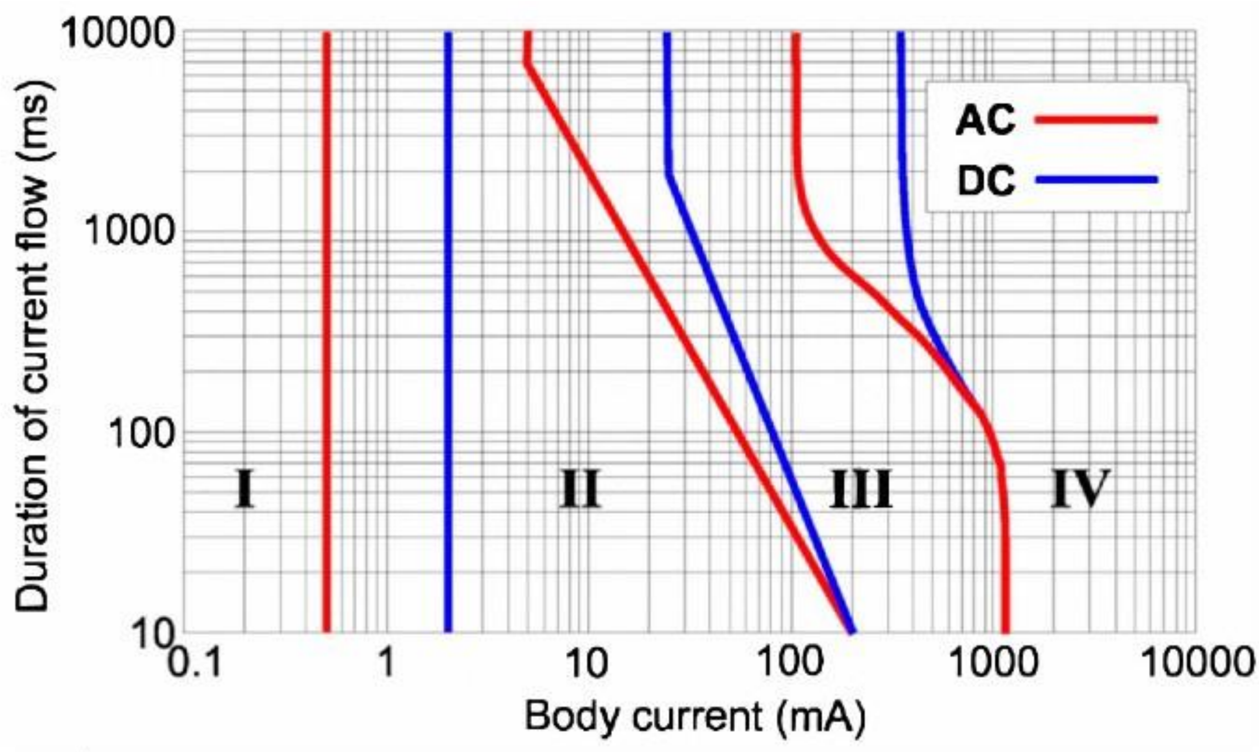


Figure 20 Characteristic curves of body current flow[5]

The graph shown above is divided into four regions based on the effects on the human body:

I. No effect
II. A little pain but no dangerous effects
III. Muscular contraction and respiratory compromise, which are reversible
IV. Critical effects such as ventricular fibrillation

Facts about electric shock

- It is the **magnitude** (size/amount) of current and the duration that produces effect. That means a low-value current for a long duration can be fatal. The approximate current/time limit for a victim to survive at 500 mA is 0.2 seconds and at 50 mA is 2 seconds.

- The voltage of the electric supply is only important because it determines the current. Current = Voltage / Resistance, so **body resistance** is also an important factor. Sweaty or wet persons have a lower body resistance and could be fatally electrocuted at lower voltages, because more current will flow.

- **Let-go current** is the highest current at which the subject can release a conductor. Above this limit, involuntary clasping of the conductor occurs: it is 22mA in AC and 88mA in DC.

- **Severity** of electric shock depends on body resistance, voltage, path of the current, area of contact and duration of contact.

- **Heating** due to resistance can cause extensive and deep burns because damaging temperatures are reached in a few seconds.

[5] Hirose, K.; Tanaka, T.; Babasaki, T.; Person, S.; Foucault, O.; Sonnenberg, B.J. Grounding concept considerations and recommendations for 400VDC distribution system. In Proceedings of the IEEE 33rd International Telecommunications Energy Conference (INTELEC), Amsterdam, The Netherlands, October 9-13, 2011; pp. 1–8.

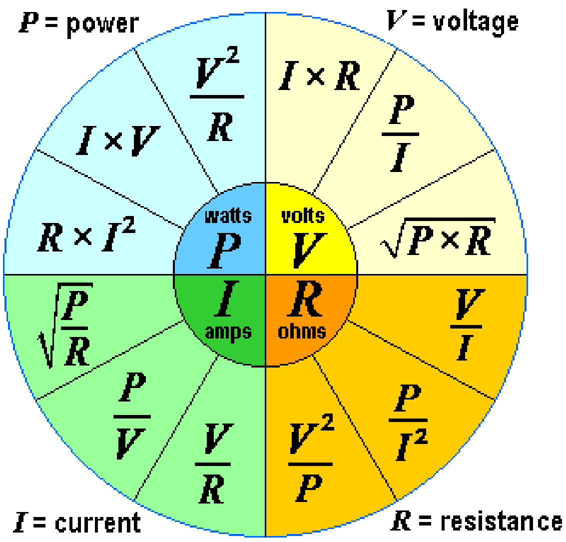


Figure 21 Calculating electrical values

An arc flash is the light and heat produced from an electric arc supplied with sufficient electrical energy to cause substantial damage, harm, fire or injury. Note that welding arcs can turn steel into a liquid with an average of only 24V DC. When an uncontrolled arc forms at very high voltages, arc flashes can produce deafening noises, supersonic concussive-forces, super-heated shrapnel, temperatures far greater than the Sun's surface, and intense, high-energy radiation capable of vaporizing nearby materials.

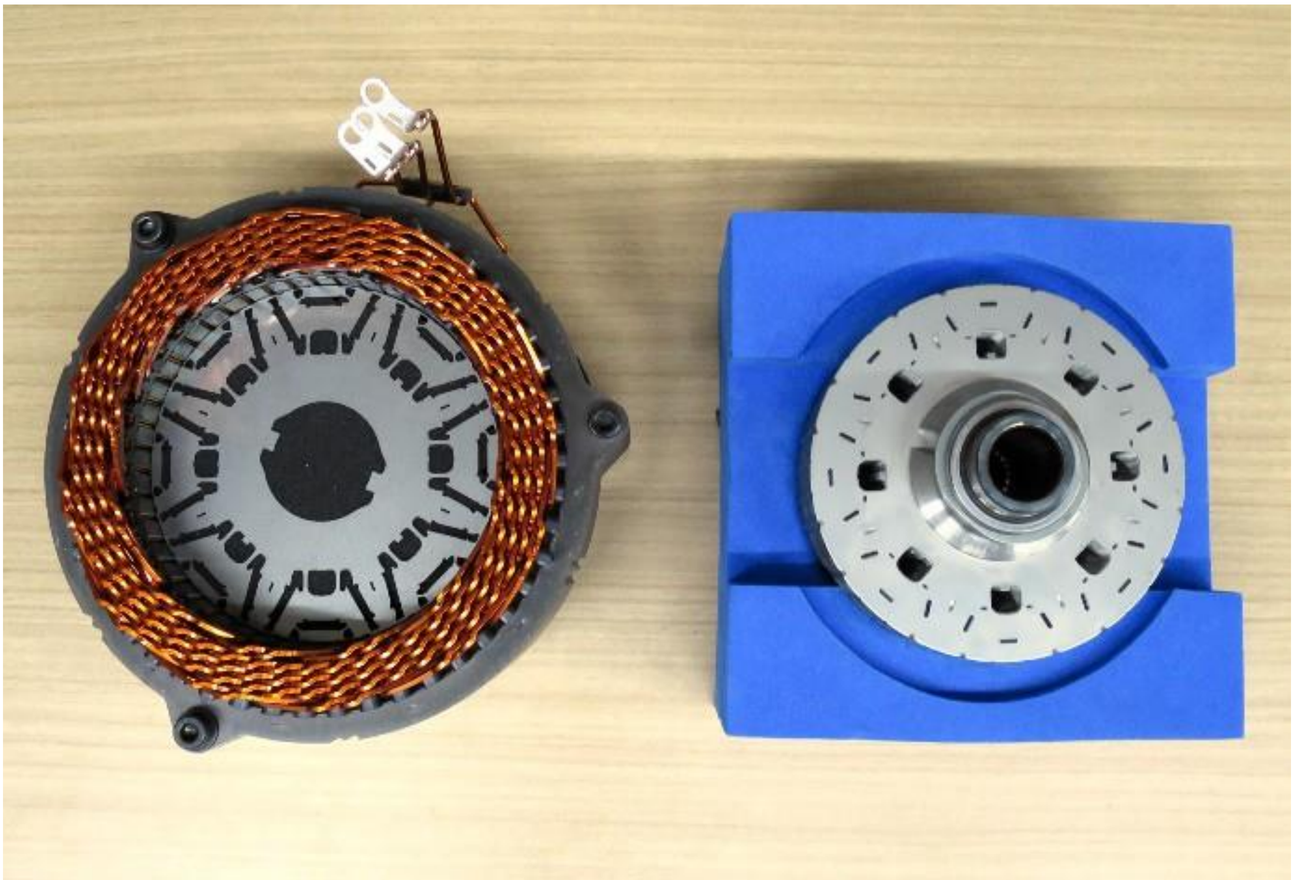


Figure 22 Motor with high strength magnetic rotor (Source: Toyota Media)

In addition to the potential for electric shock, careless work on electrical systems (at any voltage) can result in:

- Heat/fire

- Explosion
- Chemical release
- Gases/fumes.

2.2.5. Personal protective equipment

In addition to the normal automotive related personal protective equipment (PPE), the following are also recommended for work on high voltage systems:

- overalls with non-conductive fasteners
- electrical protection gloves
- protective footwear
- eye protection (when necessary)

Electrical safety gloves are categorized by the level of voltage protection they provide. The voltage breakdown is as follows for gloves appropriate to EV work:

- Class 00 is rated at a maximum use voltage of 500V AC/750V DC and proof tested to 2,500V AC/10,000V DC
- Class 0 is rated at a maximum use voltage of 1,000V AC/1,500V DC and proof tested to 5,000V AC/20,000V DC
- Class 1 is rated at a maximum use voltage of 7,500 volts AC/11.250V DC and proof tested to 10,000V AC/40,000V DC

Class 0 is recommended because EV voltages are tending to increase.

Figure 23 Class 00 electrical gloves

Gloves should be inspected for tears, holes, cuts and other defects before each use. Also, check for any swelling, which can be caused by contamination with petroleum products. An air test should be performed along with inspections for insulating gloves. The glove is filled with air and then checked for leakage. If the gloves show any signs of defects, they should be taken out of service.

Figure 24 Electrical glove inflation test

2.2.6. Additional risks

EVs introduce hazards into the workplace in addition to those normally associated with the dismantling, repair and maintenance of vehicles, roadside recovery and other vehicle related activities. These include:

- the presence of high voltage components and cabling capable of delivering a fatal electric shock
- the storage of electrical energy with the potential to cause explosion or fire
- components that may retain a dangerous voltage even when a vehicle is switched off
- electric motors or the vehicle itself that may move unexpectedly due to magnetic forces within the motors
- manual handling risks associated with battery replacement
- the potential for the release of explosive gases and harmful liquids if batteries are damaged or incorrectly modified
- the possibility of people being unaware of vehicles moving as when electrically driven they are silent in operation
- the potential for the electrical systems on the vehicle to affect medical devices such as pacemakers and insulin controllers.

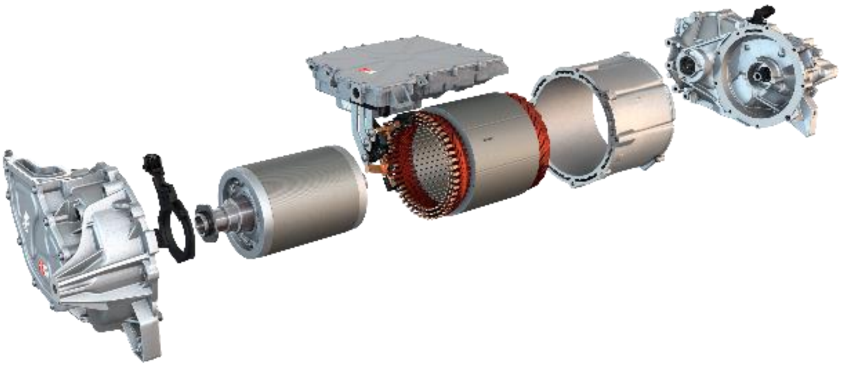


Figure 25 EV motors are very heavy and use high strength magnets (Source Volkswagen Media)

Control of substances hazardous to health (CoSHH) or similar local regulations, with regard to hazardous battery chemicals and compounds, exist to assist with how to deal with leakage from battery packs.

Figure 26 Chevrolet Bolt battery locations (Source: Chevrolet Media)

Batteries are in protective cases and even if the case is damaged, they will not leak a significant amount of electrolyte. Nickle-metal-hydride (NiMH) and lithium-ion (Li-ion) are dry cell batteries and will only produce a few drops per cell if crushed. Some models may leak battery coolant, and this should not be confused with electrolyte.

2.2.7. Protection devices

The first line protection against high voltages are **direct** methods such as:

- enclosure (keeping things covered)
- insulation (always orange colored)
- location (positions to prevent accidental tampering).

The four main **indirect** methods to protect against high voltages and excess current flow are:

- Fuses
- MCBs
- RCDs
- RCBOs

These four methods will now be outlined in more detail.

A fuse is a deliberate weak link in an electrical circuit acts as a sacrificial device to provide overcurrent protection. It is a metal wire or strip that melts when too much current flows through it and therefore, breaks the circuit. Short circuits, overloading, mismatched loads, or device failure are the main reasons for excessive current.

Figure 27 Miniature blade fuse

An MCB (miniature circuit breaker) does the same job as a fuse in that it automatically switches off the electrical circuit during an overload condition. MCBs are more sensitive to overcurrent than fuses. They are quick and easy to reset by simply switching them back on. Most MCBs work by either the thermal or electromagnetic effect of overcurrent. The thermal operation is achieved with a bimetallic strip. The deflection of the bimetallic strip as it is heated by excess current releases a mechanical latch and opens the circuit. The electromagnetic type uses magnetism to operate the contacts. During short circuit condition, the sudden increase in current, causes a plunger to move and open the contacts.

An RCD (residual current device) is designed to prevent fatal electric shock if a live connection is touched. RCDs offer a level of personal protection that ordinary fuses and circuit-breakers cannot provide. If it detects electricity flowing down an unintended path, such as through a person who has touched a live part, the device will switch the circuit off very quickly, significantly reducing the risk of death or serious injury.

Figure 28 RCD circuit breaker

An RCBO (residual current breaker with overcurrent) is a type of circuit breaker designed to protect life in the same way as the RCD (Residual Current Device), but it also protects against an overload on a circuit. An RCBO will normally have two circuits for detecting an imbalance and an overload but use the same interrupt method.

2.3. Safe work process

2.3.1. Work categories

Four categories of work have been identified. These are:

1. Valeting, sales, and other lower risk activities
2. Incident response including emergency services and vehicle recovery
3. Maintenance and repair excluding high voltage electrical systems
4. Working on high voltage electrical systems.

Professional dismantlers could be involved in all four of these categories.

Based on information from HSE[6], these categories are outlined below with the suggested primary controls.

1. Valeting, sales, and other lower risk activities

Remote operation keys that only need to be close to the vehicle for the vehicle to be powered up should be kept away from vehicles. This is to prevent the vehicle from accidentally moving. People who move these vehicles around the workplace should be aware that others may not hear it approaching them. Similarly, people who work around EVs should be aware that they may move without warning. Pressure washing has the potential to damage high voltage electrical components and cables. High voltage cables are usually colored orange. Refer to guidance from manufacturers before valeting in any under body areas including the engine bay.

Figure 29 Valeting

2. Incident response including emergency services and vehicle recovery

Vehicles should be visually checked for signs of damage to high voltage electrical components or cabling (usually colored orange). Consider whether the integrity of the battery is likely to have been compromised. Shorting or loss of coolant may present ignition sources in the event of fuel spillage. If the vehicle is damaged or faulty, and if safe to do so, isolate the high voltage battery system using the isolation device on the vehicle. Refer to manufacturer's instructions for guidance. During any recovery onto a recovery vehicle, the remote operation key should be removed to a suitable distance and the standard 12/24V battery disconnected to prevent the vehicle from being activated/started. Have access to reliable sources of information for specific vehicle types. For example, mobile data terminals used by fire and rescue services or by reference to manufacturer's data. Avoid towing EV vehicles unless it can be determined that it is safe to do so. Dangerous voltages can be generated by movement of the drive wheels.

Figure 30 Interesting recovery job!

[6] h8p://www.hse.gov.uk

3. Maintenance and repair excluding high voltage electrical systems

Refer to vehicle specific sources of information from the manufacturer and trade bodies to identify precautions necessary to prevent danger. Remote operation keys should be kept away from the vehicle to prevent any accidental operation of electrical systems and accidental movement of the vehicle. Keys should be locked away with access controlled by the person working on the vehicle. If the key is required during the work the person working on the vehicle should check that the vehicle is in a safe condition before the key is retrieved. Visually check the vehicle for signs of damage to high voltage cabling (usually colored orange) or electrical components before starting any work on the vehicle. Unless a specific task requires the vehicle to be energized always isolate or disconnect the high voltage battery in accordance with manufacturer's instructions. Determine the locations of high voltage cables before carrying out tasks such as panel replacement, cutting or welding. Take appropriate precautions to prevent them from being damaged.

Figure 31 Insulated tools

4. Working on high voltage electrical systems

Refer to vehicle specific sources of information from the manufacturer (and trade bodies) to identify precautions you need to implement which are necessary to prevent danger. Remote operation keys should always be kept away from the vehicle to prevent any accidental operation of electrical systems and accidental movement of the vehicle. Keys should be locked away with access controlled by the person working on the vehicle. If the key is required during the work the person working on the vehicle should check that the vehicle is in a safe condition before the key is retrieved. Visually check the vehicle for signs of damage to high voltage electrical components or cabling (usually colored orange). High voltage systems should be isolated (that is the power disconnected and secured such that it cannot be inadvertently switched back on) and proven dead by testing before any work is undertaken. Always isolate and lock off the source of electricity and in accordance with manufacturer's instructions. You must always test and prove that any high voltage cable or electrical component is dead prior to carrying out any work on it.

Even when isolated, vehicle batteries and other components may still contain large amounts of energy and retain a high voltage. Only suitable tools and test equipment should be used. These may include electrically insulated tools and test equipment rated to a minimum of 1000v.

Some electronic components may store dangerous amounts of electricity even when the vehicle is off and the battery isolated. Refer to manufacturers data on how to discharge stored energy.

There may be circumstances (e.g. after collision damage) where it has not been possible to fully isolate the high voltage electrical systems and to discharge the stored energy in the system. Refer to the manufacturer's instructions about what control measures should be implemented before attempting to carry out further remedial work.

Battery packs are susceptible to high temperatures. The vehicle will typically be labelled advising of its maximum temperature and this should be considered when carrying out operations such as painting where booth temperatures may exceed this limit. Measures should be implemented to alleviate any potential risks e.g. by removing the batteries or by providing insulation to limit any temperature increase in the batteries.

Working on live electrical equipment should **only** be considered when there is no other way for work to be undertaken. Even then it should only be considered if it is both reasonable and safe to do so. You should consider the risks for working on this live equipment and implement suitable precautions including, as a final measure, the use of personal protective equipment (PPE). Refer to manufacturer's instructions for precautions when working live, including their PPE requirements.

It may be necessary to locate the vehicle within an area that can be secured such that people who could be put at risk are not able to approach the vehicle. Warning signs should be used to make people aware of the dangers.

Figure 32 Battery pack on a Lexus

2.3.2. Work processes

Note: The information here is generic – always refer to and follow manufacturers' information.

There are four stages or processes to consider for working safely on an EV:

1. Before
2. During
3. Interrupted
4. After.

1. Before work starts

Electrical work should not start until protective measures have been taken against electric shock, short-circuits and arcs. Work should not be performed on live parts of electrical systems and equipment. For this purpose, these systems and equipment must be placed in the non-live state prior to, and for the duration of the work. This is achieved by following these three steps (but always check manufacturer's data):

1. Isolate

- Switch off the ignition
- Remove service plug/maintenance connector or switch off main battery switch
- Remove fuses/low voltage battery where appropriate

2. Safeguard against reconnection

- Remove the ignition key and prevent unauthorized access to it
- Store the service plug/maintenance connector against unauthorized access/safeguard the main battery switch against reconnection, for example by means of a lock of some sort
- Observe any additional manufacturer or company instructions.

3. Verify the non-live state

- The provisions of the vehicle manufacturer must be observed for verification of the non-live state
- Suitable voltage testers or test apparatus specific to the manufacturer must be used
- Until the non-live state has been verified, the system is to be assumed to be live
- Wait an additional 10 minutes before performing any maintenance procedures on the system to allow any storage capacitors to be discharged
- Make sure that the junction board terminal voltage is nearly 0V.

Figure 33 Work area fenced off and a warning sign in place

2. During work

During work it is important to prevent shorts to earth and short circuits between components – even though they are disconnected. Remember a battery that has been disconnected is still live! If necessary, you should shroud or cover adjacent live parts. Always use suitable PPE and when appropriate, use insulated tools when performing service procedures to the high voltage system. This precaution will prevent accidental short-circuits.

3. Interruption to work

When maintenance procedures have to be interrupted while some high voltage components are uncovered or disassembled, make sure that the vehicle remains de-energized and isolated. Ignition remains turned off and the key is removed. The battery module switch or service connector stays off. No untrained persons should have access to that area to prevent any unintended touching of the components.

4. Completion of work

Once the work has been completed, the safety process can be lifted. All tools, materials and other equipment must first be removed from the site of the work and the hazard area. Guards removed before the start of work must be properly replaced and warning signs removed. Before switching on the battery module switch or following the re-energization process, after repairs have been completed, make sure that all terminals have been tightened to the specified torque and no high voltage wires or terminals have been damaged. The insulation resistance between each high voltage terminal of the part you disassembled, and the vehicle's body should also have been checked.

Figure 34 PHEV showing the maintenance connector (green component on the bulkhead)

2.4. First aid for electric shock

2.4.1. Make safe

In the unlikely event that a person receives an electric shock, there are four life-saving steps you should take immediately:

1. **Assess** the situation, do not touch the casualty if they are still in contact with the electrical source
2. **Break** the contact between the electrical source and the casualty but do not touch the casualty:
    a. Turn off the electricity, or
    b. Move the casualty away, using recommended safety hook, a plastic or wooden broom handle or similar
    c. Alternatively, loop some rope around the casualty and pull them away
3. Once you are sure the contact has been broken between the casualty and the electrical source, perform a primary survey and treat any injuries (if trained)
4. Call 911, 999 or 112 for **emergency help**.

Figure 35 Do not touch a person who may still be connected to an electrical source

If another person is present, then they should be calling the emergency service while you carry out the above steps.

2.4.2. First aid

If you are not trained in basic first aid, you should seriously consider attending a course[7]. The initial process you would learn in detail is as follows (the initial process is the same for electric shock or any other injury):

1. **Danger**. Before approaching the casualty, always make sure the area is safe (see previous section).
2. **Response**. Check if the casualty is responsive. Introduce yourself and ask them questions to see if you can get a response. Kneel next to their chest and gently shake their shoulders, asking, 'What has happened?,' 'Open your eyes!.' If the casualty opens their eyes, or gives another gesture, they are responsive. If they do not respond to you in any way, they are unresponsive and should be treated as quickly as possible.
3. **Airway**. Check that the airway is open and clear. Open the airway by placing one hand on the forehead to tilt the head back and the other hand to lift the chin. If they are unresponsive, move on to breathing as quickly as possible.

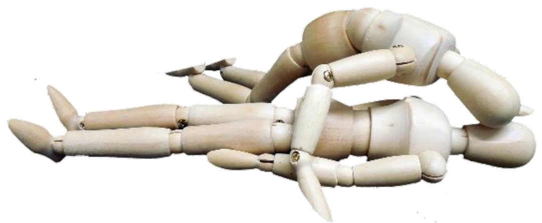


Figure 36 Checking breathing

4. **Breathing**. Check if the casualty is breathing normally. Place your ear above their mouth, looking down their body. Listen for sounds of breathing and see if you can feel their breath on your cheek. Watch to see if their chest moves. Do this for 10 seconds. If they are unresponsive and not breathing, you need to start CPR (Cardiopulmonary Resuscitation) straight away. Ask a helper to find and bring a defibrillator. If they are responsive and breathing move on to circulation.

[7] Material in this section is adapted from information on this website. Courses (highly recommended) and detailed information sources such as posters are available from St. John Ambulance: https://www.sja.org.uk/.

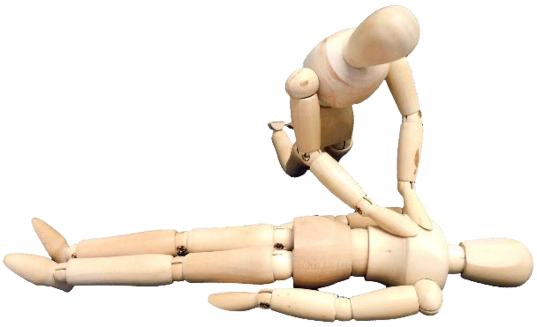


Figure 37 CPR (cardio-pulmonary resuscitation)

5. **Circulation**. Once you have established that they are breathing, look and check for any signs of severe bleeding. If they are bleeding severely you will need to control and treat the bleeding by applying direct pressure to the wound. If they are unresponsive and breathing but with no bleeding, put them in the recovery position.

Figure 38 Recovery position

Figure 39 Safety Rescue Hook 1kV

The safety hook show above is black HD polyethylene, with high temperature stabilizer additive, and 2% U.V. stabilizer for high U.V. protection. Excellent chemical resistance. Its anticipated life is 10 years. After which the hook should be renewed. The year of manufacture is embossed on the hook.

It is suitable for outdoor storage, (e.g. outdoor substation) on account of U.V. stabilization additive. However, the Safety Rescue Hook must not be stored permanently in direct sunlight. It is used for retrieval of victims of electric shock and should be placed in a prominent and easily accessible position near to the ‘live’ work area.

2.4.3. Summary

If somebody has received an electric shock, there are two distinct actions you should take. The details of these steps were outlined previously but in simple terms:

1. Make the casualty safe by switching off or safely removing them from the electrical source
2. Administer first aid and/or call the emergency services.

Figure 40 Defibrillator - sometimes called an AED (Automated external defibrillator)

2.5. Tools and Equipment

Figure 41 Toolkit (Source: Jack Sealey)

2.5.1. Introduction

By way of an introduction, the following table lists some of the basic words and descriptions relating to tools and equipment.

Table 3 Tools and equipment

Hand tools	Spanners/wrenches and hammers and screwdrivers and all the other basic bits
Special tools	A collective term for items not held as part of a normal tool kit. Or items required for just one specific job
Test equipment	In general, this means measuring equipment. Most tests involve measuring something and comparing the result of that measurement to data. The devices can range from a simple ruler to an engine analyzer
Dedicated test equipment	Some equipment will only test one specific type of system. The large manufacturers supply equipment dedicated to their vehicles. For example, a diagnostic device which plugs in to a certain type of fuel injection ECU
Accuracy	Careful and exact, free from mistakes or errors and adhering closely to a standard
Calibration	Checking the accuracy of a measuring instrument
Serial port	A connection to an electronic control unit, a diagnostic tester or computer for example. Serial means the information is passed in a 'digital' string like pushing black and white balls through a pipe in a certain order
Code reader or scanner	This device reads the 'black and white balls' mentioned above or the on-off electrical signals, and converts them into a language we can understand
Combined diagnostic and information system	Usually now PC-based, these systems can be used to carry out tests on vehicle systems and they also contain an electronic workshop manual. Test sequences guided by the computer can also be carried out
Oscilloscope	The main part of 'scope' is the display, which is like a TV or computer screen. A scope is a voltmeter but instead of readings in numbers it shows the voltage levels by a trace or mark on the screen. The marks on the screen can move and change very fast allowing us to see the way voltages change

2.5.2. Hand tools

Using hand tools is something you will learn by experience, but an important first step is to understand the purpose of the common types. This section therefore starts by listing some of the more popular tools, with examples of their use, and ends with some general advice and instructions.

Practice until you understand the use and purpose of the following tools when working on vehicles:

General advice and instructions for the use of hand tools (supplied by Snap-on):

- Only use a tool for its intended purpose
- Always use the correct size tool for the job you are doing
- Pull a spanner or wrench rather than pushing whenever possible
- Do not use a file or similar, without a handle
- Keep all tools clean and replace them in a suitable box or cabinet
- Do not use a screwdriver as a pry bar
- Look after your tools and they will look after you!

Table 4 Hand tools

Hand tool	Example uses and/or notes
Adjustable spanner (wrench)	An ideal stand by tool and useful for holding one end of a nut and bolt.
Open-ended spanner	Use for nuts and bolts where access is limited or if a ring spanner cannot be used.
Ring spanner	The best tool for holding hexagon bolts or nuts. If fitted correctly it will not slip and damage both you and the bolt head.
Torque wrench	Essential for correct tightening of fixings. The wrench can be set in most cases to 'click' when the required torque has been reached. Many fitters think it is clever not to use a torque wrench. Good technicians realize the benefits.
Socket wrench	Often contain a ratchet to make operation far easier.
Hexagon socket spanner	Sockets are ideal for many jobs where a spanner cannot be used. In many cases a socket is quicker and easier than a spanner. Extensions and swivel joints are also available to help reach that awkward bolt.
Air wrench	These are often referred to as wheel guns. Air driven tools are great for speeding up your work, but it is easy to damage components because an air wrench is very powerful. Only special, extra strong, high quality sockets should be used.
Blade (engineer's) screwdriver	Simple common screw heads. Use the correct size!
Pozidrive, Philips and crosshead screwdrivers	Better grip is possible particularly with the Pozidrive but learn not to confuse the two very similar types. The wrong type will slip, and damage will occur.
Torx®	Similar to a hexagon tool like an Allen key but with further flutes cut in the side. It can transmit good torque.
Special purpose wrenches	Many different types are available. As an example, mole grips are very useful tools as they hold like pliers but can lock in position.
Pliers	These are used for gripping and pulling or bending. They are available in a wide variety of sizes. These range from snipe nose, for electrical work, to engineers' pliers for larger jobs such as filing split pins.
Levers	Used to apply a very large force to a small area. If you remember this you will realize how, if incorrectly applied, it is easy to damage a component.
Hammer	Anybody can hit something with a hammer, but exactly how hard and where is a great skill to learn!

2.5.3. Test equipment

To remove or refit and adjust components to ensure the vehicle system operates within specification, is a summary of almost all the work you will be doing. The use, care, calibration, and storage of test equipment are therefore very important. In this sense 'test equipment' means:

- Measuring equipment - such as a micrometer
- Hand instruments - such as a spring balance
- Electrical meters - such as a digital multimeter (DMM) or an oscilloscope

Figure 42 Digital multimeter in use

The operation and care of this equipment will vary with different types. I suggest therefore, that you should always read the manufacturer's instructions carefully before use, or if you have a problem. The following list however sets out good general guidelines:

- Always follow the manufacturer's instructions –
- Handle with care – do not drop, keep the instrument in its box
- Ensure regular calibration – check for accuracy
- Understand how to interpret results – if in doubt ask!

For high voltage EV work, electrical meters such as a digital voltmeter should be rated to a **minimum 1000V CAT. III or CAT. IV**. There is a range of different multimeters available and choosing the right one is essential. Indeed, like me, you may choose to own more than one, and of course you get what you pay for. The figure below shows my current selection. Each of these meters has advantages and disadvantages, and some examples are listed in this table:

Table 5. Meter advantages and disadvantages

Multimeter	Advantages	Disadvantages
Megger	1000V insulation tester Standard range of other functions	No CAT rating No additional features
Snap-on Verdict	CAT III 1000V, Cat IV 600V so ideal for H/EV work Comprehensive automotive options Accurate Oscilloscope	Expensive compared to some others but the number of features is much larger
Fluke 78 Automotive	Comprehensive range of functions related to automotive testing such as duty cycle and RPM Accurate	This version is CAT II 300V, so not to be used on H/EVs, but this meter is over 10 years old and more up to date Fluke versions have higher CAT ratings
Uni-T amp clamp	Quick and easy to measure current up to 100A – even on H/EVs as it is non-contact	Cheaper end of the market so less accurate and fewer features
Sealey Pocket	Great for a first look and quick measurements as it is easily portable	Cheap, not very strong and only CAT II

Figure 43 Multimeters (left to right): Megger insulation tester and meter, Snap-on Scope meter, Fluke 78 Automotive meter, Uni-T amp clamp meter and Sealey pocket meter

The Fluke 78 automotive meter shown above, is several years old now but perfectly functional and ideal for low voltage applications. It has the following features and specifications:

- Volts, amps, continuity, and resistance
- Frequency for pulsed-DC and AC frequency tests
- Duty cycle to verify operation of sensors and actuator supply signals
- Direct reading of dwell for 3, 4, 5, 6 and 8-cylinder engines
- Temperature readings up to 999°C (F or C) using the thermocouple bead probe and adapter plug
- Min/max recording that works with all meter functions
- Precision analog bar graph
- RPM inductive pickup for both conventional and distributorless (DIS) ignitions
- 10MΩ input impedance
- Cat II 300V (ideal for low voltage automotive and even mains voltages, but not recommended for H/EV high voltage use)

Figure 44. Fluke 78 Automotive meter and accessories (test leads, 600A clamp, plug lead RPM, temperature thermocouple)

Meters and their leads have category ratings that give the voltage levels up to which they are safe to use. CAT ratings can be a little confusing but there is one simple rule of thumb: Select a multimeter rated to the highest category in which it could possibly be used. In other words, err on the side of safety. This table lists some of the different ratings.

Table 6 CAT ratings

Category	Working voltage (voltage withstand)	Peak impulse (transient voltage withstand)	Test source impedance
CAT I	600V	2500V	30 Ω
CAT I	1000V	4000V	30 Ω
CAT II	600V	4000V	12 Ω
CAT II	1000V	6000V	12 Ω
CAT III	600V	6000V	2 Ω
CAT III	1000V	8000V	2 Ω
CAT IV	600V	8000V	2 Ω

The voltages listed in the table above are those that the meter will withstand without damage or risk to the user. A test procedure (known as IEC 1010) is used, and takes three main criteria into account:

- steady state working voltage
- peak impulse transient voltage
- source impedance.

These three criteria together will tell you a multimeter's true ***'voltage withstand'*** values. However, this is confusing because it can look as if some 600V meters offer more protection than 1000V ones.

Within a category, a higher working voltage is always associated with a higher transient voltage. For example, a CAT III 600V meter is tested with 6000V transients while a CAT III 1000V meter is tested with 8000V transients. This indicates that they are different, and that the second meter clearly has a higher rating. However, the 6000V transient CAT III 600V meter and the 6000V transient CAT II 1000V meter are not the same even though the transient voltages are. This is because the source impedance has to be considered.

Ohm's Law (I = V/R) shows that the 2Ω test source for CAT III will have six times the current of the 12Ω test source for CAT II. The CAT III 600V meter therefore offers better transient protection, compared to the CAT II 1000V meter, even though in this case the voltage rating appears to be lower.

The combination of working voltage and category determines the total 'voltage withstand' rating of a multimeter (or any other test instrument), including the very important 'transient voltage withstand' rating. Remember, for working on vehicle high voltage systems, you should choose **a CAT III or CAT IV meter AND leads**.

Figure 45. Cat III 1000V and CAT IV 600V meter

Figure 46. Cat III 1000V and CAT IV 600V leads

There are lots of different options or settings available when using a multimeter, but the three most common measurements are: voltage (volts), resistance (ohms) and current (amps).

To measure voltage the meter is connected in parallel with the circuit. The most common measurement on a vehicle is DC voltage. Remember to set the range of the meter (some are auto-ranging) and if in doubt, start with a higher range and work downwards.

Figure 47. Voltage supply to a fuse box

To measure resistance the meter must be connected across (in parallel with) the component or circuit under test. However, the circuit must be switched off or isolated. If not, the meter will be damaged. Likewise, because an ohmmeter causes a current to flow, there are some circuits such as Hall effect sensors, that can be damaged by the meter.

Figure 48. Checking a simple resistor

Current can be measured in two ways:

1. Connecting the meter in series with the circuit (in other words break the circuit and reconnect it through the meter)
2. Using an inductive amp clamp around the wire (as shown below), which is a safer way to measure, but is less accurate at low values.

Figure 49. Inductive ammeter clamp on a high voltage cable (measuring the current drawn by the EV cabin heater)

This internal resistance of a meter can affect the reading it gives on some circuits. It is recommended that this should be a minimum of 10MΩ, which ensures accuracy because the meter only draws a very tiny (almost insignificant) current. This stops the meter loading the circuit and giving an inaccurate reading, and it prevents damage to sensitive circuits (in an ECU for example).

However, the very tiny current draw of a good multimeter can also be a problem. A supply voltage of say 12V, can be shown on a meter when testing a circuit, but does not prove the integrity of the supply. This is because a meter with a 10MΩ internal resistance connected to a 12V supply, will only cause a current of 1.2µA (I=V/R) – that is 1.2 millionths of an amp, which will not cause any noticeable voltage loss even if there is an unwanted resistance of several thousand ohms in the supply circuit. A test lamp can be connected in parallel with the meter to load the circuit (make more current flow) but should be used carefully so you do not damage sensitive electronic switching circuits that may be present.

Voltmeters can display a 'ghost' voltage rather than zero when the leads are open circuit. In other words, if checking the voltage at an earth/chassis connection we would expect a 0V reading. However, the meter will also display zero before it is connected, so how do we know the reading is correct, when it is connected?

The answer is to shake the multimeter leads (see the image below), a 'ghost' voltage will fluctuate, a real voltage will not!

Figure 50. Ghost voltage caused by shaking the red lead

An insulation tester does exactly as its name suggests. On automotive systems, this test is mostly used on electric and hybrid vehicles. Refer to manufacturers' information before carrying out any tests on the high voltage system – and be TechSafe™.

The device shown here is known as a Megger, it is a multimeter but is also able to supply a voltage of up to 1000V to test the resistance of insulation on a wire or component. A reading well in excess of 10MΩ is what we would normally expect if the insulation is in good order. The high voltage is used because it puts the insulation under pressure and will show up faults that would not be apparent if you used an ordinary ohmmeter.

Take care when using insulation testers, the high voltage used for the test will not kill you, because it cannot sustain a significant current flow, but it still hurts!

Figure 51. Checking the insulation resistance between conductors in an EV charging lead (in this case the reading is greater than 20GΩ)

2.5.4. Workshop equipment

In addition to hand tools and test equipment, most workshops will also have a range of equipment for lifting and supporting as well as electrical or air operated tools. Table 7 lists some examples of common workshop equipment together with typical uses.

Table 7 Examples of workshop equipment

Equipment	Common use
Ramp or hoist	Used for raising a vehicle off the floor. Other designs include four-post and scissor types where the mechanism is built into the workshop floor
Jack and axle stand	A trolley jack is used for raising part of a vehicle such as the front or one corner or side. It should always be positioned under suitable jacking points, axle, or suspension mountings. When raised, stands must always be used in case the seals in the jack fail causing the vehicle to drop
Air gun	A high-pressure air supply is common in most workshops. An air gun (or wheel gun) is used for removing wheel nuts or bolts. Note that when replacing wheel fixings, it is essential to use a torque wrench
Electric drill	The electric drill is just one example of electric power tools used for automotive repair. Note that it should never be used in wet or damp conditions
Parts washer	There are a number of companies that supply a parts washer and change the fluid it contains at regular intervals.
Steam cleaner	Steam cleaners can be used to remove protective wax from new vehicles as well as to clean grease, oil, and road deposits from cars in use. They are supplied with electricity, water, and a fuel to run a heater – so caution is necessary.
Electric welder	There are a number of welding types used in repair shops. The two most common are metal inert gas (MIG) and manual metal arc (MMA).
Gas welder	Gas welders are popular in workshops as they can also be used as a general source of heat, for example, when heating a flywheel ring gear.
Engine crane	A crane of some type is essential for removing the engine on most vehicles. It usually consists of two legs with wheels that go under the front of the car and a jib that is operated by a hydraulic ram. Chains or straps are used to connect to or wrap around the engine.
Transmission jack	On many vehicles the transmission is removed from underneath. The car is supported on a lift and then the transmission jack is rolled underneath.

Figure 52 Trolley jack and axle stands (Source: Snap-on Tools)

2.5.5. High voltage tools

Many manufacturers have designed ranges of tools that are designed to protect mechanics from the high voltage systems in electric vehicles. A company called EINTAC used its experience of manufacturing insulated tools to produce a selection of products that comply with EN 60900.

Figure 53 It is essential that insulated tools and PPE are used to reduce risk of harm to technicians and vehicles (Source: EINTAC Ltd.)

The range comprises a full complement of insulated tools including ratchets, sockets, screwdrivers, spanners, T-wrenches, pliers, and an insulated torque wrench. Latex insulation gloves, protective outer gloves and a secure roller cabinet are also available.

An important safety feature of the EV tool range is the two-step color-code system. If any of the orange-colored outer insulation material is missing, a bright interior color (often yellow) is exposed, clearly indicating to the technician that the tool is no longer safe for use.

2.5.6. On board diagnostics

On-board diagnostics (OBD) is a generic term referring to a vehicle's self-diagnostic and reporting system. OBD systems give the vehicle owner or a technician access to information for various vehicle systems.

The amount of diagnostic information available via OBD has varied considerably since its introduction in the early 1980s. Early versions of OBD would simply illuminate a malfunction indicator light (MIL) if a problem was detected but did not provide any information about the problem. Modern OBD systems use a standardized digital communications port to provide real-time data in addition to a standardized series of diagnostic trouble codes (DTCs), which allow a technician to identify and remedy faults on the vehicle. The current versions are OBD2 and in European EOBD2. The standards OBD2 and EOBD2 are quite similar.

Figure 54 Diagnostic data link connector (DLC)

A diagnostic tool (scanner) is connected to this socket and will read out stored error codes, as well as displaying live data.

2.6. Recovery and transportation

2.6.1. Introduction

Recovery and transportation are key parts of a dismantler's work. Many ICE vehicles require special handling in this respect, but there are even more issues to consider when EVs are involved. For example, the speed at which they may, or may not be towed, and electrical safety after a serious collision.

Roadside repairs should only be carried out by qualified personnel and by following all the safety and repair procedures outlined previously and as specified by the manufacturer.

2.6.2. Initial assessment

First responders should carry out an initial visual risk assessment. Personal protection should be worn. Steps should then be taken to secure the safety of themselves and others at incident scenes involving EVs. For example, people who may be at risk are:

- occupants
- on-lookers
- recovery personnel
- emergency service personnel

Vehicles damaged by fire or impact can result in these risks:

- electric shock
- burns
- arc flash
- arc blast
- fire
- explosion
- chemicals
- gases/fumes

It may therefore be necessary to implement evacuation procedures and site protection.

2.6.3. Fire

A fire involving a BEV or HEV should generally be approached in the same manner as a conventional motor vehicle, although several additional factors should be considered. One approach indicating the basic steps that should be considered for extinguishing a fire involving any motor vehicle (including an EV or HEV) is illustrated here:

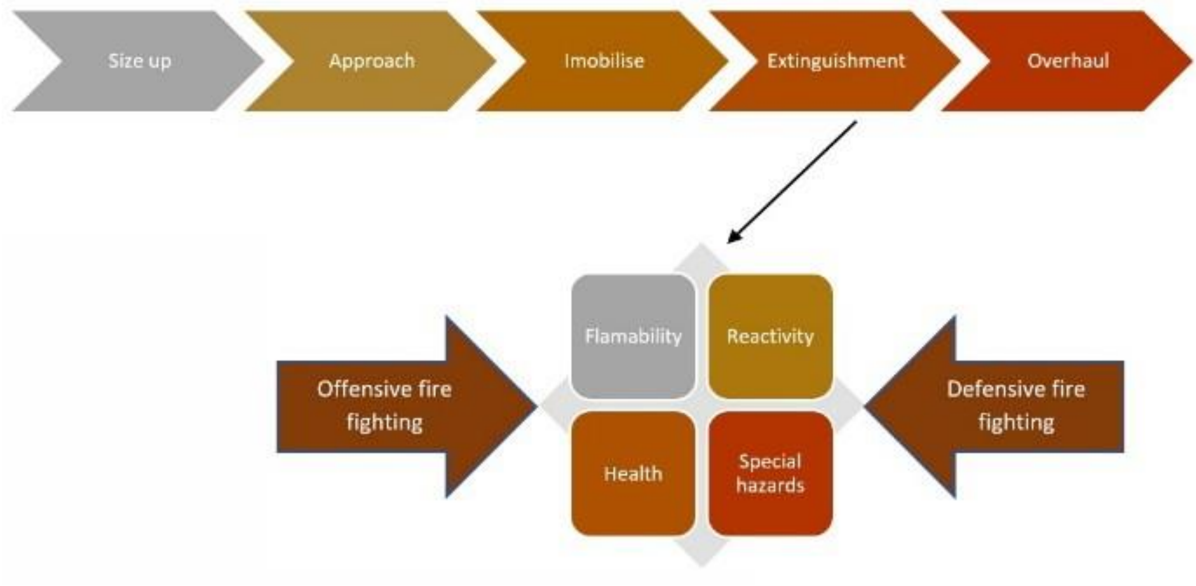


Figure 55 Example of approach to vehicle fire extinguishment

Vehicle extrication and rescue and/or vehicle fire involves key steps to stabilize and disable the vehicle. A vehicle may appear to be off, but there may still be a hazard for fire fighters. Emergency responders must always disable the vehicles ability to operate as per the vehicle manufacturer's instructions.

Emergency response guides from vehicle manufacturers usually recommend a defensive approach to a battery fire. In other words, let it burn and consume itself. However, exposure to the heat and/ or products of combustion must be considered.

Methods for extinguishing a vehicle battery fire depends on many things such as type of battery, extent of fire, configuration, physical damage to battery unit. If water is used, copious amounts are normally required. However, this may be impractical if the vehicle and battery unit is not accessible and/or runoff is a concern. Some emergency organizations advise that for lithium-ion battery fires, extinguishment can be attempted using dry chemical, CO_2, water spray, or regular foam. The advantage of water is that is also cools the battery (see next section).

Vehicle Fire Blankets are available that work by allowing the vehicle or battery to burn out and prevent the fire spreading to adjacent vehicles or buildings.

High voltage batteries are well sealed and do not contain much liquid electrolyte. Most spills can, therefore, normally be handled with an absorbent. As new battery designs and technologies are introduced, this basic approach may need to be re-evaluated.

A further consideration is that built-in protection measures, that prevent electrocution from the high voltage system, may be prevented from working properly. The normally open relays (contactors) for the high voltage system could fail in a closed position if exposed to heat or if they are damaged. In serious accidents, short circuits to the chassis/body may become possible with the energy still contained in the high voltage battery or any of the high voltage components. Always plan for the worst-case scenario.

2.6.4. Thermal runaway

Lithium-ion batteries can, if overheated, go into a thermal runaway process. This can be separated into three stages:

Figure 56 Thermal runaway stages. The SEI (solid electrolyte interphase) layer is a component of lithium-ion batteries, formed from the decomposition of materials associated with the electrolyte of the battery

An exothermic reaction (one that gives off heat) increases the battery temperature and therefore the internal pressure of the li-ion battery. Gas evolution also increases the pressure of the cell. If the cell is equipped with a pressure relief valve (not found on pouch cells), this valve will open and release flammable organic compounds. A pouch cell may burst if internal pressure is too high.

Emission of organic carbonates is seen as white smoke. During further heating of the cell the color of the smoke turns into grey by emitting active electrode material (mainly graphite particles). This thermal runaway process heats the cell up to 700℃ - 1000℃. This high temperature may affect adjacent cells and cause a chain reaction. With the organic solvent the conducting salt, LiPF6 is also emitted and reacts as follows.

- When heated in dry environments the salt decomposes
- In contact with water/air moisture, toxic hydrogen fluoride (HF) gas is created.

If a thermal runaway occurs, many kinds of chemicals are generated. Combustion reactions mainly create:

- CO, C02 from organic materials
- NOx, HF
- Low molecular weight organic acids, aldehydes, ketones.

Although a li-ion battery fire should not ideally be extinguished with pure water, using plenty of water may be reasonable because it cools the surrounding cells to avoid a following process. Additionally, many of the emitted particles and toxic gaseous compound will bind and be diluted by water.

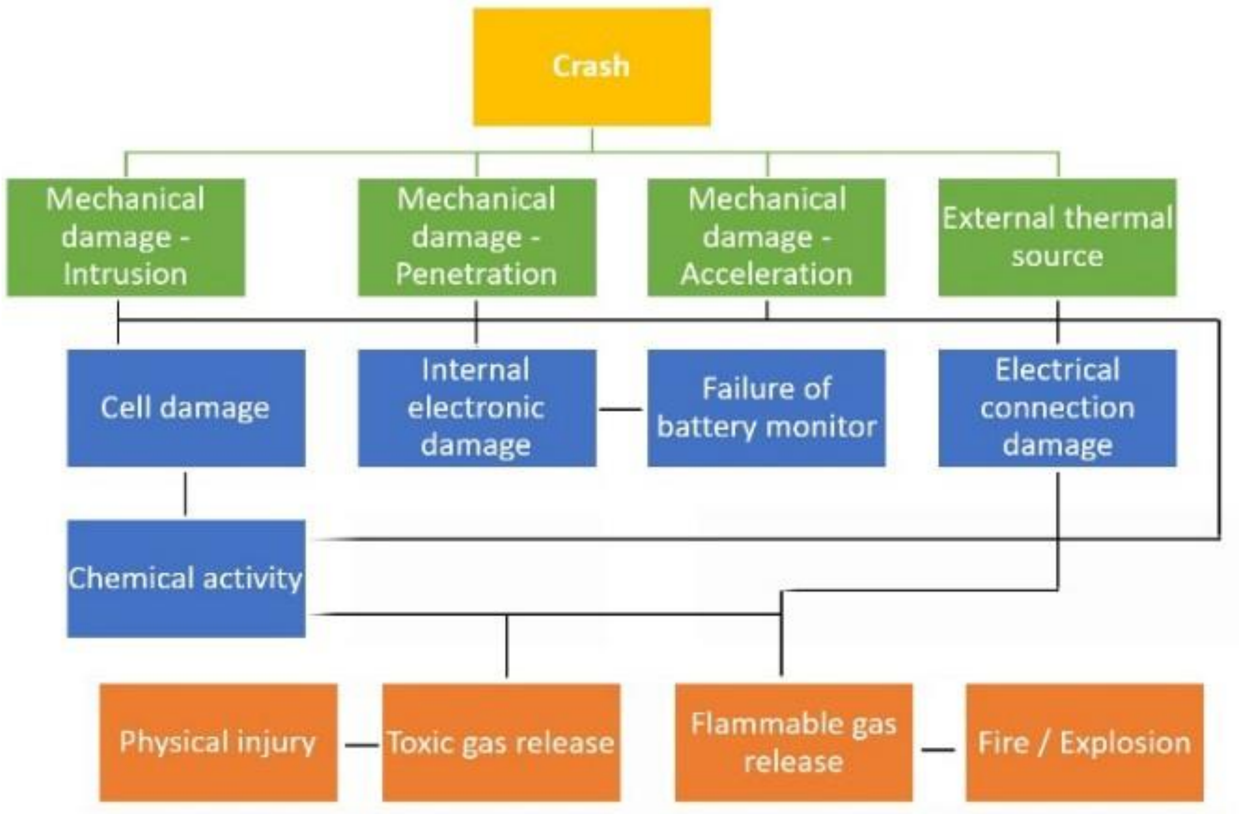


Figure 57 Battery harmful event flowchart

2.6.5. Manufacturers' information

Most manufacturers supply detailed information that covers aspects such as:

- model identification
- high voltage components
- low voltage system
- disabling high voltage
- stabilizing the vehicle
- airbags and SRS (supplemental restraint system)
- reinforcements
- No-cut zones
- Rescue operations
- lifting
- opening

A good example of this material is available from Tesla Motors on their website: www.teslamotors.com/firstresponders

For roadside recovery, many manufacturers provide roadside assistance numbers for the driver to call. In addition, detailed data sheets are provided that give information similar to the following instructions for transporters (provided by Tesla in relation to the Model S):

Use a flatbed only

Use a flatbed trailer only, unless otherwise specified by Tesla. Do not transport Model S with the tires directly on the ground. To transport Model S, follow the instructions exactly as described. Damage caused by transporting Model S is not covered by the warranty.

Disable self-levelling (air suspension vehicles only)
If Model S is equipped with Active Air Suspension, it automatically self-levels, even when power is off. To prevent damage, you must use the touchscreen to activate Jack mode, which disables self-levelling:

1. Touch CONTROLS on the bottom left of the touchscreen.
2. Press the brake pedal, then touch Controls > Driving > Very High to maximize height.
3. Touch Jack

When jack mode is active, Model S displays this indicator light on the instrument panel, along with a message telling you that active suspension is disabled.
NOTE: Jack mode cancels when model S is driven over 4.5 mph (7km/h).
CAUTION: Failure to activate Jack mode on a Model S equipped with active suspension can result in the vehicle becoming loose during transport, which may cause significant damage.

Activate tow mode
Model S may automatically shift into Park when it detects the driver leaving the vehicle, even if it has previously been shifted into Neutral. To keep Model S in Neutral (which disengages the parking brakes), you must use the touchscreen to activate Tow Mode:

1. Shift into Park.
2. Press the brake pedal, then on the touchscreen, touch Controls > E-Brakes & Power Off > Tow Mode.

When Tow mode is active, Model S displays this indicator light on the instrument panel along with a message telling you that Model S is free rolling.
NOTE: Tow mode cancels when Model S is shifted into Park.
CAUTION: If the electrical system is not working, and you therefore cannot release the electric parking brake, attempt to quick start the 12V battery. For instructions, call the number noted on the previous page. If a situation occurs where you cannot disengage the parking brake, use tire skids, or transport Model S for the shortest possible distance using wheeled dollies. Before doing so, always check the dolly manufacturer's specifications and recommended load capacity.

Connect the tow chain
The method used to connect the tow chain depends on whether Model S is equipped with a towing eye.

Lower suspension arms
Attach the tow chains using the large hold on each of the rearmost lower suspension arms. Place a 2" x 4" piece of wood between the tow chains and the underbody.
CAUTION: Before pulling, position the wood between the tow chain and the underbody to protect the underbody from any damage that could be caused by the tow chain.

Towing eye (if equipped)
Remove the nose cone by inserting a plastic pry tool into the top right corner, then gently pry the nose cone towards you. When the clip releases, pull the nose cone toward you, without twisting or bending it, to release the three remaining clips.
CAUTION: Do not use a metal object (such as a screwdriver). Doing so can damage the nose cone and the surrounding area. Fully insert the towing eye (found in the front trunk) into the opening on the right side, then turn it counterclockwise until securely fastened. When secure, attach the tow chain to the towing eye.
CAUTION: Before pulling, make sure the towing eye is securely tightened.

Pull onto the Trailer and Secure the Wheels

- Secure wheels using chocks and tie-down straps.
- Ensure any metal parts on the tie-down straps do not contact painted surfaces or the face of the wheels.
- Do not place straps over body panels or through the wheels.

CAUTION: Attaching straps to the chassis, suspension or other parts of the vehicle body may cause damage.
CAUTION: To prevent damage, do not transport Model S with the tires directly on the ground.

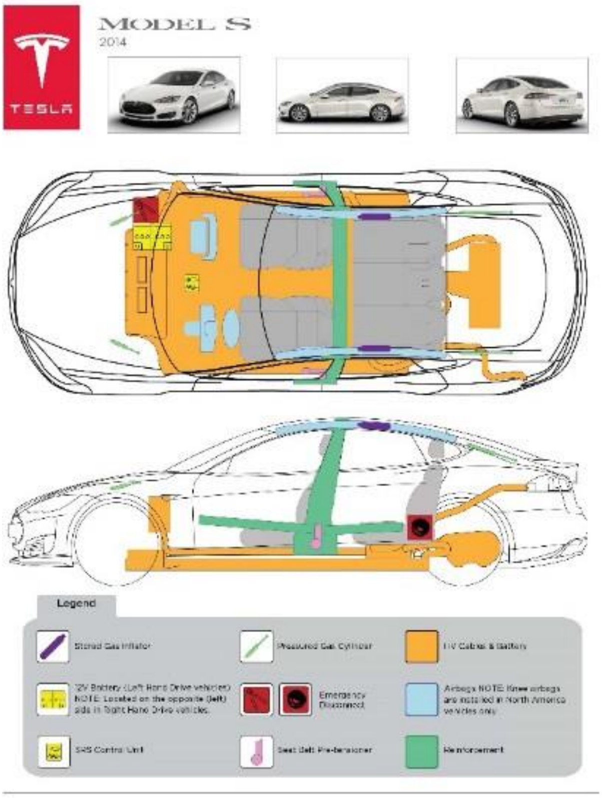


Figure 58 Key component and high voltage information (Source: Tesla Motors)

Figure 59 General instructions and deactivation information (Source: Tesla Motors)

The following is another example, of information supplied by Volkswagen in relation to their e-Golf:

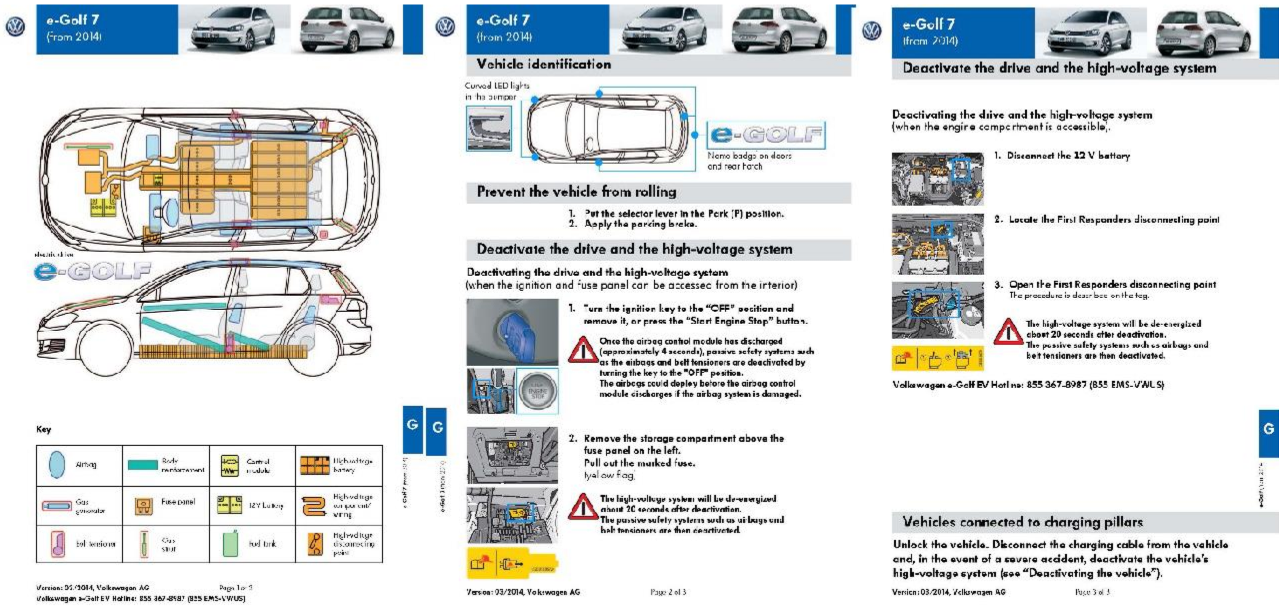


Figure 60 Basic information about the VW e-Golf

2.6.6. Pro-assist app

Pro-moto are long standing experts in the field of vehicle technical training, specializing in EVs, hybrids and hydrogen propelled vehicle technologies. The company is committed to improving the effectiveness and experience of service professionals and businesses that provide rescue, recovery, recycling, and repair services to the EV, HEV and hydrogen fuel cell industry. Safety is a key factor in this commitment. They are also focused on assisting any potential or active hybrid and EV owners to improve their education, insight, choice, and options regarding their vehicles and in optimizing their experience of ownership and lifetime value. Pro-assist is a subsidiary of Pro- moto.

The Pro-Assist Hybrid app was commissioned to help first responders, recyclers and repairers understand the special and different requirements of hybrid vehicles. This is particularly important when dealing with emergency, critical, recovery, repair, and routine maintenance situations. As well as continuing to develop the hybrid app, by adding more information and additional vehicles, further apps are planned for pure-electric and fuel cell vehicles. The apps are created in collaboration with the Society of Motor Manufacturers and Traders (SMMT) and the industry's leading hybrid and electric vehicle manufacturers. It is available through all major app stores.

Figure 61 Main menu of the Pro-assist hybrid app

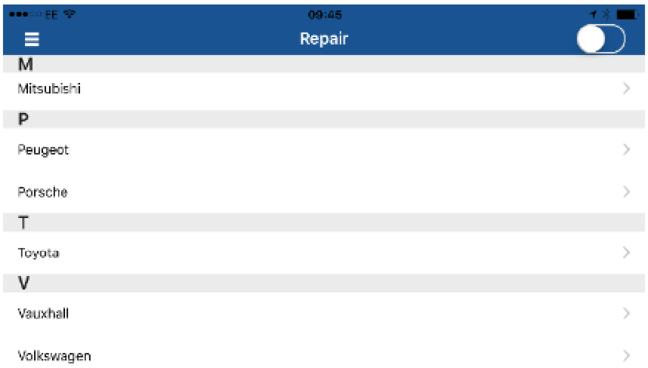


Figure 62 Alphabetical list showing just some of the manufacturers covered in the app

Vehicle specific information is accessed from the main menu and then by an alphabetical list of vehicles as shown above. Generic information is also supplied in relation to hazard assessment, battery technology and some historical events. The following screenshot images are just a very small example of the detailed information supplied via this essential app.

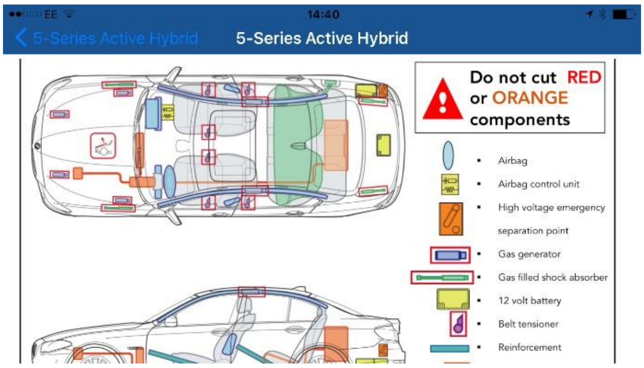


Figure 63 Information relating to locations and layouts on a BMW 5-series with the emphasis on safety critical and high voltage components

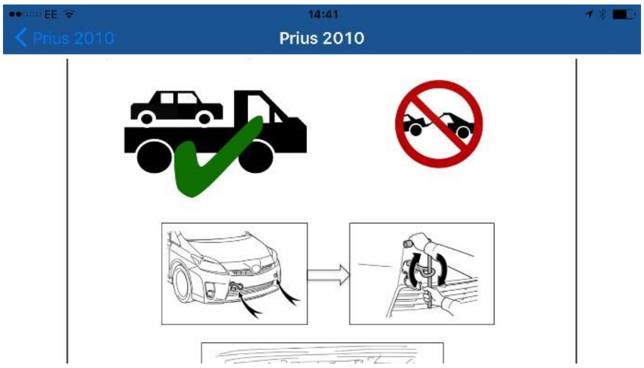


Figure 64 Information on a 2010 Prius for recovery professionals

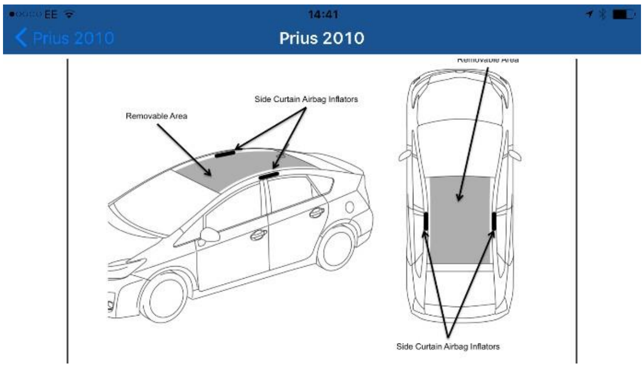


Figure 65 This area of the 2010 Prius is removable in an emergency rescue situation

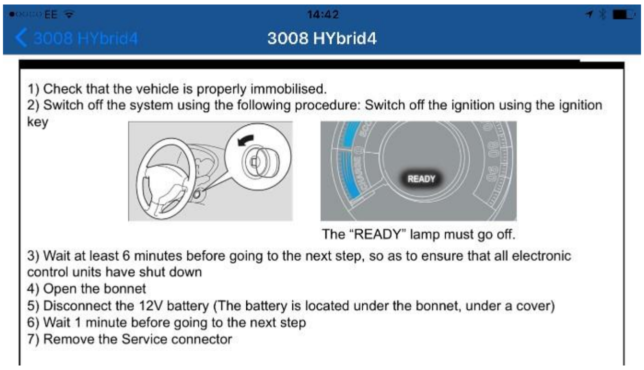


Figure 66 Part of the information relating to shut down and disconnection procedures on a selected vehicle

Figure 67 Like many vehicles the Ampera has a dedicated cut-zone for emergency use when disconnecting the 12V supply

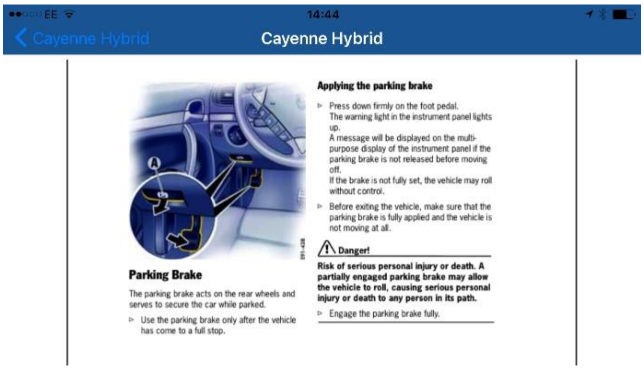


Figure 68 Details about parking brake application on a Porsche Cayenne hybrid.

Content reproduced here by kind permission from the company. Find out more about Pro-Moto and the Pro-assist Hybrid app at www.pro-moto.co.uk

2.6.7. Emergency start

On some vehicles, even if the high-voltage battery has been discharged completely, there is still an option allowing the car to be restarted twice for a short distance. The eGolf for example, has an emergency start function:

1. For approx. 100 meters, after switching the ignition off and on
2. For approx. 50 meters, after switching the ignition off and on once again.

No further emergency starts are possible.

Figure 69 eGolf (Source: Volkswagen Media)

2.6.8. Vehicle recovery

In the event of an accident or breakdown, electric vehicles will need to be recovered, just like traditional ICE vehicles. However, towing can be more of a problem because electric vehicles have a fixed connection between the drive wheels and the three-phase current drive (electric drive motor/generator). This connection cannot be undone without mechanical work.

If the vehicle needs to be towed, there are usually two options (this example is from the manufacturer's information about the e-Golf):

1. **Towing the vehicle with the high-voltage system intact:**
   Switch the ignition on and engage the selector lever in the N position to allow electric freewheel mode. The vehicle can now be towed for a maximum distance of 50 km at 50 km/h using a rope or tow bar. Using a bar for towing is recommended for safety reasons.

2. **Towing with a damaged high-voltage system:**
   If it is not possible to activate the high-voltage system, the vehicle must be transported with all four wheels stationary. Freewheel mode cannot be activated, as there is a risk of overheating.

However, in general, it is recommended that the vehicle is NOT towed above walking pace and only then for a very short distance to reduce the risks if broken down in a dangerous place such as a busy road with no hard shoulder. The vehicle should then be lifted onto a flatbed. Once again, the guidance to always refer to manufacturer's information applies here. Further guidance about towing can be found in the owner's handbook.

If a vehicle is to be handed over to the authorities or another recovery company, they should be informed of the vehicle's type of drive and any measures taken such as de-energization. In particular, they must be informed of any potential danger, such as:

- damaged high-voltage components
- high-voltage components which have come into contact with water.

Particular dangers are:

- electric shock
- risk of fire (particularly delayed fire, from the HV battery).

If an EV has been involved in a serious accident, the high-voltage system should be de-energized before loading onto a flatbed. Instructions can be found in the owner's manual for the vehicle or the rescue data sheet for first responders.

Figure 70 If an EV is submersed in water, it does not increase the risk of electric shock

If a vehicle is to be recovered using in a lifting cradle (spectacle lift), the high voltage system could be damaged if a drive axle remains in contact with the road surface. You should therefore be particularly aware of which axles are driven – and that the vehicle may be four-wheel drive!

Vehicles with a damaged high-voltage battery should ideally be transported to the nearest suitable workshop or to a safe storage area.

Contrary to popular belief, if a high-voltage vehicle has been submersed in water, it does not increase the risk of electric shock. The recovery procedure is the same as that for conventional vehicles and the extra information as stated above.

National regulations or standards for loading and transportation must always be observed.

2.6.9. Vehicle transportation and storage

If a vehicle is collected from a recovery yard or salvage auction, or is being delivered to a recycling yard, a flatbed transport is the only recommended method.

After delivery, an EV should be parked and stored just like an ICE vehicle. However, for fire safety reasons EVs that have been involved in accidents should be parked in the open air, in a restricted-access area. They should also be parked a suitable distance away from other vehicles, buildings, and any other flammable objects.

The person, who is to take responsibility for the vehicle, should be informed of the vehicle's type of drive and any measures taken such as de-energization. In particular, they must be informed of any potential danger, such as damaged high-voltage components or those which have come into contact with water.

Never park an EV with a damaged high-voltage system in an enclosed space. EVs that have been involved in accidents, which have high-voltage components directly exposed to the weather, should be covered with a suitable tarp.

Vehicle should be marked as high voltage, and information provided as above in a written format, especially if it is delivered outside normal hours.

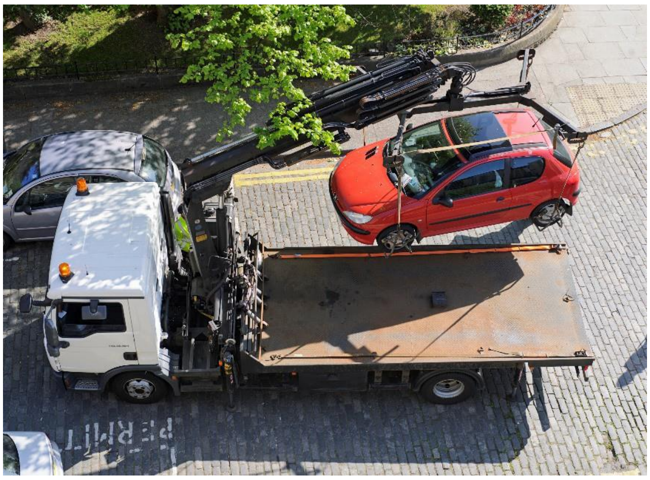


Figure 71 Using a flatbed for recovery is always the preferred option

3. Electric vehicle technology

3.1. Electric vehicle layouts

3.1.1. Overview

The figure below shows the general layout in block diagram form of an electric vehicle (EV). The drive batteries are a few hundred volts, so a lower 12/24V system is still required for normal lighting and other systems.

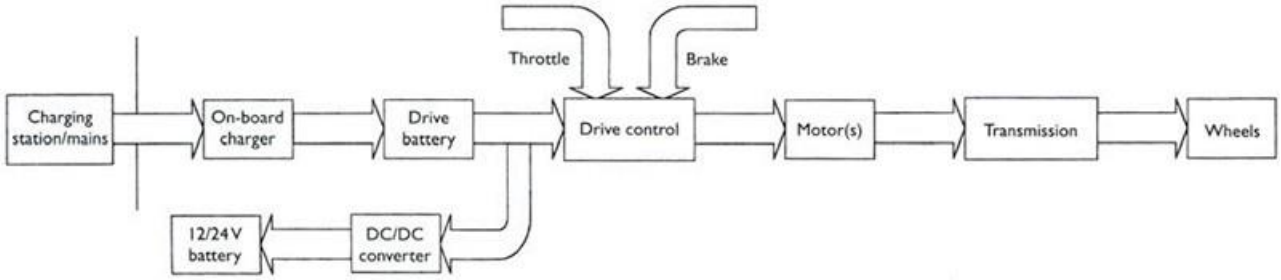


Figure 72 Generic electric vehicle layout

3.1.2. Single motor

The classic pure-EV layout is to use a single motor driving either the front or rear wheels. Most EVs of this type do not have a transmission gearbox as the motor operates at suitable torque throughout the required speed range.

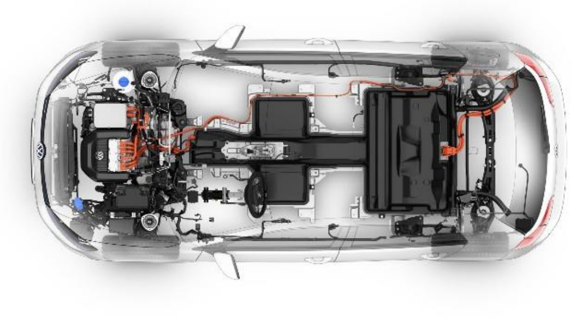


Figure 73 VW Golf-e layout with the motor at the front and the battery in the center and at the rear (Source: Volkswagen Media)

The following picture shows a sectioned view of a drive motor and the basic driveline consisting of a fixed ratio gear-set, the differential and driveshaft flanges.

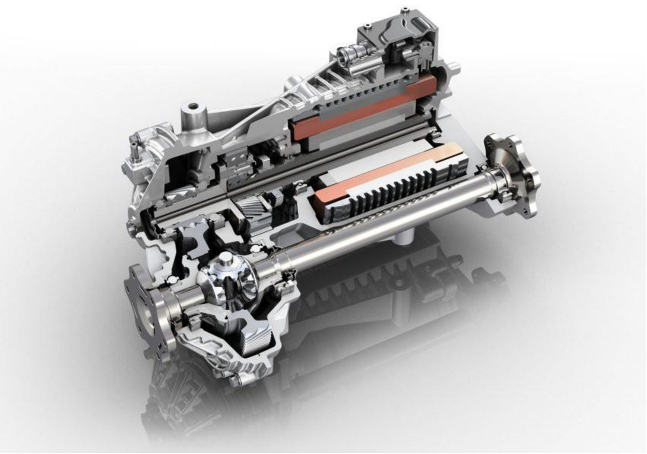


Figure 74 EV motor rear (Source: Volkswagen Media)

Hybrid cars vary in layout and this is examined in detail later. However, the basic design is similar to the pure-electric car mentioned above. The obvious difference being the addition of an IC engine.

Figure 75 PHEV layout (Source: Volkswagen Media)

The motor for the plug-in hybrid is shown here where it forms part of the gearbox assembly. Motors used on light hybrids are sometimes described as integrated motor assist (IMA) as they form part of the flywheel. This type of motor is shown as figure 77.

Figure 76 PHEV engine, motor, and gearbox (Source: Volkswagen Media)

Figure 77 Motor integrated with the engine flywheel (Source: Bosch Media)

3.1.3. Wheel motors

Protean Electric[8] is a key player in the development of in-wheel EV motors. Their ProteanDrive consists of a permanent-magnet synchronous motor and integrated electronics. The electronics precisely control current to each in-wheel motor so it can deliver the torque required in about a millisecond. In-wheel motors allow for torque-vectoring. This means different torques can be applied to different wheels, which can significantly improve handling.

Figure 78 Mounting the motors in the wheels makes more space available for batteries, passengers, or cargo (Source: Protean Electric)

The electronic circuitry fits within the overall motor package and shares cooling with the motor. The motor windings can have up to 90A[9] flowing through them. The heat that is therefore developed, along with heat from the electronics, is controlled by coolant flowing through a channel in the motor housing. The coolant is in thermal contact with the electronic components and the motor windings. Those windings are encapsulated in epoxy resin, which also helps to conduct heat. Integration of the motor and drive electronics means a small motor can still generate significant power.

The challenge with wheel motors has always been to keep unsprung mass to a minimum. This is the mass that is below the suspension springs, such as the wheel, hub, brakes etc., and can move independently. A low mass improves ride quality for the driver and passengers and makes it easier for the suspension to keep the tires in contact with the road. A vehicle powered by in-wheel electric motors will have significantly greater unsprung mass, because the weight of a motor will be carried in each powered wheel. However, this can be all but mitigated by careful suspension design. Every technology on a car is a compromise of some sort, it is important to remember that while wheel motors have some disadvantages, they also have major advantages.

Figure 79 Protean Electric's in-wheel motor system is arguably simpler than a conventional electric automobile, which has constant-velocity joints, drive shafts, and a centrally mounted transmission and motor (Source: Protean Electric)

[8] Protean Electric: h8ps://www.proteanelectric.com

[9] To set a context here, 90A at 400V is 36kW, which is going on for 50hp directly to just one wheel

3.2. Hybrid electric vehicle layouts

3.2.1. Introduction

Hybrid vehicles use at least one electric drive motor in addition to the internal combustion engine (ICE). There are several different ways in which this can be combined and a number of different motors and engines. Note that for clarity, we will generally refer to the ICE as an engine and the electric drive motor as a motor. Take care though in other parts of the world, the ICE can be referred to as a motor!

There are three main objectives in the design of a hybrid vehicle:

1. Reduction in fuel consumption
2. Reduction in emissions
3. Increased torque and power.

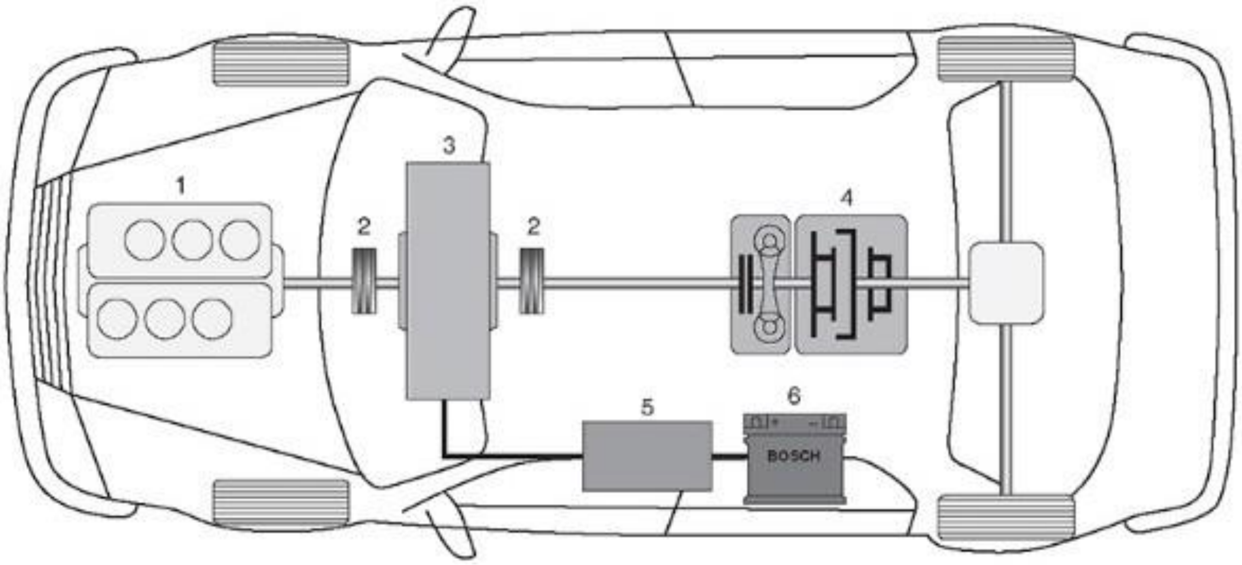


Figure 80 Hybrid layout (parallel): 1. ICE, 2. Clutch, 3. Motor, 4. Transmission, 5. Inverter, 6. Battery

A hybrid vehicle needs a battery to supply the motor. The most common types are nickel-metal-hydride (Ni-MH) or lithium-ion (Li-ion) and usually work at voltages between 200 and 400V. However, higher voltages are now being used. The batteries on hybrids are smaller than on pure EVs.

The motors are generally permanent magnet types and work in conjunction with an inverter (converts DC to AC, but more on this later). The key benefit of an electric drive is high torque at low speed, so it is an ideal supplement to an internal combustion engine where the torque is produced at higher speeds. The combination therefore offers good performance at all speeds. The following graph shows typical results – note also that the engine capacity is reduced in the hybrid, but the result is still an improvement.

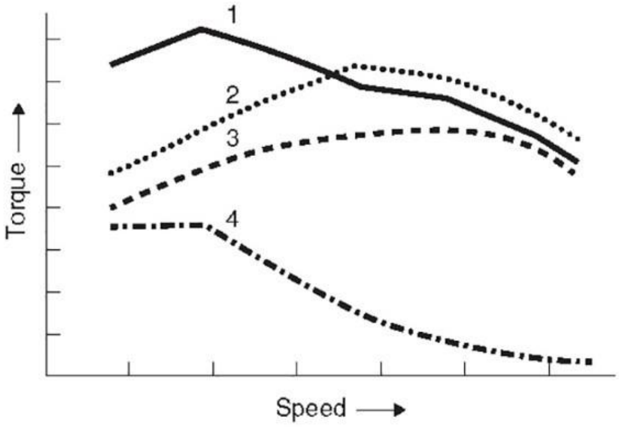


Figure 81 Comparing torque curves: 1. Hybrid, 2. Standard engine (1600cc), 3. Downsized engine (1200cc), 4. Motor (15kW)

The result of the hybridization of a motor and an engine is that it can always be operated (with suitable electronic control) at its optimum speed for reducing emission and consumption while still producing good torque. A smaller capacity engine can also be used (downsizing) in conjunction with a higher-geared transmission so the engine runs a lower speed (down speeding) but performance is maintained.

During braking the motor becomes a generator and the energy that would normally be wasted as heat from the brakes, is converted into electrical energy and stored in the battery. This is used at a later stage and in some cases the vehicle can run on electric only with zero emissions. Plug-in hybrids have larger batteries so take this option even further.

3.2.2. Classifications

Hybrids can be classified in different ways. There have been several different variations of this list, but the accepted classification is now that a hybrid will fit in one of these four categories:

- Start/stop system
- Mild hybrid
- Strong hybrid
- Plugin hybrid.

The functions available from the different types are summarized in the following table:

Table 8 Hybrid functions

ClassificaHon / FuncHon	Start/stop	RegeneraHon	Electrical assistance	Electric only driving	Charging from a power socket
Start/stop system	√	√			
Mild hybrid	√	√	√		
Strong hybrid	√	√	√	√	
Plugin hybrid.	√	√	√	√	√

Figure 82 Charging

A stop/start system has the functions of stop/start as well as some regeneration. The control of the normal vehicle alternator is adapted to achieve this. During normal driving, the alternator operates with low output. During overrun the alternator output is increased in order to increase the braking effect to increase power generation. Stopping the engine when idling saves fuel and reduces emissions. An uprated starter motor is needed to cope with the increased use as the vehicle is auto started as the driver presses the accelerator. Fuel savings can be up to 5%.

The mild hybrid is as above but also provides some assistance during acceleration, particularly at low speeds. Pure electric operation is not possible; the motor can propel the vehicle, but the engine is always running. Fuel savings can be up to 15%.

A strong hybrid takes all of the above functions further and over short distances the engine can be switched off to allow pure electric operation. Fuel savings can be up to 30%.

The plug-in hybrid is a strong hybrid but with a larger high voltage battery that can be charged from a suitable electrical power supply. Fuel savings can be up to 70%.

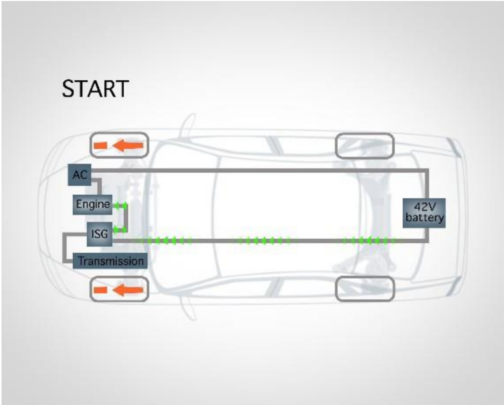
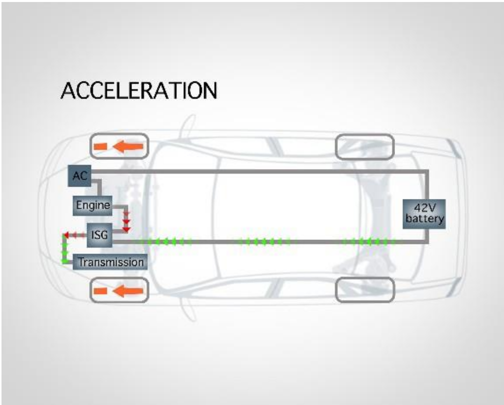
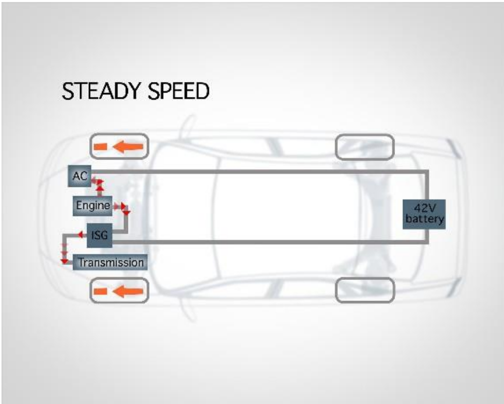
3.2.3. Operation

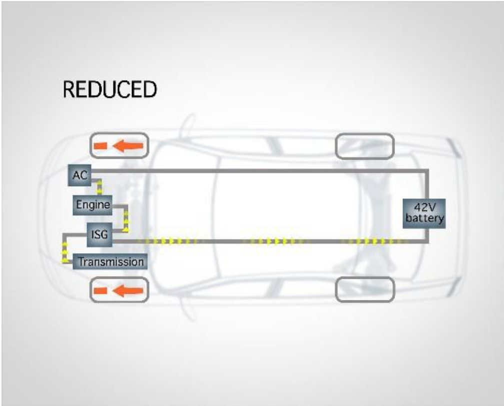
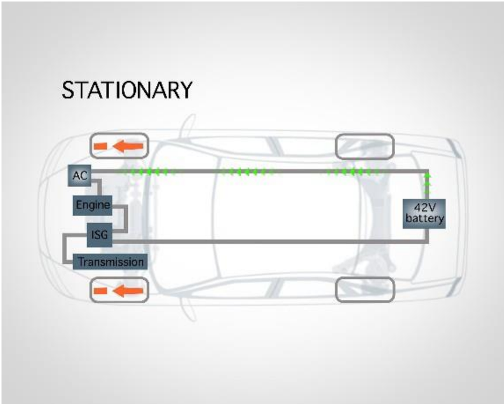
In addition to a stop/start function and full electric operation, there are five main operating modes that a hybrid vehicle will use, some vary a little, but the following modes are typical:

- Start
- Acceleration
- Cruising
- Deceleration
- Stationary

The operating modes are explained in detail in this table. Note, the images show a 42V hybrid system developed by Volvo, but higher voltage light hybrids follow similar operating principles. The motor here is labelled as ISG (integrated starter generator).

Table 9 Detailed operating modes

Mode	Details	
Start	Under normal conditions, the ISG will immediately start the engine using energy from the drive battery. On some cars, if the state of charge (SOC) of the high voltage battery is low, the temperature is too low, or if there is a failure of the motor system, the engine is cranked by a normal 12V starter.	 Figure 12 Start (Source: Volvo Media)
Acceleration	During acceleration, current from the battery module is converted to AC by an inverter and supplied to the ISG - which functions as a motor. The motor output is used to supplement the engine output so that power available for acceleration is maximized. Current from the battery module can also be converted to 12V DC for supply to the vehicle electrical system. This reduces the load that would have been caused by a normal alternator and so improves acceleration. When the drive battery state of charge is reduced to the minimum level, no assist will be provided.	 Figure 13 Acceleration (Source: Volvo Media)
Cruising	When the vehicle is cruising at a steady speed, the engine drives the transmission because this is the most efficient mode for an internal combustion engine (ICE). The drive battery may be charged if needed.	 Figure 14 Steady speed/cruising (Source: Volvo Media)

Deceleration	During deceleration (as well as fuel cut-off for the ICE), the ISG is driven by the wheels such that regeneration takes place. The generated output is used to charge the high voltage battery. During braking (brake switch on for example), a higher amount of regeneration will be allowed. This will increase the deceleration force so the driver will automatically adjust the force on the brake pedal. In this mode, more charge is sent to the battery module.	 **Figure 15 Reduced speed/deceleration (Source: Volvo Media)**
Stationary	On most hybrids now, the engine will almost never run at idle. This is because the motor will be used to move the vehicle and start the engine if necessary. Other vehicle functions such as AC can be run from the high voltage battery if enough power is available.	 **Figure 16 Stationary (Source: Volvo Media)**

The technique used by most hybrid cars can be thought of as a kinetic energy recovery system (KERS). This is because instead of wasting heat energy from the brakes as the vehicle is slowed down, a large proportion is converted to electrical energy and stored in the battery as chemical energy. This is then used to drive the wheels so reducing the use of chemical energy from the fuel.

Figure 83 Hybrid car (Source: Porsche Media)

3.2.4. Configurations

A hybrid power system for an automobile can have a series or parallel configuration (or a combination of the two). With a series system, an engine drives a generator, which in turn powers a motor. The motor propels the vehicle. With a parallel system, the engine and motor can both be used to propel the vehicle. Most hybrids in current use employ a parallel system. The power split is a combination of series and parallel and has additional advantages, but it is more complex.

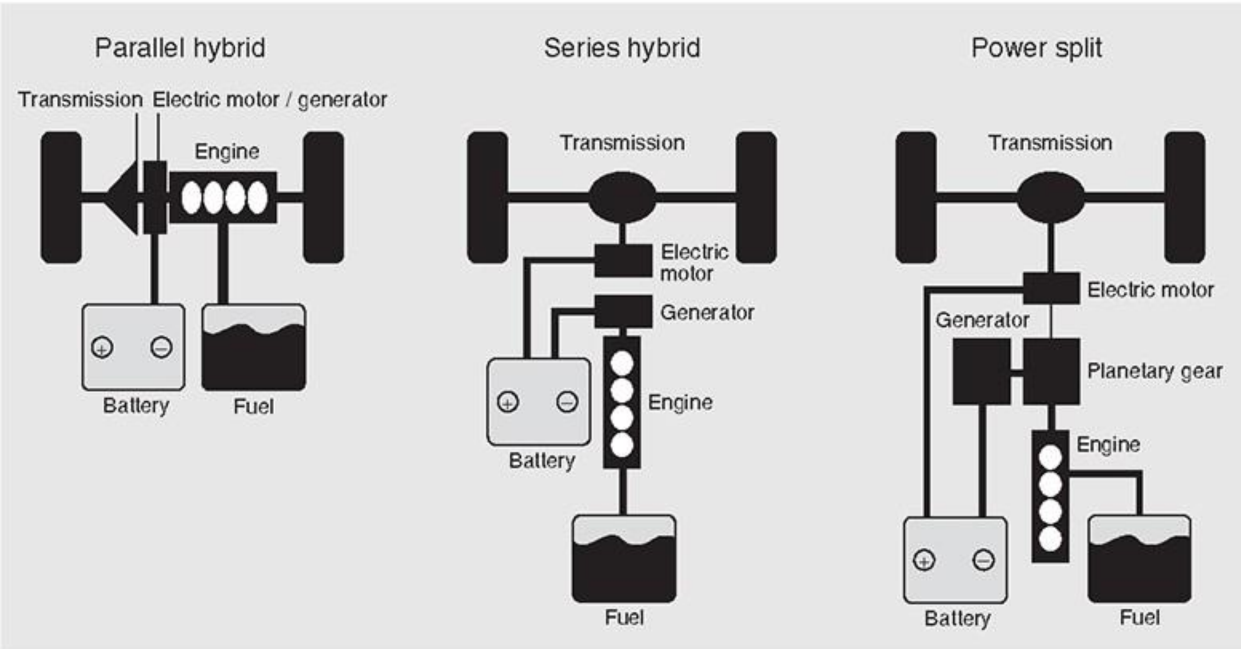


Figure 84 Three types of hybrid vehicles (Parallel, Series, Power split)

Hybrids electric vehicles are often described as being in categories P0 to P4, PS, or EE as shown here:

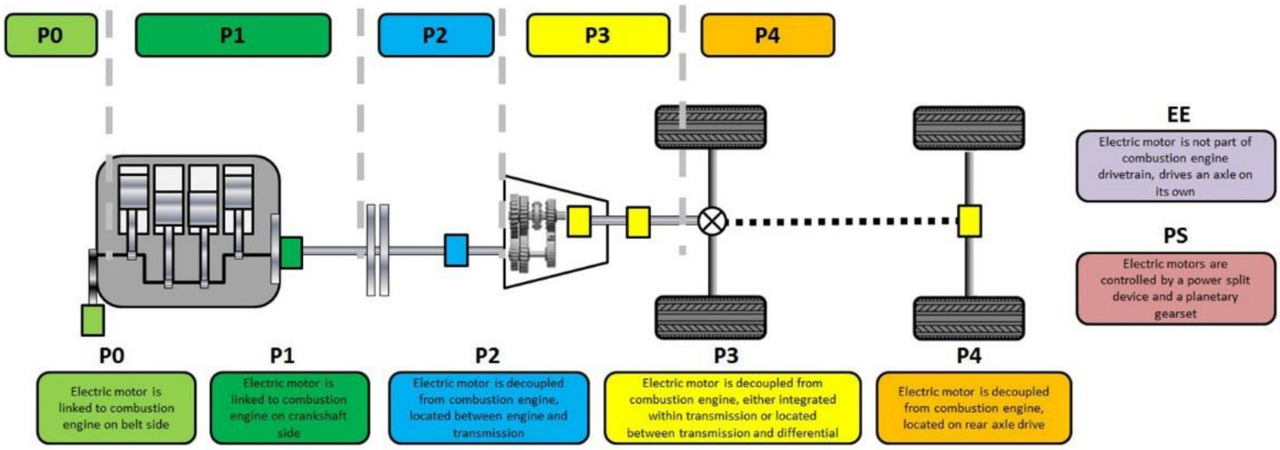


Figure 85 Hybrid descriptions (Source: Solvay)

There are numerous configurations as manufacturers have developed different systems and methods. However, it is now generally accepted that HEVs fall into one of the following descriptions:

- Belt drive hybrid (P0)
- Parallel hybrid with one clutch (P1)
- Parallel hybrid with two clutches (P2)

- Parallel hybrid with double-clutch transmission (P3)
- Axle-split parallel hybrid (P4)
- Series hybrid (EE)
- Series-parallel hybrid (EE/P2/PS)
- Power-split hybrid (PS)

The ‘parallel hybrid with one clutch’ is shown in the following figure. This layout shown is a mild hybrid where the engine and motor can be used independently of each other, but the power flows are in parallel and can be added together to get the total drive power. The engine will run all the time the vehicle is driving, at the same speed as the motor.

The main advantage of this configuration is that the conventional drivetrain can be maintained. In most cases only one motor is used, and fewer adaptations are needed when converting a conventional system. However, because the engine cannot be decoupled it produces drag on overrun and reduces the amount of regeneration. Pure electric driving is not possible.

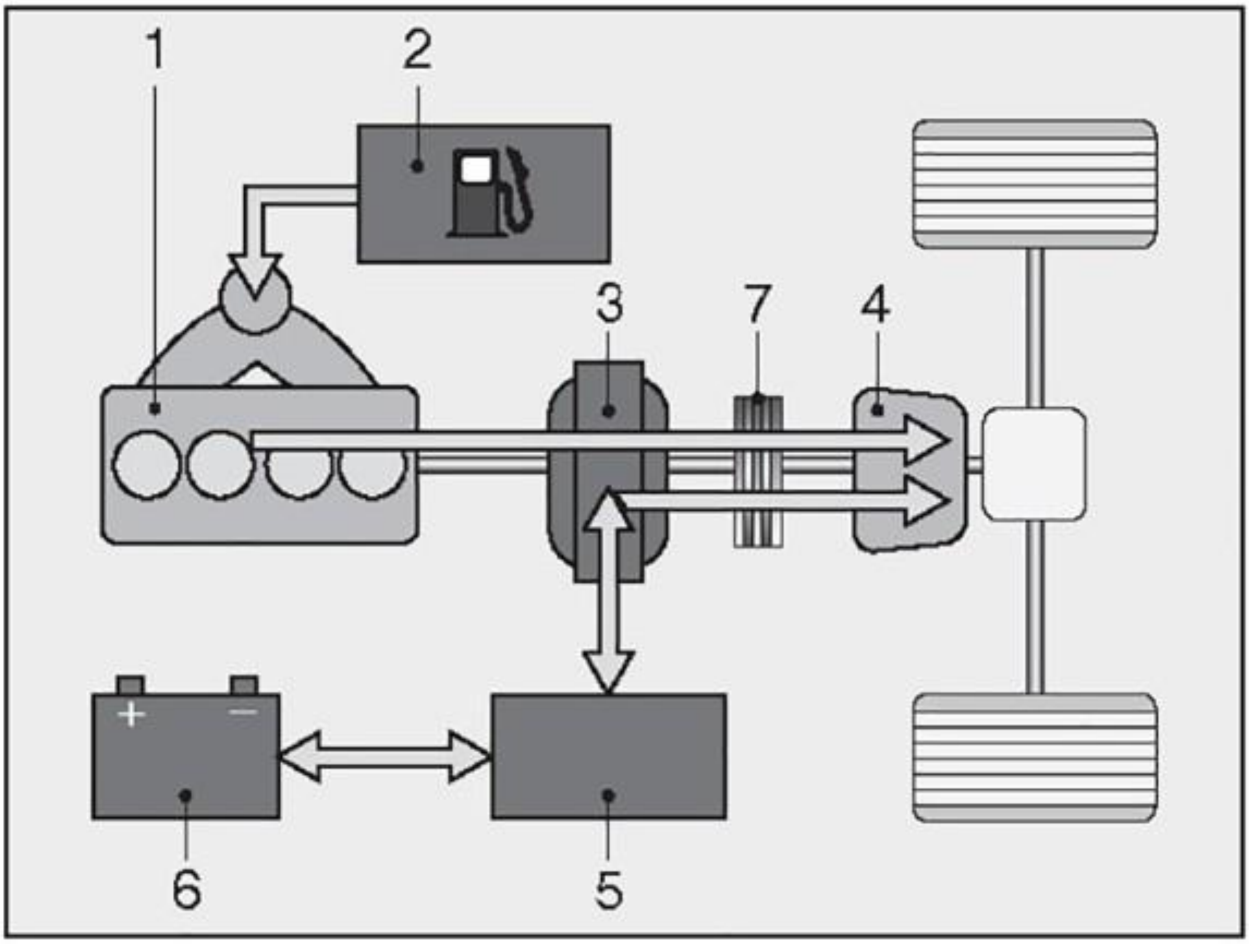


Figure 86 Parallel hybrid with one clutch (P1-HEV). 1. Engine, 2. Fuel tank, 3. Motor (integrated motor generation – IMG), 4. Transmission, 5. Inverter, 6. Battery, 7. Clutch

A parallel hybrid with two clutches is a strong hybrid and is an extension of the mild hybrid outlined above except that the additional clutch allows the engine to be disconnected. This means pure electric use is possible.

Electronic control systems are used to determine when the clutches are operated, for example the engine can be decoupled during deceleration to increase regenerative braking. It even allows the vehicle to go into ‘sailing’ mode where it is slowed down only by rolling friction and aerodynamic drag.

If the engine-clutch is operated in such a way as to maintain torque, then the engine can be stopped and started using the clutch – a sophisticated bump start! Sensors and intelligent controls are needed to achieve this. In some cases, a separate starter motor is used as a backup.

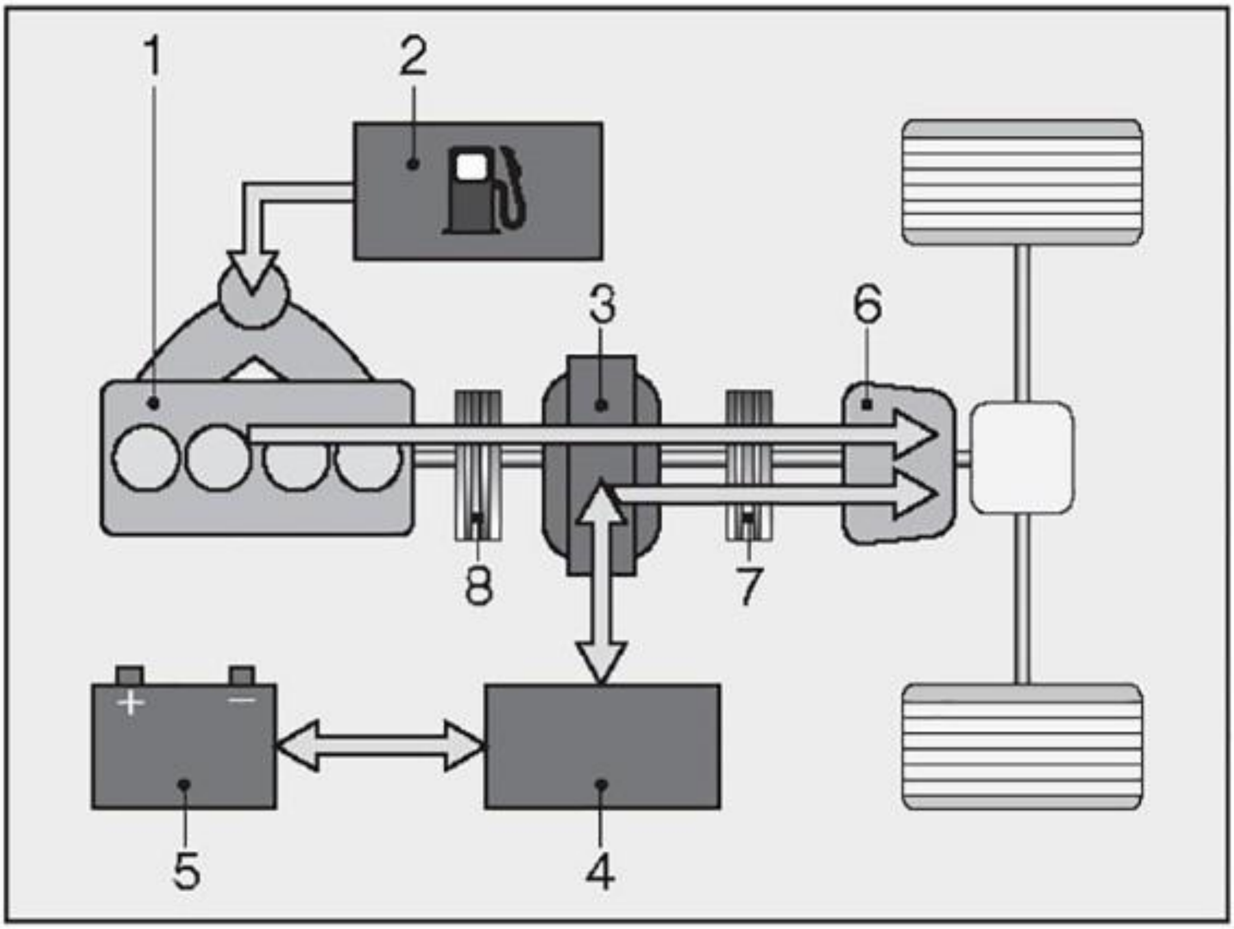


Figure 87 Parallel hybrid with two clutches (P2-HEV). 1. Engine, 2. Fuel tank, 3. Motor (integrated motor generation – IMG), 4. Inverter, 5. Battery, 6. Transmission, 7. Clutch one, 8. Clutch two

Adding the extra clutch in the previous system increases the length of the transmission and this may be a problem, particularly in FWD cars. If a double-clutch transmission is used in the configuration shown in the following picture, then this problem is overcome. The motor is connected to a subunit of the transmission instead of the engine crankshaft or flywheel. These transmissions are also described as direct shift gearboxes or DSG. Pure electric driving is possible by opening the appropriate transmission clutch or both engine and motor can drive in parallel. The gear ratio between engine and motor can also be controlled in this system allowing designers even greater freedom. Sophisticated electronic control, sensor and actuators are necessary.

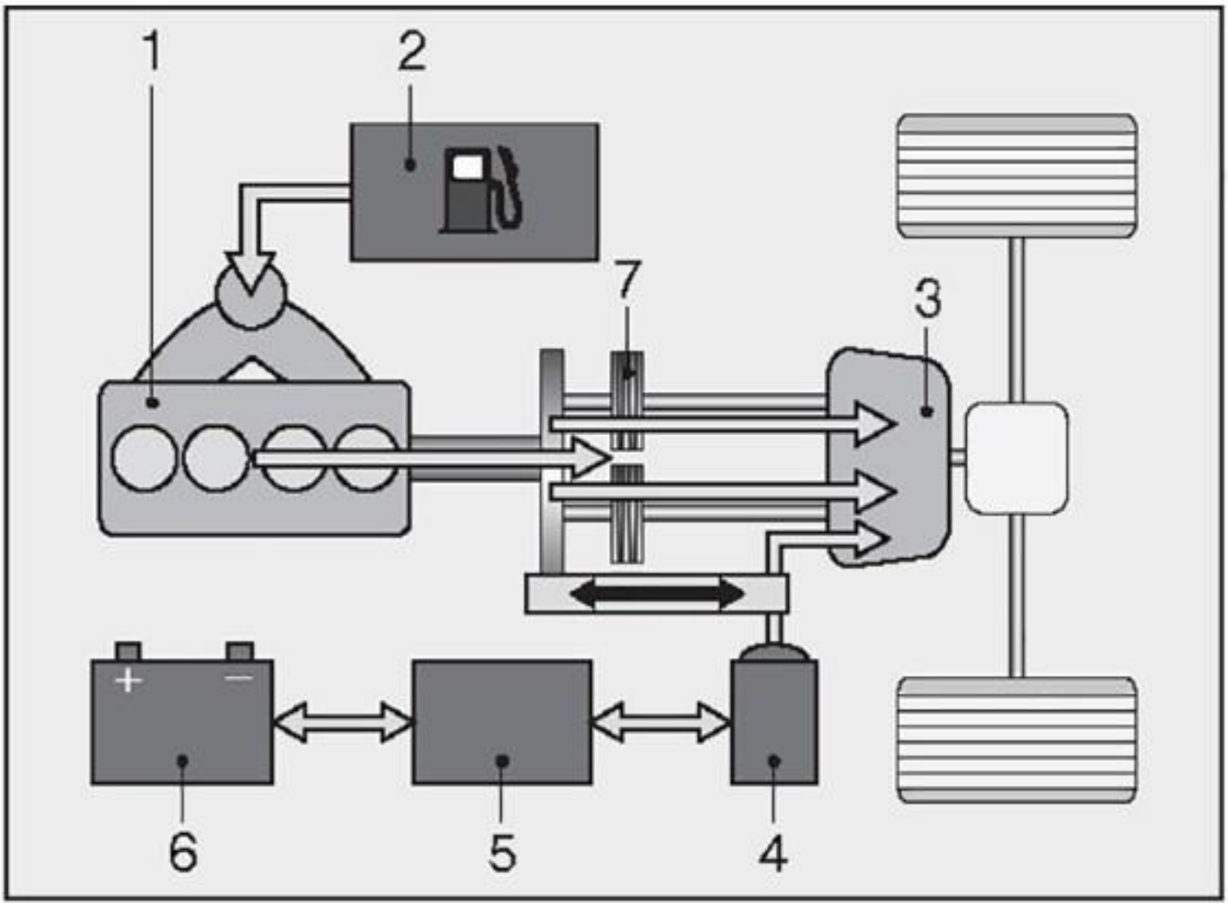


Figure 88 Parallel hybrid with double-clutch transmission. 1. Engine, 2. Fuel tank, 3. Transmission, 4. Motor, 5. Inverter, 6. Battery, 7. Clutches

The axle-split parallel hybrid is also a parallel drive even though the motor and engine are completely separated. As the name suggests, they drive an axle each. A semi-automatic transmission together with a stop/start system are needed with this layout. As the engine can be completely decoupled this configuration is suitable for operation as a strong hybrid. It can effectively deliver all-wheel drive when the battery is charged and, in some cases, to ensure this, an additional generator is fitted to the engine to charge the high voltage battery even when the vehicle is stationary.

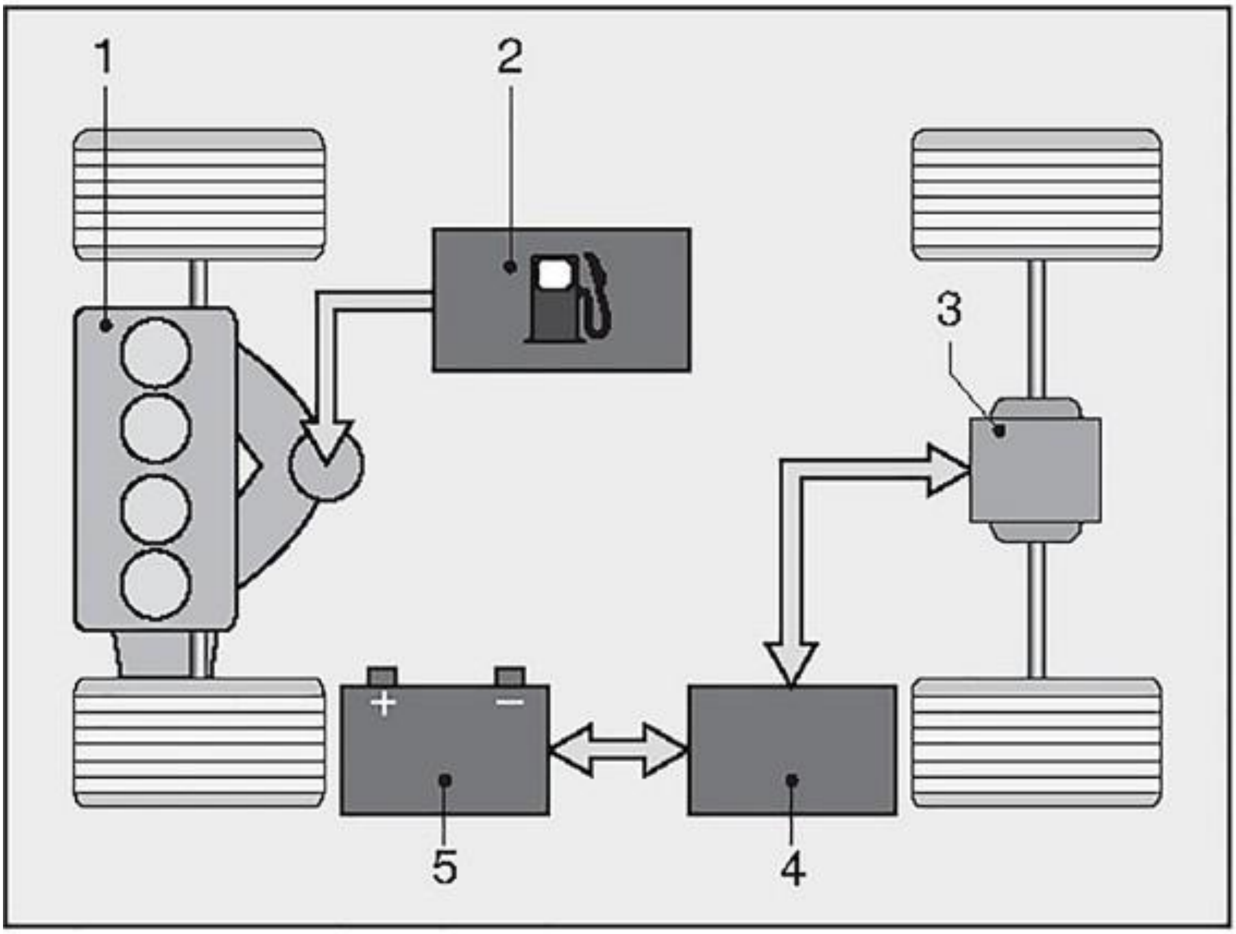


Figure 89 Axle-split parallel hybrid. 1. Engine, 2. Fuel tank, 3. Motor, 4. Inverter, 5. Battery

A series hybrid configuration is a layout where the engine drives a generator (alternator) that charges the battery that powers a motor that drives the wheels! A series configuration is always a strong hybrid since all the previously stated functions are possible (table 1). A conventional transmission is not needed so this creates space for packaging the overall system – a larger battery for example. The engine can be optimized to only operate in a set range of rpm. Stopping and starting the engine has no effect on the vehicle drive therefore the control systems are less sophisticated. The main disadvantage is that the energy must be converted twice (mechanical to electrical, and electrical back to mechanical) and if the energy is also stored in the battery, three conversions are needed. The result is decreased efficiency, but this is made up for by operating the engine at its optimum point. There is a 'packaging advantage' in this layout because there is no mechanical connection between the engine and the wheels.

This is the layout is now used for range extended electric vehicle (REVs). In this case the car is effectively pure electric, but a small engine is used to charge the battery and 'extend the range' or at least reduce range anxiety.

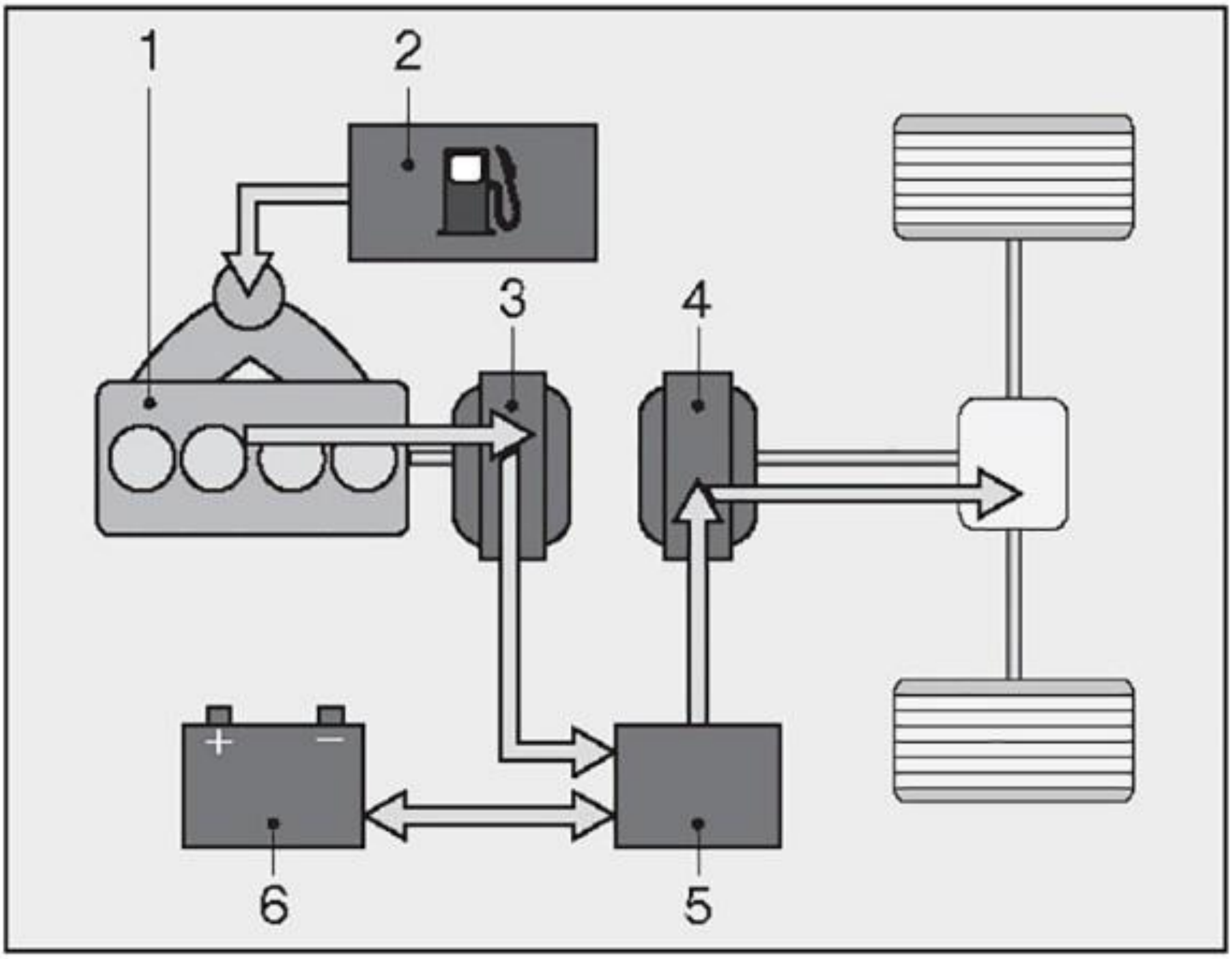


Figure 90 Series hybrid. 1. Engine, 2. Fuel tank, 3. Alternator/Generator, 4. Motor, 5. Inverter, 6. Battery

Series-parallel hybrid systems are an extension of the series hybrid because of an additional clutch that can mechanically connect the generator and motor. This eliminates the double energy conversion except at certain speed ranges. However, the ‘packaging advantage’ of the series drive is lost because of the mechanical coupling. Further, two electric units are required as compared to the parallel hybrid.

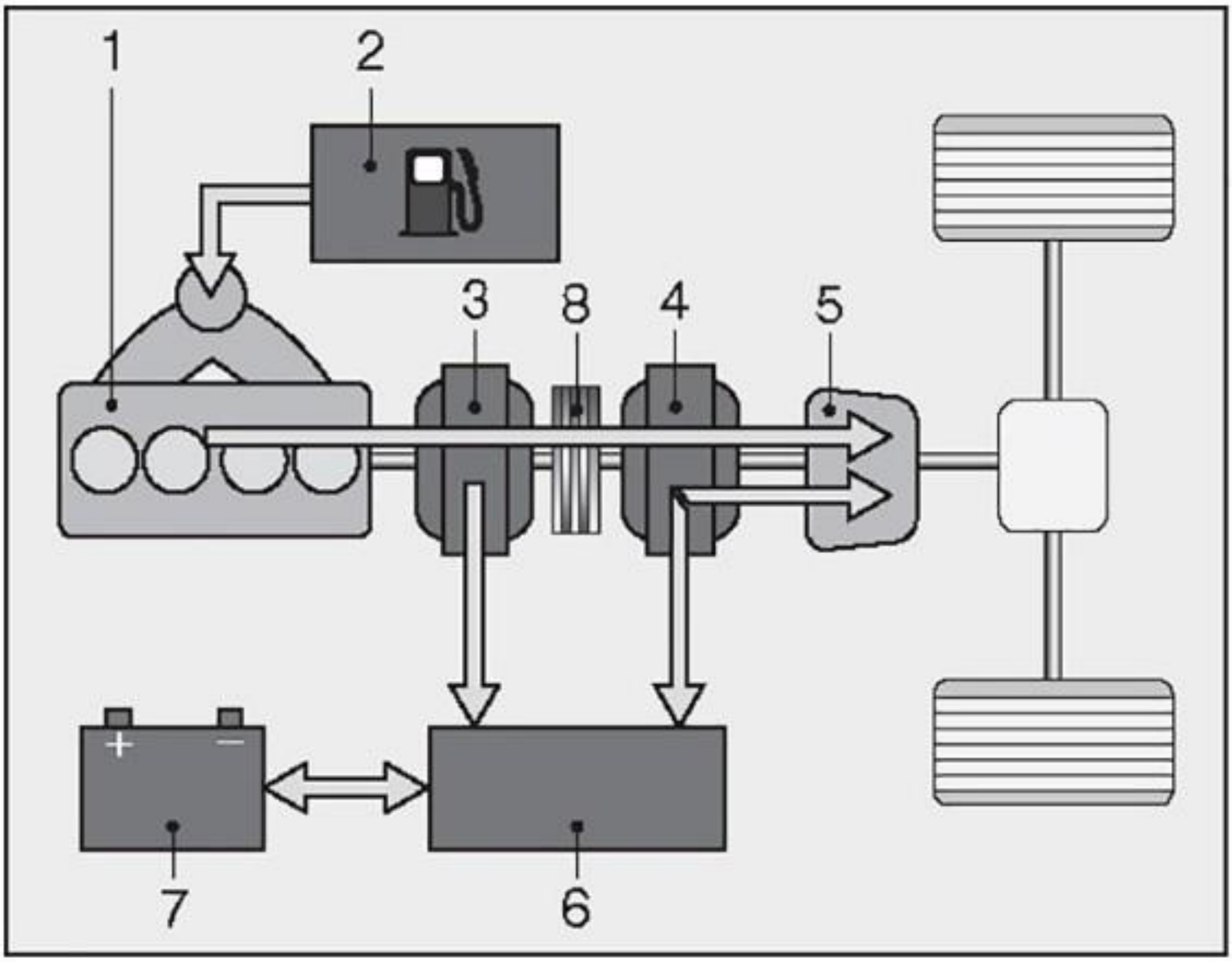


Figure 91 Series-parallel hybrid. 1. Engine, 2. Fuel tank, 3. Alternator/Generator, 4. Motor, 5. Transmission, 6. Inverter, 7. Battery, 8. Clutch

The power-split hybrids combine the advantages of series and parallel layouts but at the expense of increased mechanical complexity. A proportion of the engine power is converted to electric power by the alternator and the remainder, together with the motor, drives the wheels. A power-split hybrid is a strong hybrid.

The single mode concept shown in the following diagram, uses one planetary gear set (a dual mode system uses two and can be more efficient but even more complex mechanically). The gear set is connected to the engine, alternator, and the motor. Because of the epicyclic gearing the engine speed can be adjusted independently of the vehicle speed (think of a rear wheel drive differential action where the two half shafts and prop shaft all run at different speeds when the car is cornering). The system is effectively an electric constantly variable transmission (eCVT). A combination of mechanical and electrical power can be transmitted to the wheels. The electrical path can be used at low power requirements and the mechanical path for higher power needs.

The system therefore achieves good savings at low and medium speeds but none at high speeds where the engine only drives mostly via the mechanical path.

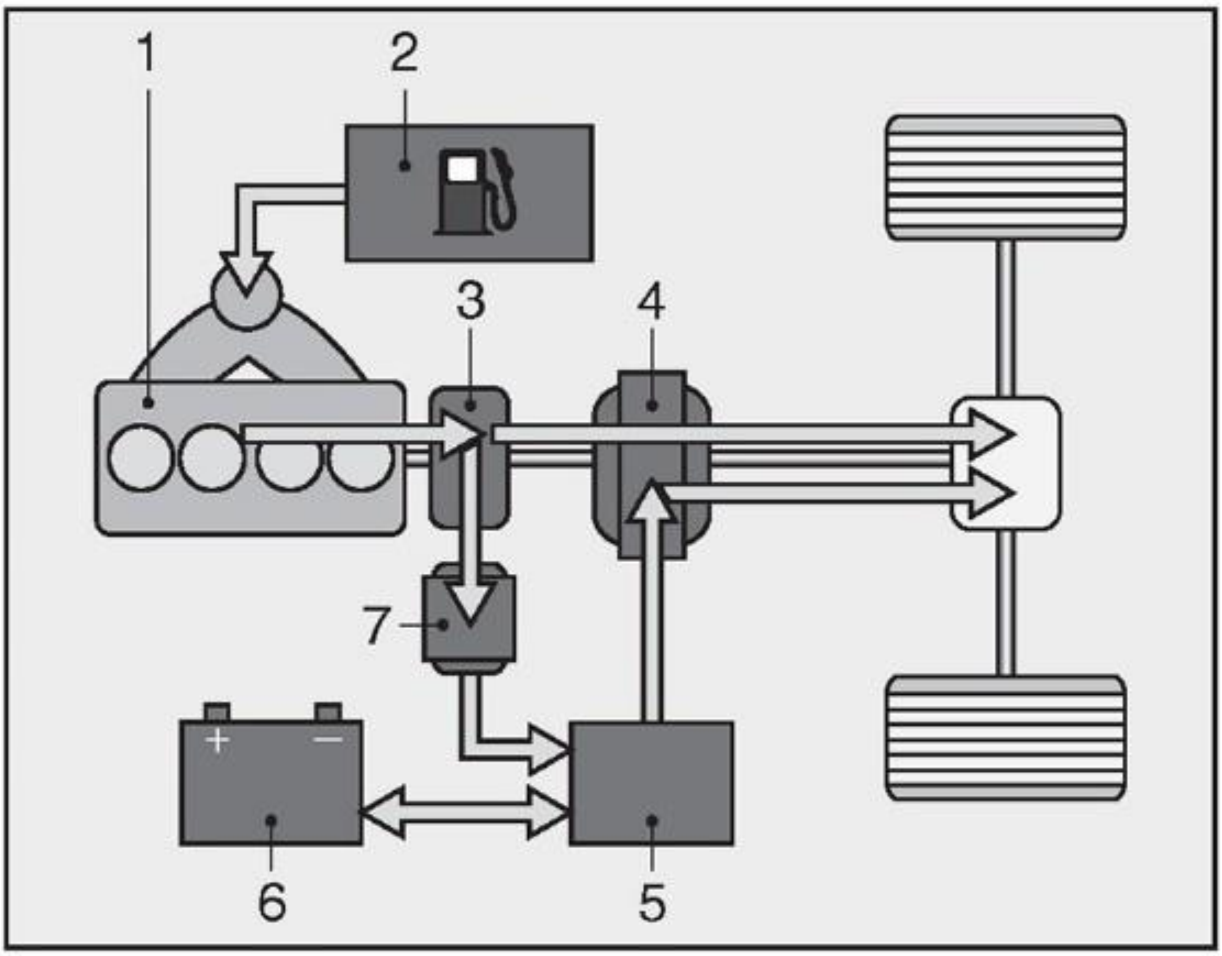


Figure 92 Power-split hybrid (single mode concept). 1. Engine, 2. Fuel tank, 3. Planetary gear set, 4. Motor, 5. Inverter, 6. Battery, 7. Generator

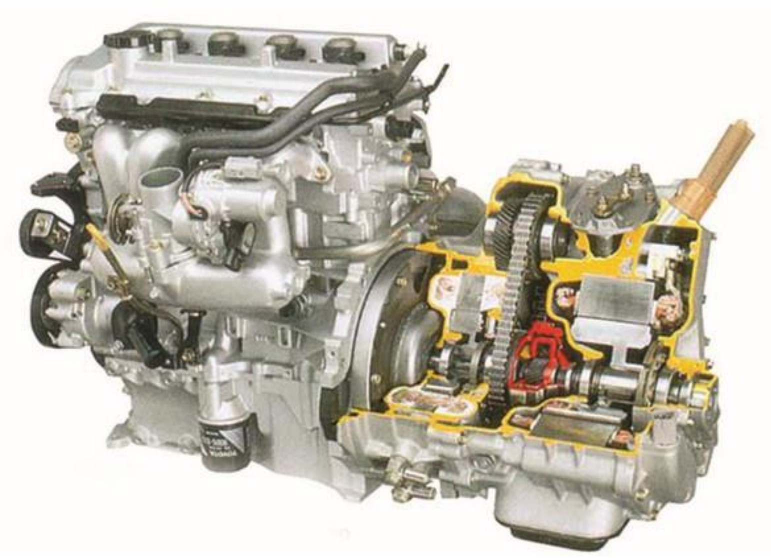


Figure 93 Power split hybrid (Source: Toyota)

3.2.5. 48V Hybrid

Bosch has developed a hybrid powertrain that makes economic sense even in smaller vehicles. The system costs much less that normal hybrid systems but could still reduce consumption by up to 15%. The electrical powertrain provides the combustion engine with an additional 150Nm of torque during acceleration. That corresponds to the power of a sporty compact-car engine.

Unlike conventional high voltage hybrids, the system is based on a lower voltage of 48V and can therefore make do with less expensive components. Instead of a large electric motor, the generator has been enhanced to output four times as much power. The motor generator uses a belt to support the combustion engine with up to 10kW. The power electronics forms the link between the additional low-voltage battery and the motor generator. A DC/DC converter supplies the car’s 12V on-board network from the 48V vehicle electrical system. The newly developed lithium-ion battery is also significantly smaller.

Figure 94 Bosch expects some 4 million new vehicles worldwide to be equipped with a low voltage hybrid powertrain in 2020 (Source: Bosch Media)

3.2.6. Hybrid control systems

The efficiency which can be achieved with the relevant hybrid drive is dependent on the hybrid configuration and the higher-level hybrid control. The following figure uses the example of a vehicle with a parallel hybrid drive. Shown are the networking of the individual components and control systems in the drivetrain. The higher-level hybrid control coordinates the entire system, the subsystems of which have their own control functions. These are:

- battery management

- engine management
- management of the electric drive
- transmission management
- management of the braking system.

In addition to control of the sub-systems, the hybrid control also includes an operating strategy which optimizes the way in which the drivetrain is operated. The operating strategy directly affects the consumption and emissions of the hybrid vehicle. This is during start-stop operation of the engine, regenerative braking, and hybrid and electric driving.

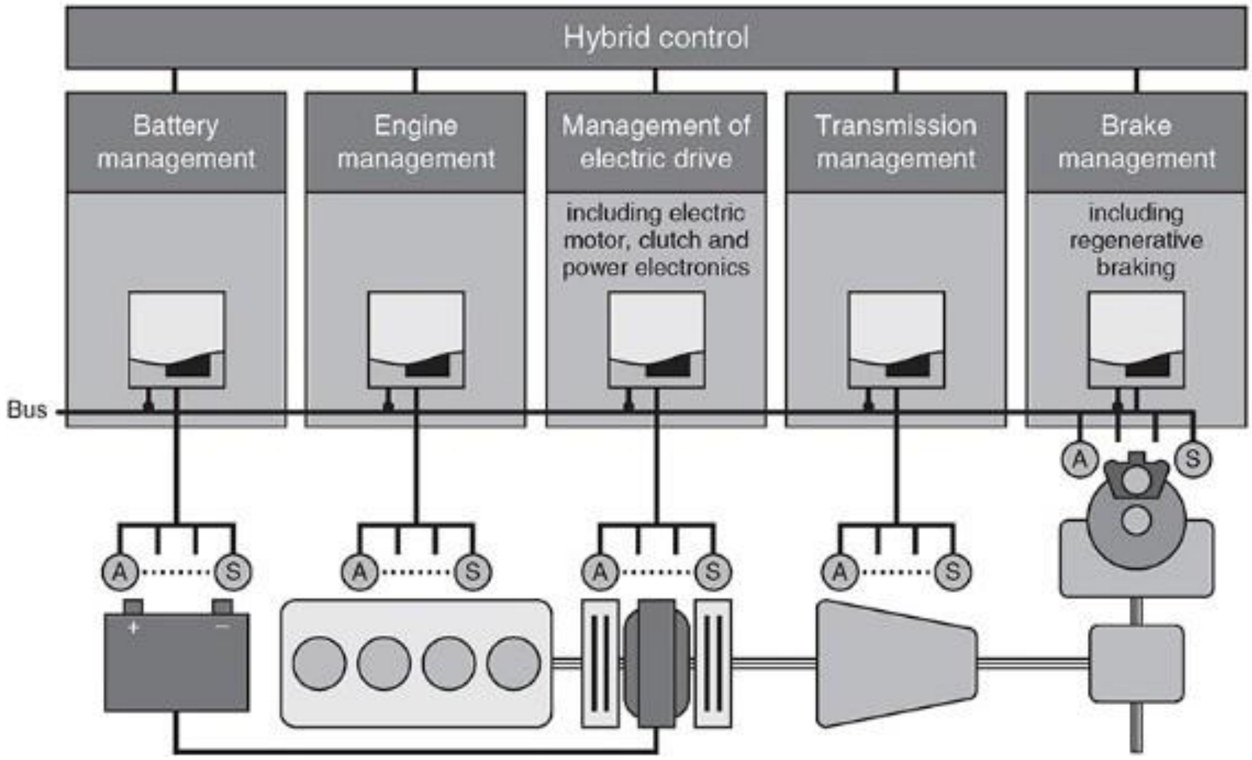


Figure 95 Parallel hybrid control system. A. actuator, S, sensor.

3.2.7. Efficiency

The big E word is: Efficiency! This is where engineers spend most of their time making small but important steps that improve operation of a vehicle. Efficiency is the ratio of the useful work performed by a machine or process, compared to the total energy consumed. It can be expressed as a percentage, but engineers also use the Greek letter Eta (η) as the symbol for efficiency.

Figure 30 shows the main types of hybrid and notes some typical transmission efficiency figures:

- P0: e-machine is connected to the crankshaft by belt
- P1: e-machine is assigned to the transmission input shaft between ICE and coupling
- P2: e-machine is assigned to the transmission input shaft. (P2.5: e-machine is integrated in the hybrid transmission)
- P3: e-machine is assigned to the transmission output shaft
- P4: e-machine is integrated in the axle drive

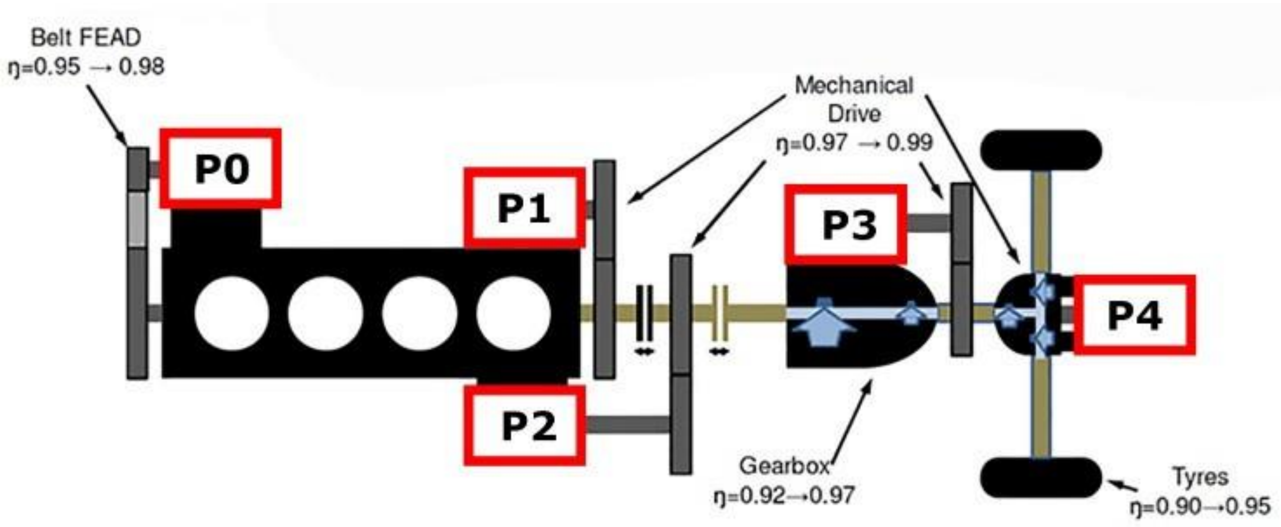


Figure 96 Typical efficiency figures for different hybrid drives

In addition to the mechanical efficiency of various drives, it is important to look at the figures for the battery, motor/generator, and power transmission (cabling). The way the battery is constructed has an impact on efficiency too. An interesting comparison is between a 350V system and a 48V system.

The battery will have a typical efficiency of 0.83 to 0.91 at 350V, and 0.80 to 0.88 at 48V. However, at lower voltage and therefore higher current, the cabling power loss increases. Cables have a typical impedance of 1.5 to 3mΩ. Figure 31 shows typical power loss in cables and how it is greater at lower voltage.

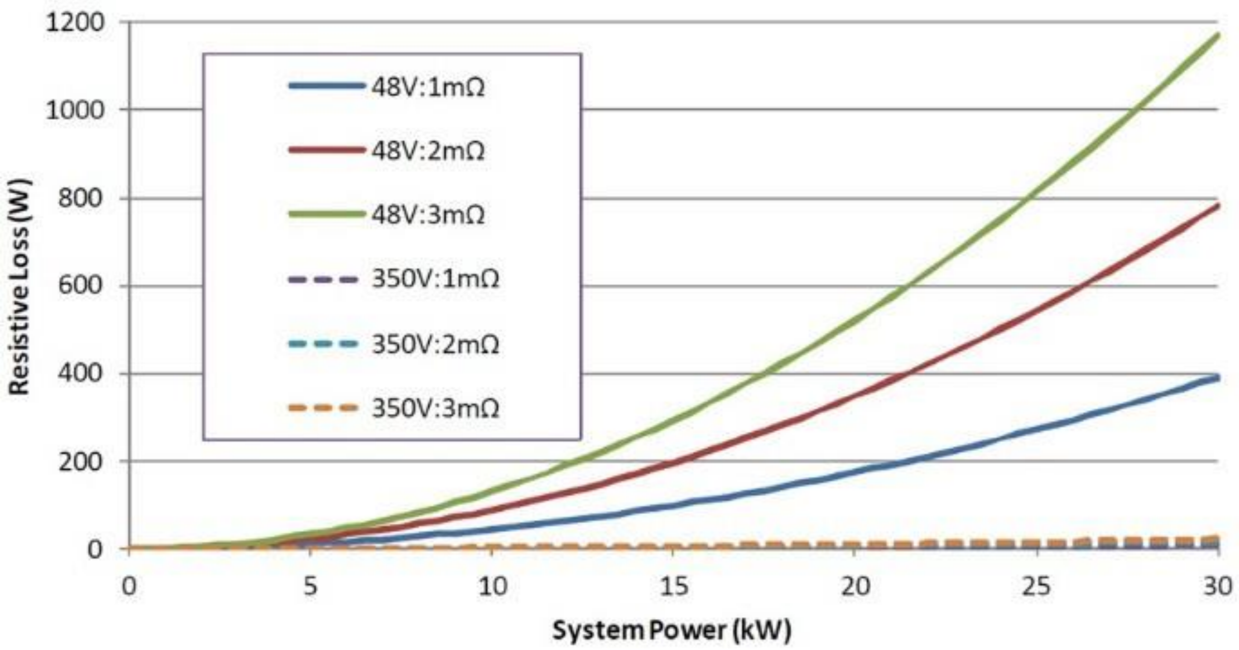


Figure 97 Cable losses

3.3. Cables and components

3.3.1. High voltage cables

Any cable used on a vehicle should be insulated to prevent contact and short circuits. Most cables are made from many strands of copper wire as this offers low resistance and retains flexibility. The insulation is normally a form of PVC.

Figure 98 VW e-Golf showing some of the orange cables

High voltage cables require greater insulation to prevent voltage leakage, but also because the risk of harm if touched is very high. Stickers with various symbols are used as a warning together with the bright orange color.

Figure 99 Orange cables and warning stickers on a Golf GTE

To deliver high power, they must carry a high current – even at high voltage! Remember:

- Power equals voltage multiplied by current (P = IV)
- Current therefore equals power divided by voltage (I = P/V).

We will assume a voltage of 250V to make the calculations easy! If a cable must deliver, say, 20kW (20,000W) then 20,000/250 = 80A. Under hard acceleration this figure is even higher 80kW for example, which would require a current of 320A. For this reason, the cables are quite thick as well as being highly insulated.

Figure 100 Battery cables (Source: BMW Media)

3.3.2. Components

It is important to be able to identify EV components. In many cases manufacturers' information will be needed to assist with this task. Slightly different names are used by some manufacturers but in general the main components are:

- battery
- motor
- relays (switching components)
- control units (power electronics)
- charger (on-board)
- charging points
- isolators (safety device)
- inverter (DC to AC converter)
- battery management controller
- DC to DC converter
- ignition/key-on control switch
- driver display panel/interface

Some of these components are also covered in other parts of this book. Possible additions to this list are other vehicle systems such as braking and steering or even air conditioning as they must work in a different way on a pure EV.

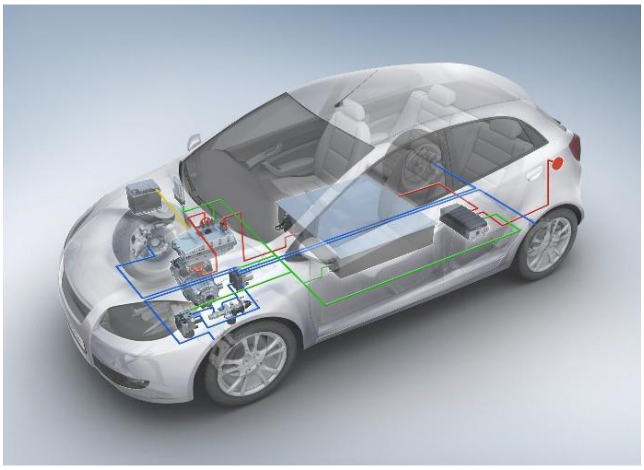


Figure 101 High voltage components shown in red, braking components in blue, low voltage in yellow and sensor/date shown in green (Source: Bosch Media)

The key components will now be described further.

Battery: The most common battery technology now is lithium-ion. The complete battery pack consist of several cell modules (the actual battery consists of at least 200-300 cells), a cooling system, insulation, junction box, battery management and a suitable case or shell. These features combine so that the pack can withstand impacts and a wide range of temperatures. On some vehicles 2-3000 cells are used in a combination of series and parallel to achieve the required voltage and capacity.

The battery is usually installed in the underbody of the car. On a Pure-EV it can weight in excess of 300kg (660lbs) and for a PHEV in the region of 120kg (265lbs). Voltages vary and can be up to 800V, however, typically this is around 400V. The capacity of the battery is described in terms of kilowatt hours and will be in the region of 20-25kWh for a PHEV and can be up to 100kWh for a pure EV, but again this varies widely.

Battery management controller: This device monitors and controls the battery and determines amongst other things, the state of charge of the cells. It regulates the temperature and protects the cells against overcharging and deep discharge. Electronically activated switches are included that disconnect the battery system when idle and in critical situations such as an accident or fire. The device is usually part of the battery pack – but not always to check manufacturers' data.

Figure 102 Plugin hybrid car with components labeled (Source: Volkswagen Media)

Motor: This is the component that converts electrical energy into kinetic energy or movement – in other words it is what moves the vehicle. Most types used on EVs, HEVs (Hybrid Electric Vehicles) and PHEVs are a type of AC synchronous motor supplied with pulses of DC. They are rated in the region of 85kW on Pure- EVs.

Inverter: The inverter is an electronic device or circuit that changes direct current (DC) from the battery to alternating current (AC) to drive the motor. It also does this in reverse for regenerative charging. It is often described as the power electronics or similar.

DC to DC converter: This may be part of the inverter unit or a separate package. It is used to step down the high voltage to supply the 12V system because a normal alternator is not used on strong hybrids. On some systems it can work on both directions.

Control unit: Also called power control unit or motor control unit, this is the electronic device that controls the power electronics (inverter). It responds to signals from the driver (brake, acceleration etc.) and causes the power electronics to be switched accordingly. The control makes the motor drive the car or become a generator and charge the battery. It can also be responsible for AC, PAS, and brakes.

Charging unit: This device is used on pure-EVs and PHEVs and usually located near where the external power source is connected. It converts and controls the 'mains' voltage (typically 230/240V AC in Europe and 120V AC in the USA) to a suitable level for charging the battery cells (now usually about 400V DC).

Driver interface: To keep the driver informed there are a number of methods used. Most common now is a touch screen interface where information can be presented as well as allowing the driver to change settings such as the charge rate on this PHEV.

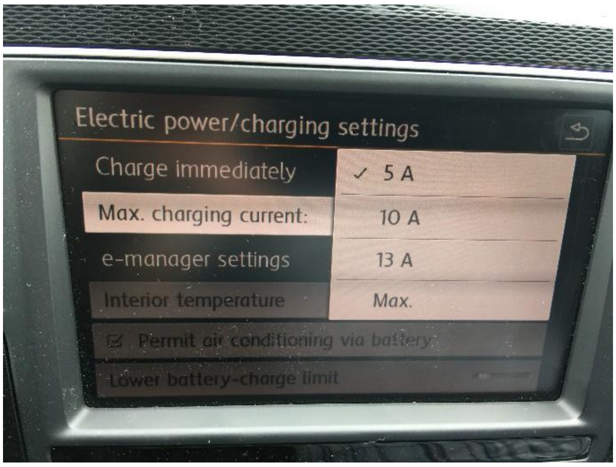


Figure 103 Setting the maximum charge current

3.3.3. ECE-R100

ECE-R100 is a standard developed by the United Nations (UN) to harmonize EV systems[10]. It is applicable for EVs, vehicle category M and N and capable of a top speed above 25km/h (15.5mph). In this section I have highlighted some key aspects of the regulation. It is generally about safety of the high voltage parts in an EV. Protection against electrical shock is a key aspect of the standard:

- It should not be possible that live high voltage parts in passenger and luggage compartments can be touched with a standardized test-pin or test-finger (yes, there really is a standardized test-finger!)
- All covers and protection of live high voltage parts should be marked with the official symbol (figure below) and access to live high voltage parts should only be possible by using a tool, and on purpose
- Traction battery and powertrain shall be protected by properly rated fuses or circuit breakers
- The high voltage powertrain must be isolated from the rest of the EV.

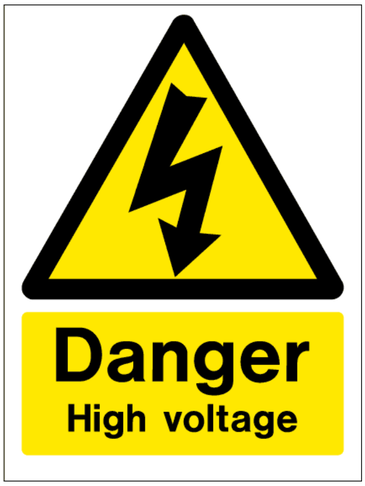


Figure 104 This warning symbol may be used with or without the text

[10] At the time of writing, the standard was on its third revision

Charging:

- The EV should not be able to move during charging
- All parts which are used while charging, should be protected from direct contact, under any circumstance
- Plugging in the charging cable must shut the system off and make it impossible to drive.

General safety and driving points:

- Starting the EV should be enabled by a key or suitable keyless switch
- Removing the key, prevents the car being able to drive.
- It should be clearly visible if the EV is ready to drive (just by pushing the throttle)
- If the battery is discharged the driver should get an early warning signal to leave the road safely
- When leaving the EV, the driver should be warned by a visible or audible signal if the EV is still in driving mode
- Changing the direction of the EV into reverse should only be possible by the combinations of two actuations or an electric switch which only operates when the speed is less then 5km/hr.
- If there is an event, like overheating, the driver should be warned by an active signal

Search www.unece.org for 'ECE 100' for a full copy of the latest standard.

3.4. Other systems

3.4.1. Heating and air conditioning

Most EVs allow the operation of heating or cooling when the vehicle is plugged in and charging. Some also allow this function directly from the battery. The most important aspect is that this allows the vehicle cabin to be 'pre-conditioned' (heated or cooled) on mains power, therefore saving battery capacity and increasing range. The two most common systems allow:

- Cooling with an electrically driven air conditioner compressor
- Heating with a high-voltage positive temperature coefficient (PTC) heater

These cooling and heating functions using the high-voltage components are usually activated with a timer or a remote app.

Many hybrid car systems combine the heating circuit by running it in parallel to the coolant circuit. It consists of a heat exchanger, a heater unit, and a feed pump.

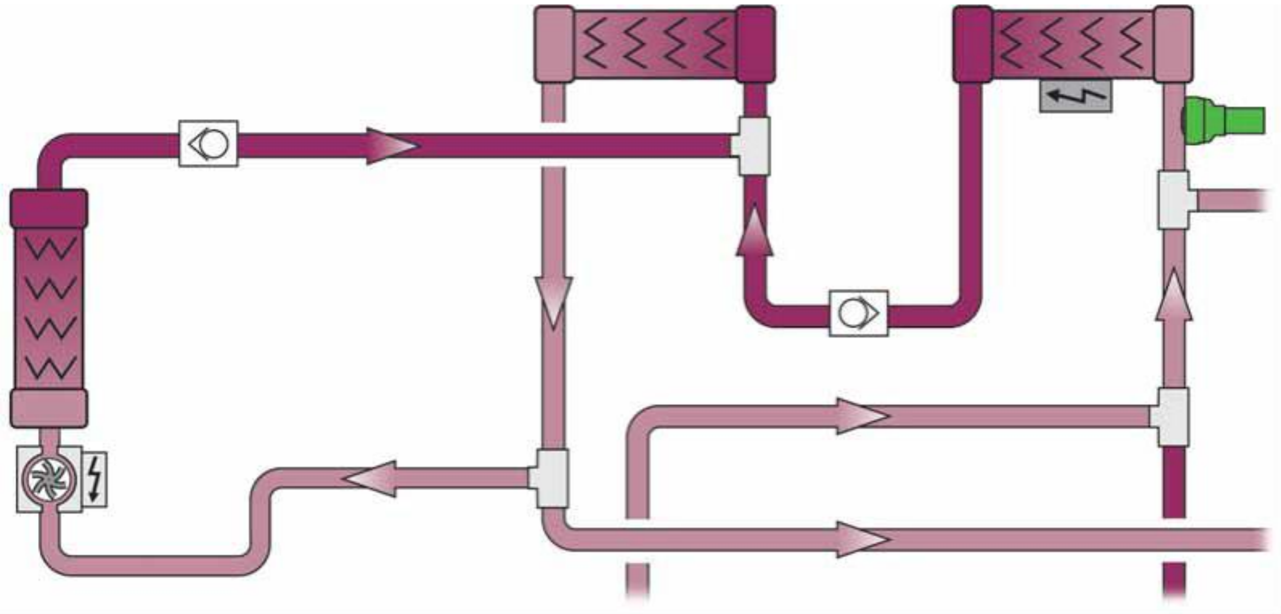


Figure 105 Heating circuit (Source: Volkswagen)

Cabin cooling systems operate in much the same way as on a conventional vehicle except that the AC compressor is electrically driven. This can be by the high voltage or a lower voltage system such as 42V (but not normally from 12V).

When necessary, the battery control unit can request cooling of the battery when it is being charged, so for this reason the battery cooling circuit and in some case the motor cooling circuit are combined with the engine cooling system on a hybrid. The electric pump makes the coolant flow.

3.4.2. Thermal challenges

Battery electric vehicle (BEV) supporters are keen to point to the 95% efficiency of the electric motor. This is compared with the most advanced petrol/gasoline engines, which have 40% thermal efficiency. These numbers can, however, be misleading. The figure for petrol engines is under high load conditions. The number is lower, more like 30% under other operating conditions. BEVs also suffer from electro-thermal losses. However, engineers are looking at how to use all waste heat to warm passengers in cold conditions.

3.4.3. Liquid cooling

The operation of the DC-DC converter, power electronics, and battery charging/discharging cycles all produce heat (table below). The electrical energy losses may total up to 40%. There is, therefore, a need for liquid cooling.[11]

Table 10 Thermal losses (increased charge and discharge power significantly increases waste heat)

Component	Thermal loss %	Temperature limit °C	Temperature limit F
Motor/Generator	3-5	85	185
Power electronics/Inverter	3-5	65	149
High voltage ba8ery	5-8	50	122
DC/DC converter	3-5	70	158
Charger	3-5	65	149

[11] Note, figures will vary across systems and manufacturers but these are a good average

Electric propulsion appears to have a significant efficiency advantage compared to ICE because of losses in the form of waste heat. However, the comparison is closer when the energy to produce the electricity is considered.

The size and weight of the lithium-ion battery pack are significant contributor to the cost of a BEV. There are also the resulting issues of range, recharging time, and the deteriorating effects on lithium-ion batteries in high-voltage, high-rate charging. In due course, solid-state batteries, could open the path to alternative chemistries with lower flammability than current lithium-ion batteries. For the same energy density, the solid-state type would be more compact and lighter. In the meantime, we have to work with what we have.

The current focus is on liquid cooling as an ideal way to deal with the challenges of high-voltage, high-rate charging and greater battery density. Air cooling is adequate for the smaller battery packs in hybrids. Liquid cooling permits controlled use of waste heat. Using this heat energy is better than adding expensive battery capacity or even a heat pump, which is a costly addition. Liquid cooling is also ideal for power electronics waste heat management and recovery. Battery refrigeration systems are under development for future BEVs (Battery Electric Vehicle) so they can withstand rapid charging of 100kW or more.

3.4.4. Heat pumps

A heat pump transfers heat energy from a source of heat to a thermal reservoir. It moves thermal energy in the opposite direction of spontaneous heat transfer. It does this by absorbing heat from a cold space and releasing it to a warmer one.

A heat pump uses external power to accomplish the work of transferring energy from the heat source to the heat sink. The most common design of a heat pump is almost exactly like a car AC system, working in reverse. It includes a condenser, an expansion valve, an evaporator, and a compressor. The heat transfer medium is a refrigerant. The key process is that evaporation of the refrigerant draws heat from its surroundings. Lick the back of your hand and blow on it! It feels cool because the moisture draws heat from your body as it evaporates.

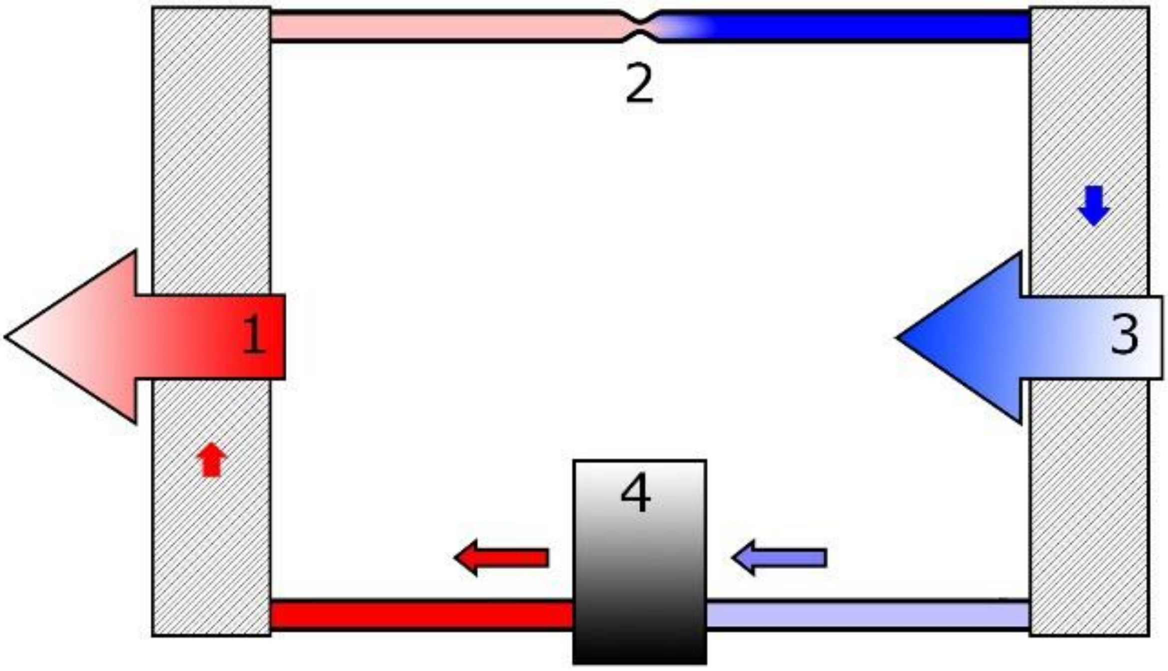


Figure 106 A simplified diagram of a heat pump's vapor-compression refrigeration cycle: 1) condenser, 2) expansion valve, 3) evaporator, 4) compressor

Heat pumps usually can be used either in heating mode or cooling mode, as required by the user. When a heat pump is used for heating, it employs the same basic refrigeration cycle used by an air conditioner or a fridge, but in reverse. It releases heat into the conditioned space rather than the surrounding environment. In-car heat pumps draw heat from the external air even when it is cooler than the cabin.

Heat pumps are significantly more energy efficient than simple electrical resistance heaters. However, the cost of installing a heat pump is much higher than a PTC heater.

3.4.5. Brakes

Brakes are normally operated hydraulically, but with some sort of servo (booster) assistance. This can be from a hydraulic pump but on most ICE driven vehicles, the vacuum (low pressure) from the inlet manifold is used to operate a servo. On a pure EV or a hybrid running only on electricity, another method must be employed.

An electrically assisted master cylinder can be used, which also senses the braking pressure applied by the driver. The reason for this is that as much braking effect as possible is achieved through regeneration because this is the most efficient method. The signals from the master cylinder sensor are sent to an electronic control system and this in turn switches the motor to regenerative mode, charging the batteries and causing retardation, or regenerative braking. If additional braking is needed, determined by driver foot pressure, the traditional hydraulic brakes are operated, with electrical assistance if needed.

Figure 107 Electronically controlled brake master cylinder

Some braking systems have a feedback loop to the master cylinder to give the driver the appropriate feel from the brake pedal that is related to the amount of retardation overall (friction brakes and regenerative brakes).

A fully hydraulic actuation system (HAS) has been developed by Bosch for use on hybrid and electric vehicles. The system is suitable for all brake-circuit splits and drive concepts. It comprises a brake operation unit and a hydraulic actuation control module which supplement the ESP® hydraulic modulator. The brake pedal and wheel brakes are mechanically decoupled. The brake actuation unit processes the braking command, and an integrated pedal travel simulator ensures the familiar pedal feel. The braking pressure modulation system implements the braking command using the electric motor and wheel brakes. The aim is to achieve maximum recuperation while maintaining complete stability. Depending on the vehicle and system status, deceleration of up to 0.3g can be generated using only the electric motor. If this is not sufficient, the modulation system uses the pump and high-pressure accumulator.

Figure 108 Vacuum-independent braking system specially designed for plug-in hybrids and electric vehicles. It comprises a brake operation unit (left) and an actuation control module (right) which supplement the ESP® hydraulic modulator (Source: Bosch Media)

3.4.6. Power assisted steering

When running on electric only, or if there is no engine available to run a power steering pump, an alternative must be used. However, most modern ICE vehicles use one of two main ways to use electric power assisted steering (ePAS), the second of these is now the most common by far:

1. An electric motor drives a hydraulic pump which acts on a hydraulic ram/rack/servo cylinder
2. A drive motor, which directly assists with the steering.

With the direct acting type an electric motor works directly on the steering via an epicyclic gear train. This completely replaces the hydraulic pump and servo cylinder.

On many systems, an optical torque sensor is used to measure driver effort on the steering wheel (all systems use a sensor of some sort). The sensor works by measuring light from an LED (Light Emitting Diode), which is shining through holes. These are aligned in discs at either end of a torsion bar, fitted into the steering column. An optical sensor element identifies the twist of two discs on the steering axis with respect to each other, each disc being provided with appropriate codes. From this sensor information the electronic control system calculates the torque as well as the absolute steering angle.

Figure 109 Direct electric PAS (Source: Ford Media)

3.4.7. DC to DC converter

A DC-to-DC converter is a device that converts a source of direct current (DC) from one voltage level to another. In most systems, one DC voltage is converted to AC using an inverter, the voltage of this AC is changed using a transformer, and it is then rectified back into DC.

Electric vehicles use a high-voltage battery (generally 200 to 450V) for traction and a low-voltage (12V) battery for supplying all the electric components in the vehicle. On ICE vehicles the low-voltage battery is charged from an alternator, but in an EV it is charged from the high-voltage battery. Some hybrid vehicles also allow the low voltage battery to help recharge the high-voltage pack if the vehicle does not use a starter motor.

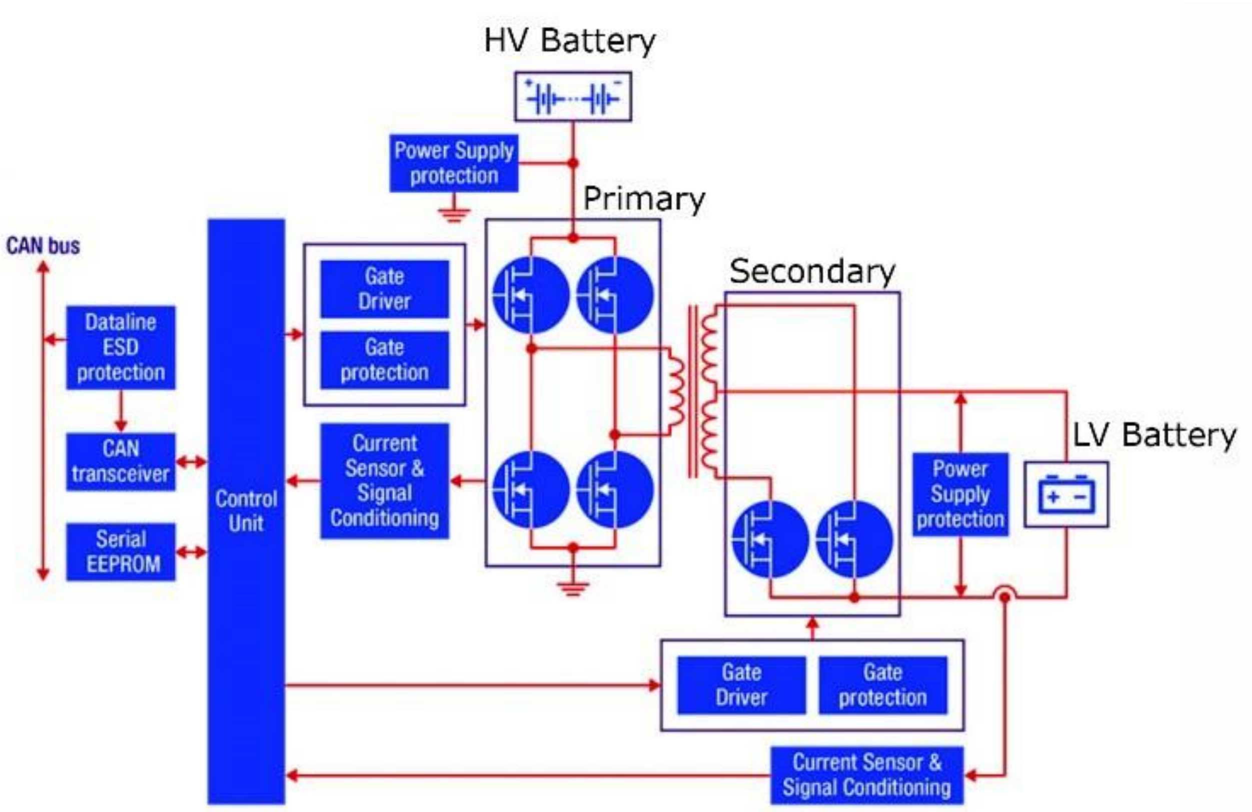


Figure 110 DC-DC bi-directional converter (Source: STMicroelectronics)

STMicroelectronics[12] is a provider of semiconductor solutions. They have a wide offer of discrete semiconductors including IGBTs and both silicon and silicon-carbide (SiC) MOSFETs and diodes. The figure above shows a bi-directional DC-DC converter.

[12] STMicroelectronics https://www.st.com/en/applications/electro-mobility/bidirectional-dc-dc-converter.html

3.5. High voltage safety system

3.5.1. Introduction

The high-voltage battery is effectively connected to all the high-voltage components. However, each high-voltage connection can operate a relay. This connects the high voltage system in the vehicle when the main contactor is closed or disconnects it when it is open (figure below).

If the contactors are de-energized, they open, and the high-voltage battery is disconnected. The command to open can be triggered by different situations. For example, turning off the vehicle and removing the ignition key opens the contactors. It also activates the other safety systems.

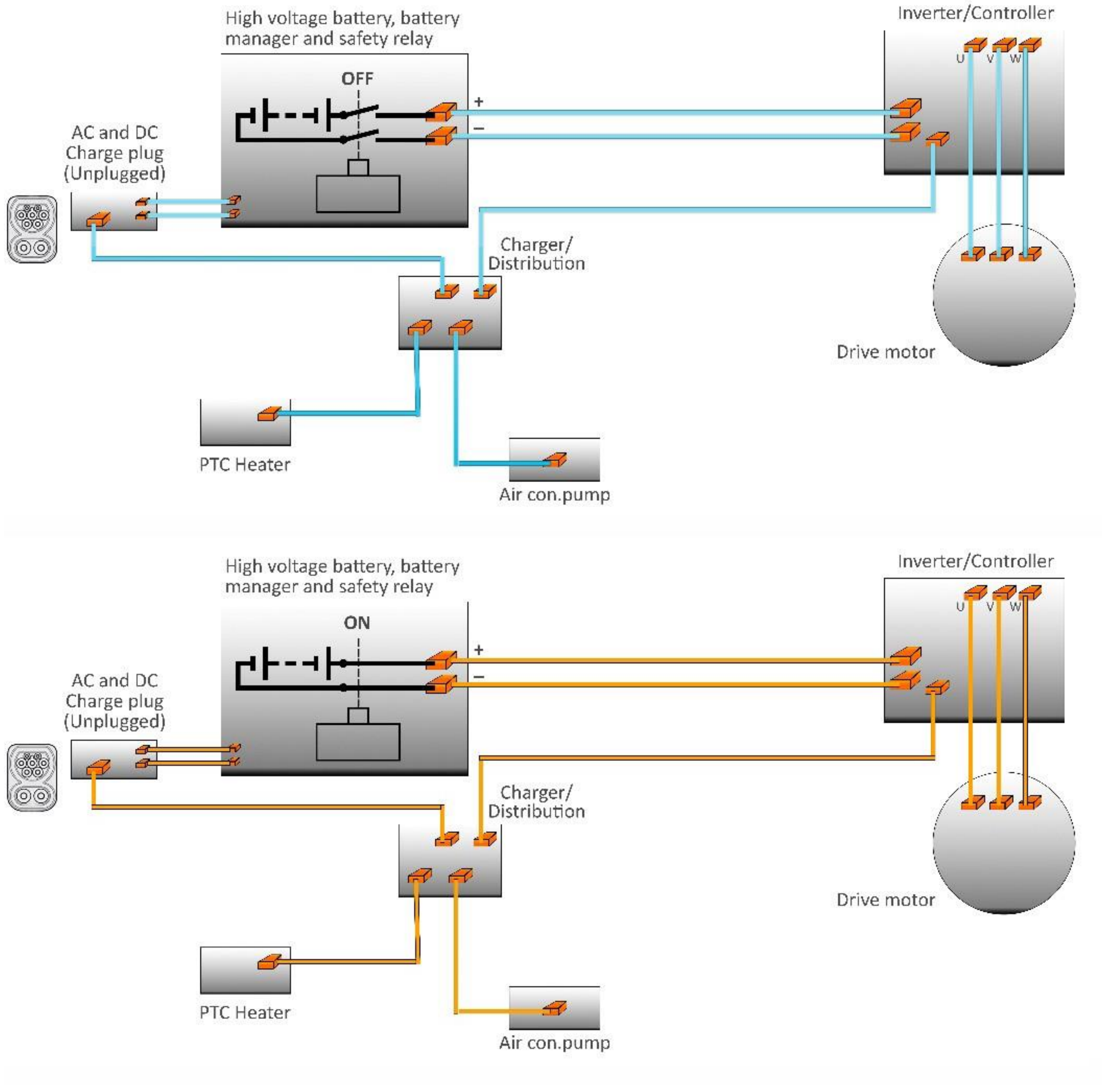


Figure 111 High voltage system components deactivated (OFF) and activated (ON)

3.5.2. Pilot line

The pilot line, also known as an interlock system, is a completely independent safety system that checks if all high-voltage components are correctly connected to the high-voltage system. It connects all high-voltage components and operates on low voltage. The system continuously determines if the high-voltage connections of the components in the pilot line are correctly connected.

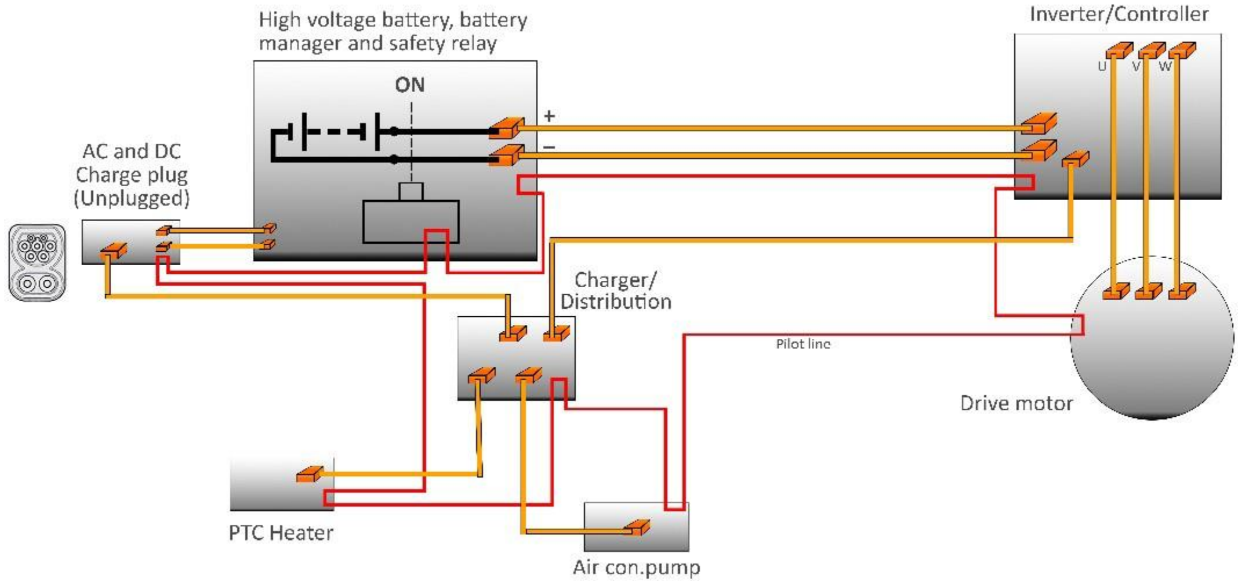


Figure 112 The pilot line (in red) runs through every component via all their plugs and sockets

The pilot line circuit is interrupted if a high voltage connection on a high-voltage component is disconnected. This occurs if a cable is disconnected, the maintenance connector is removed, or a high-voltage component is replaced. The pilot line circuit is a continuous loop such that breaking it at any point, causes the protective relays to open, and isolate the high-voltage battery.

The high-voltage system normally has a maintenance connector near the high-voltage battery as an additional safety feature for de-energizing the high-voltage system. There may also be a maintenance connector under the bonnet or in other locations (always refer to manufacturer's information). If any connector is unlocked and removed, the pilot line is disconnected the main contactors open. This disconnects the high voltage battery, and in many cases, it also electrically separates the battery into two halves.

The location and appearance of the connector will vary and depends on the vehicle type. When disconnected, the system is de-energized and only the battery modules are live. If electrically halved, the voltage is also halved.

As a reminder, always follow the three basic rules of high-voltage safety:

1. De-energize the high-voltage system
2. Secure the vehicle against reactivation
3. Check/determine whether the high-voltage system is de-energized.

De-energization should only be performed by a qualified person.

3.5.3. Crash safety

The high-voltage safety system is linked to the crash detection system, usually via the airbag control module. De-energization of the high-voltage system protects the vehicle occupants, first responders and technicians working on a vehicle in for repair after an accident.

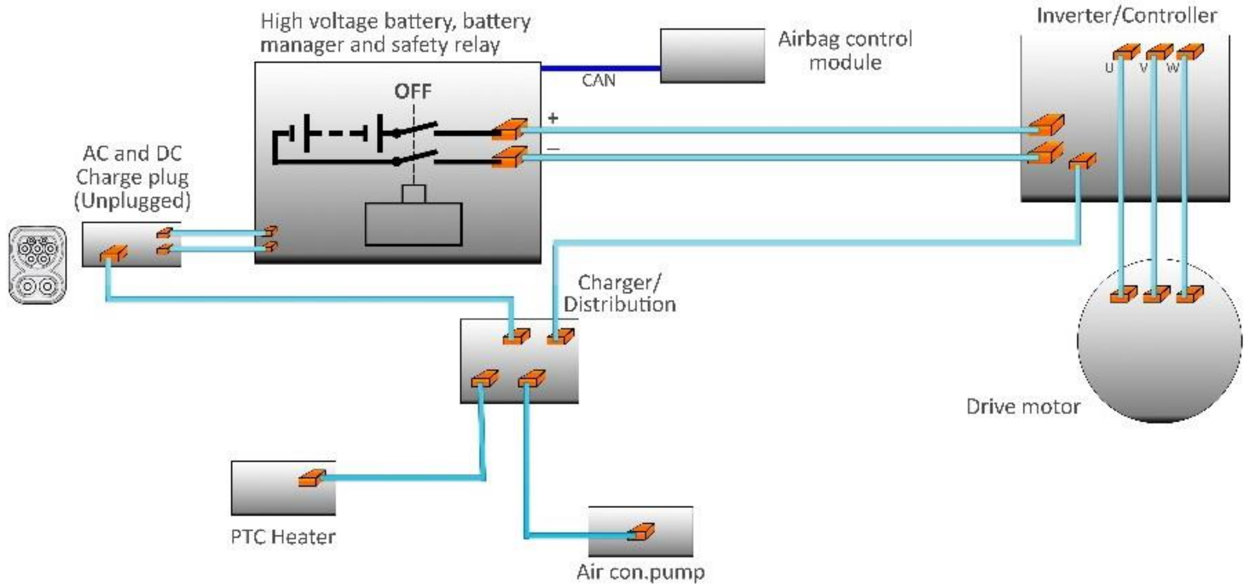


Figure 113 Crash detection

When the airbag control module detects an accident and deploys the belt tensioner or airbags, the battery regulation control module is instructed, via the CAN data bus, to open the protective relays. There are two scenarios:

- Single stage crash deployment: If just the belt tensioners are deployed, the contactor can be closed by turning the ignition on and off again
- Second crash stage crash deployment: If the belt tensioners and airbags are deployed, the contactors can often only be closed again using the manufacturer's or other suitable equipment.

3.5.4. Insulation resistance

The battery regulation control module transmits a test voltage to check the insulation resistance of the high-voltage system. The voltage is usually about 500V and has a low current which is not dangerous. This checks that all the high-voltage components and cables are correctly insulated and shielded. The control module calculates and compares readings with previously measured resistance values of the high-voltage system.

If the insulation of a wire is damaged, for example by an animal bite or fraying due to rubbing, the insulation resistance changes. The control module detects this as an insulation fault. A range of messages can appear in the vehicle instrument cluster depending on the severity of the fault. A severe fault will prevent the vehicle from being used.

3.6. Heavy vehicles

3.6.1. Overview

Heavy vehicle electric drive systems are fundamentally the same as those used on light vehicles, except that they generally need to produce more torque. Some also use more than three phases to drive the motor. The block diagram shown here is a generic layout of a plug-in hybrid electric vehicle (PHEV) or a pure/battery electric vehicle (P/BEV). It could be a light or a heavy vehicle.

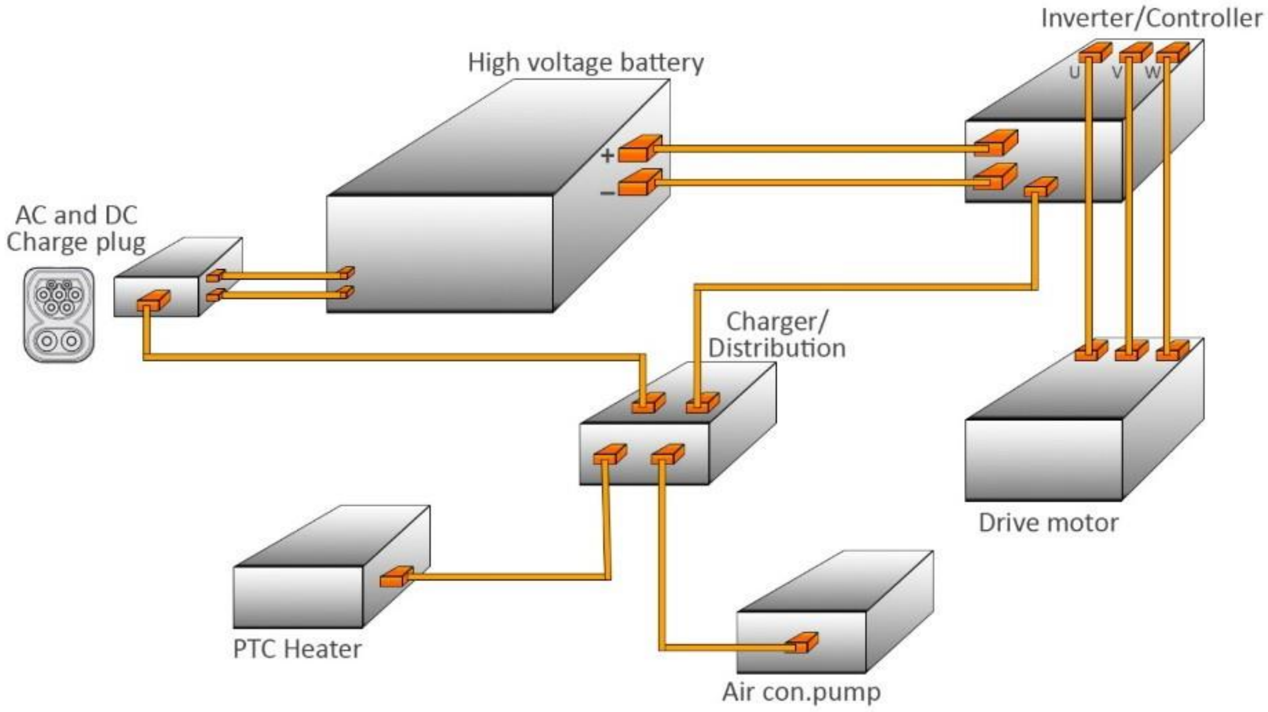


Figure 114. EV layout block diagram

The high voltage battery is the main source of energy and is usually lithium-ion based technology. It is made of many cells in a series and parallel combination to produce a voltage of about 400V. However, this is tending to increase on newer models and 700V or more is likely to become popular. On heavy vehicles the voltage tends to be higher because more power, and therefore more current, needs to be delivered.

The inverter uses insulated gate bipolar transistors (IGBTs), or similar, to convert DC to three-phase AC, which is used to drive the motor. It is also able to work as a rectifier and take three-phase AC generated in the motor (generator) during braking and change it into DC to recharge the battery. Some systems use a separate electronic control unit (ECU) but many have it integrated into this unit.

The drive motor shown above, is three-phase and it drives the vehicle or assists with its movement if in hybrid configuration. It also acts as a generator when driven via the wheels and transmission when braking. The charge plug is the type that allows either direct DC charging or normal AC charging. It is plugged into a domestic or more heavy-duty industrial charging unit.

When charging from a normal unit or domestic or industrial mains supplies, the charger unit steps up the voltage (often 120 or 230Vac) to the 400+Vdc needed to charge the battery. It also acts to distribute the higher voltage three-phase AC to items such as the air conditioning pump and positive temperature coefficient (PTC) heater.

Using a high voltage air conditioning pump allows the system to run when either the ICE engine is not operating (on a hybrid) or on a pure electric vehicle.

The heater is effectively an electric fire! It produces heat by using PTC elements in an air flow. PTC or positive temperature coefficient elements increase in resistance, as temperature increases, so are self-limiting with respect to current flow.

To operate the motor, different phases are switched on at different times to cause rotation. The signals used to switch the IGBTs are pulse width modulated for finer control. For some heavy vehicle applications, multiphase motors are used. Arguably a three-phase motor is multiphase, but the term is generally used to mean more than three. The switching of the inverters that drive these motors is more complex but still follows the basic principle of switching a phase in turn. Multiphase drives have some advantages, in addition to their improved power to weight ratio, when compared to the standard three-phase versions, for example:

- the current stress of the semiconductors is reduced
- torque ripple is reduced.

Other advantages include a reduction in the noise and reduced stator copper loss, which results in improved efficiency. Some systems are more reliable because even if one or more phases are lost, the motor can still operate with reduced performance. The inverter shown here can operate in either three-phase mode or nine-phase mode.

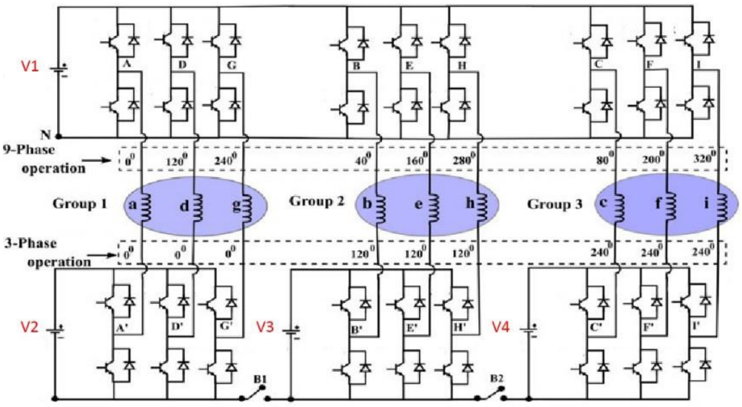


Figure 115. Multiphase inverter[13]

The batteries for heavy vehicle use are the same as for light vehicle systems but are often made modular so that they can be used at different capacities and voltages. The modular approach also allows easier fitting into different spaces, as well as easier repairs when required. Lithium-ion technology is mostly used. Voltages up to 800V and more are becoming common.

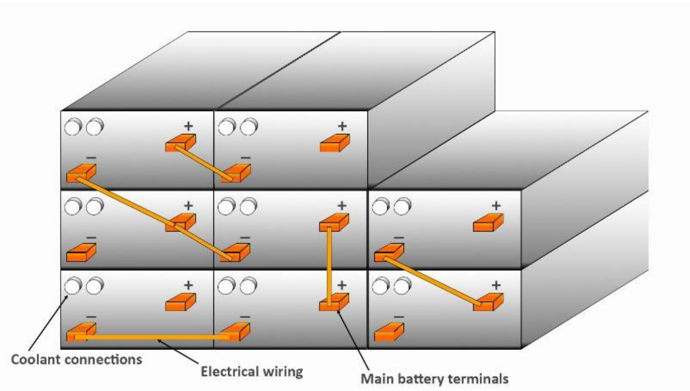


Figure 116 Modular battery design (random wiring connections shown)

[13] Multi-phase rectifier source: Reddy B. Prathap and Sivakumar Keerthipati. "A Multilevel Inverter Configuration [...}." IEEE Transactions on Industrial Electronics 65 (2018): 3035-3044.

The main components of an EV operate using the same principles, whether used on light or heavy vehicles. On heavy vehicles however, they will tend to be larger and more powerful, simply because of the higher torque and power requirements. Some motors are 6- or 9-phase instead of the normal 3-phase. This is usually described as multiphase.

3.6.2. Example components

This section will cover some current examples of the components, and methods of using them, in heavy vehicle applications. In this context R. V's, coaches and buses are considered to be heavy vehicles, not just trucks and construction vehicles.

A Canadian company TM4 (part of the Dana group) produce a family of high torque electric powertrain systems for electric and hybrid commercial vehicle applications. There are a number of motor models with varying sizes paired with a choice of medium (<450Vdc) or high voltage (<750Vdc) inverters.

Figure 117. Inverter and motor (Source: TM4)

These high torque/low speed permanent magnet motors are designed to interface with standard rear differentials without the need for an intermediate gearbox. By allowing direct drive operation, it reduces powertrain complexity and cost. A direct drive system can produce over 10% efficiency gains throughout the driving cycle, representing an equivalent gain in battery usage and therefore range. Typical applications for these technologies are:

- City buses
- Delivery trucks
- Tow tractors
- Mining vehicles
- Marine applications
- Shuttles.

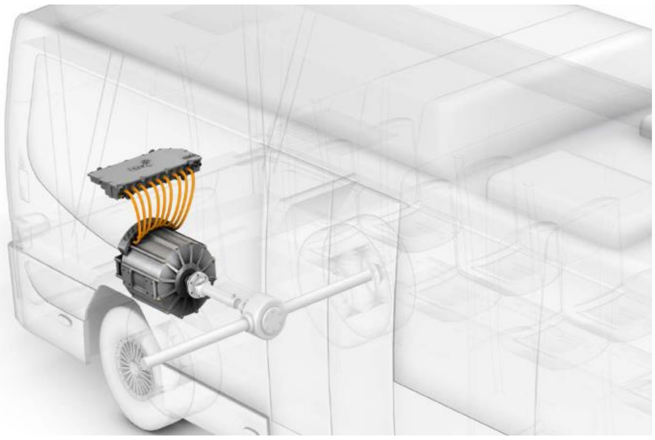


Figure 118 Nine-phase motor driving the rear axle of a bus (Source: TM4)

The inverters used for heavy vehicle applications have to be able to handle significant power levels (voltages and current). Just like on smaller vehicles these devices convert DC from the battery into 3 or more phases of AC to drive the motors. They also act to rectify the output of the motor during regenerative braking.

A common approach to increasing power is to use multiple power transistors (IGBTs) in parallel. However, IGBTs are never perfectly matched and when in parallel, current does not distribute evenly, which can cause a loss in performance of 10% or more compared to the same number of independent IGBTs.

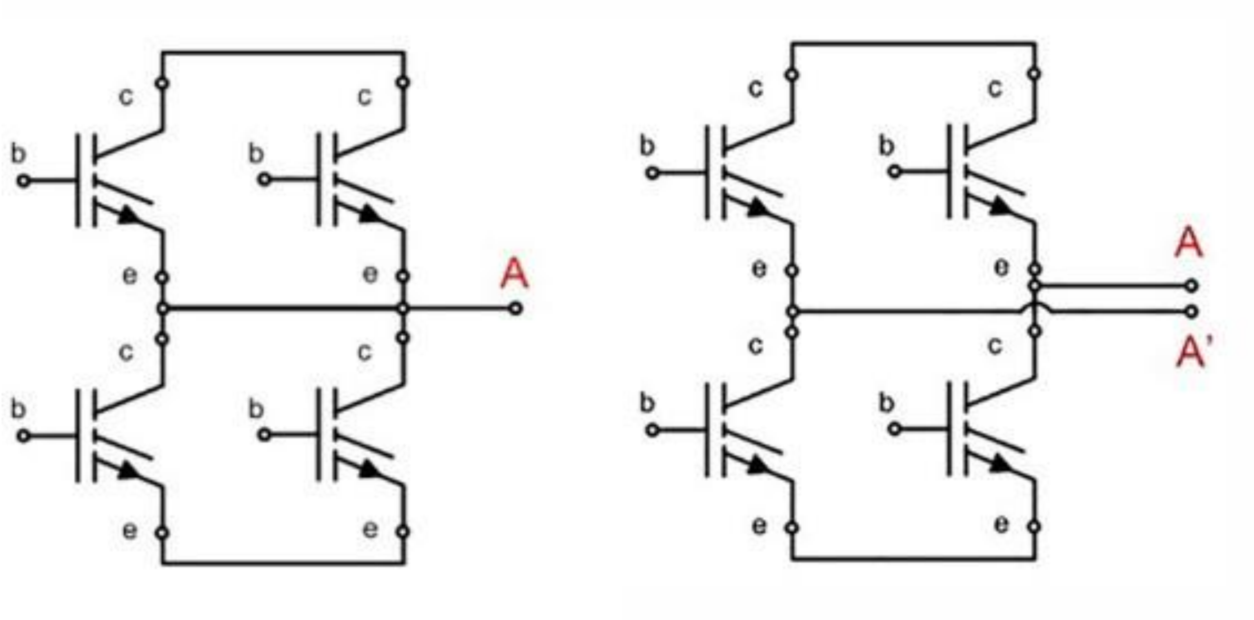


Figure 119 IGBTs in parallel (left) and multiphase modular topology (Source: TM4)

A multiphase topology for inverters and motors uses separate IGBTs to drive independent electromagnetic subsets of the motor. This allows each IGBT (insulated gate bipolar transistors) to be used to its fullest potential. Because the IGBTs are fully independent it is possible to use interleaved IGBT switching. This spreads the current ripple demand from the DC bus filtering capacitor among the IGBTs.

Almost all EV motors work on the principle of a permanent magnet rotor and a rotating field stator. Heavy vehicle systems in this respect are no different. However, the extra power requirements of heavy vehicles mean some innovative technologies have been used. As discussed in the first section, multiphase systems are used but another interesting method is to mount the rotor outside the stator. This external rotor motor topology has a greater magnetic flux and can produce higher torque. Torque (Nm) is the product of the force (N) and the distance (m) from the center of rotation. This is represented in the following figure and shows how the greater distance can result in increased torque.

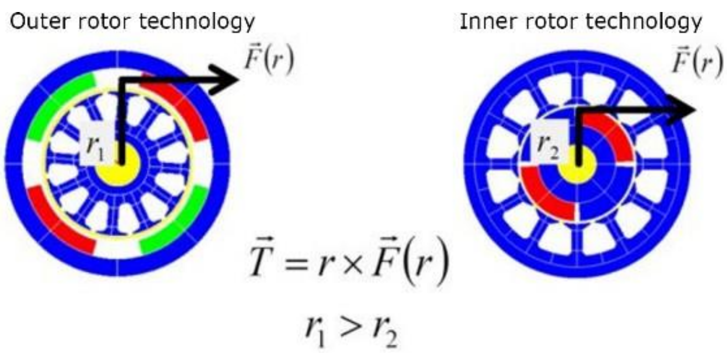


Figure 120 Motor torque (Source: TM4)

The example motor (HV3500) shown in the following figure is 572 x 591 x 505mm, and weighs 340kg (750lbs). The associated inverter is 414 x 126 x 801 mm and weighs in at 36kg (80lbs).

Figure 121 Inverter and motor (Source: TM4)

The electronic control unit (ECU) runs the hybrid or pure EV system based on operating conditions and driver demand. It is programmed (like all engine or EV control ECUs (Electronic Control Unit)) to meet the specific needs of the vehicle, operating environment, and associated systems.

Figure 122. The appropriately named 'neuro 200' vehicle management unit is the brain of the system (Source: TM4)

In a bus used for trials, two ZF electric motors near the wheels are used, each with 120 kW (160 bhp) of maximum power. Like all EV motors, they can also run in generator mode to feed power back into the batteries (regenerative braking).

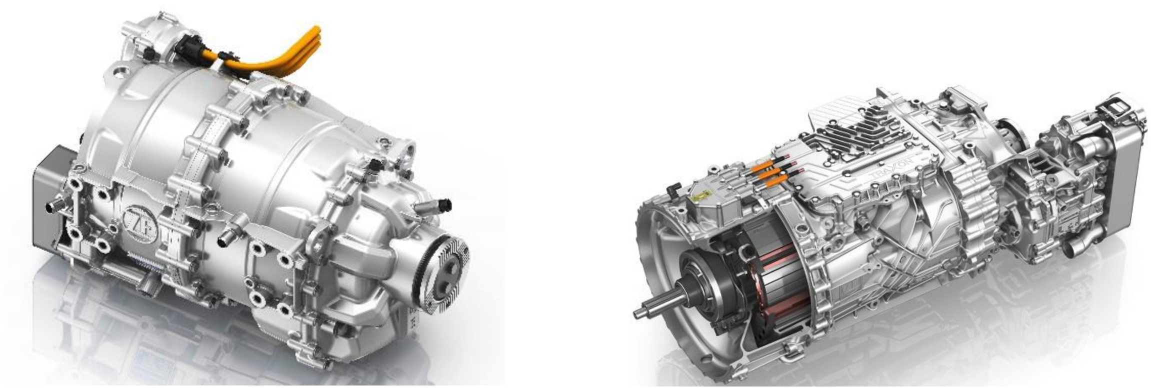


Figure 123. Drive motors (Source: ZF)

A key aspect of this system is that it fits into the same space and has the same interface dimensions as portal axles for conventional ICE vehicles. This makes it easy to add to an existing chassis, without needing to redesign the entire vehicle. Shown here is an alternative, but similar arrangement of two drive motors:

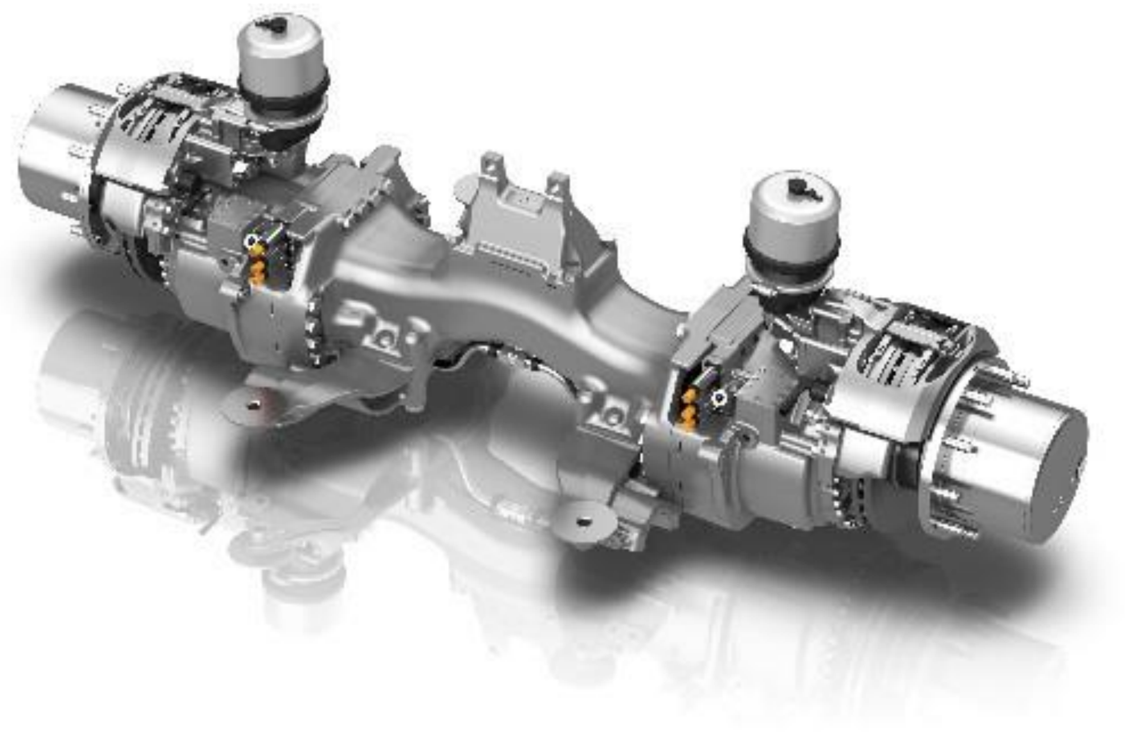


Figure 124 Alternative drive axle arrangement (Source: ZF)

4. Batteries

4.1. Overview

4.1.1. Battery range

The main thing that affects the range of an EV is your right foot! Smooth driving with gentle acceleration and minimal braking has the most impact on range – as it does in any vehicle.

However, the range is also affected by cold weather as well as the use of AC (heating or cooling) and other items (such as lights). This is because these systems use battery energy. Vehicle manufacturers are using solutions such as LED exterior lights to reduce consumption. Control systems can also minimize the energy used by additional items. Mains powered pre-conditioning is now common, allowing the driver to start their journey with the interior at a comfortable temperature without draining the battery. One plus point is that EVs don‘t need a warm-up period like many conventional ICE vehicles in the winter.

Figure 125 Battery pack and other HV components on the Volvo SUV (Source: Volvo Media)

4.1.2. State of charge

State of charge (SOC) is a measure of the amount of energy left in a battery compared with the energy it had when it was full. It gives the driver an indication of how much longer a battery will continue to work before it needs recharging. It is considered as a measure of the short-term capability of a battery.

However, it is more difficult to define SOC than it would first appear. It is defined as the available capacity expressed as a percentage of a given reference. This could be its:

- Rated capacity (as if new)
- Latest charge-discharge capacity

Particularly on an EV, this can be a problem. A vehicle that has a range of, say, 100km on a fully charged brand new battery, could reasonably expect a range of 50km if it was 50% charged.

However, after several years the capacity of the battery when fully charged may only be 80% of what it used to be. An indication of 50% charge would now only give a 40km range.

Because electric vehicles use the SOC to determine range, it should ideally be an absolute value based on capacity of the battery when new. Several methods of estimating the state of charge of a battery have been used. Some are specific to particular cell chemistries. Most depend on measuring a parameter which varies with the state of charge.

The easiest way to monitor SOC is a voltage measurement, but this does depend on several factors. An open circuit voltage will be higher than when current is flowing due to cell internal resistance. Temperature also has a big effect. Lithium-ion batteries also have a cell voltage that does not change that much between fully charged and fully discharged. Most are also actually operated between 80% and 20% as this reduces degradation over time. The voltage changes are therefore even smaller. Nonetheless, taking all factors into account, a voltage measurement under a known load, gives a reasonable estimate of SOC.

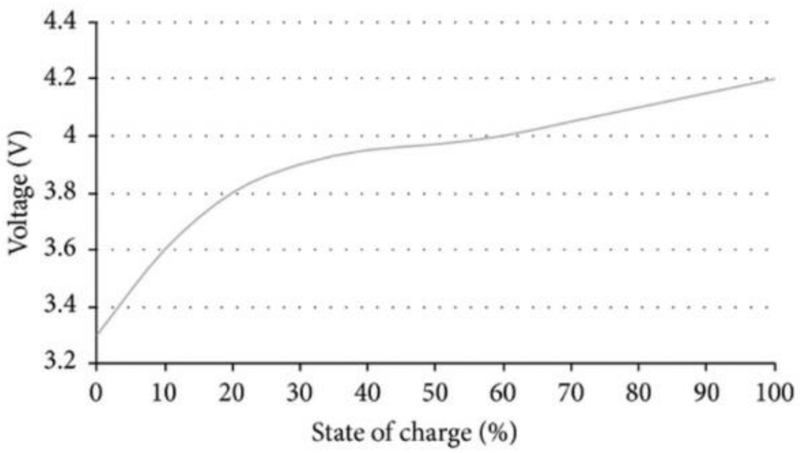


Figure 126 State of charge (SOC) vs. voltage

It is also possible to calculate state of charge by measuring current and time (in or out). Current multiplied by time gives a suitable value for SOC. Unfortunately, there are a few problems with this:

- The discharge current changes non-linearly as the battery becomes discharged
- To know how much charge it contained, the battery must be discharged
- There are losses during the charge/discharge cycle.

A battery will always deliver less during discharge than was put into it during charging. This is sometimes described as the Coulombic efficiency of the battery. Temperature is once again an issue. However, if all factors are considered, a reasonable figure for state of charge can be calculated. Most battery manufacturers use a Coulombs in and Coulombs out as a benchmark for their warranties.

4.1.3. State of health

The state of health (SOH) of a battery is a measurement that indicates the general condition of a battery and its ability to perform compared with a new battery. It considers charge acceptance, internal resistance, voltage, and self-discharge. It is considered as a measure of the long-term capability of a battery.

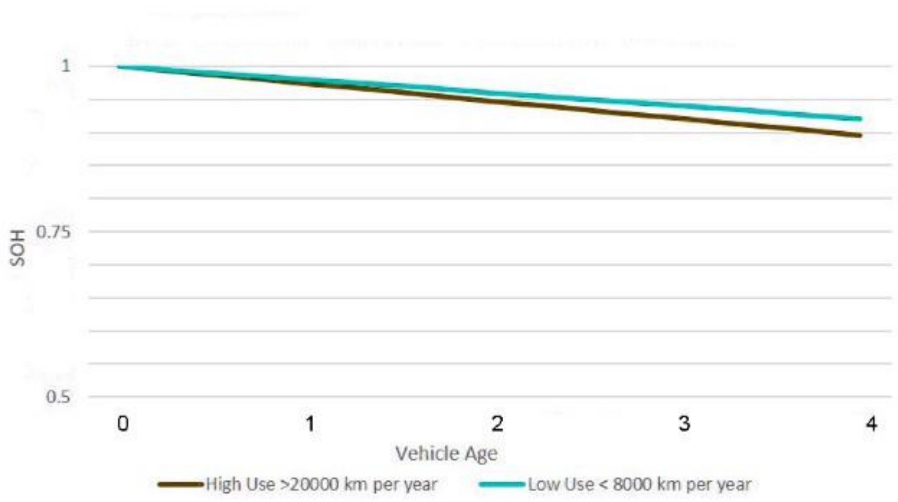


Figure 127 State of health (SOH) vs. time[14]

SOH is an indication not an absolute measurement. During the lifetime of a battery, its performance deteriorates due to physical and chemical changes. Unfortunately, there is no agreed definition of SOH.

Cell impedance or cell conductivity is often used as a reasonable estimate of SOH. More complex systems monitor other parameters and involve a range of calculations. Because SOH is a figure relative to the condition of a new battery, the measurement system must collect and save data over time and monitor the change.

Counting the charge/discharge cycles of the battery is a measure of battery usage and can be used to indicate SOH, if compared to the expected values over time. This is because the capacity of lithium-ion cell deteriorates quite linearly with age or cycle life. The remaining cycle life can therefore be used as a measure of the SOH.

4.2. Types of battery

4.2.1. Lead-acid batteries (Pb-Pb02)

Even after over 150 years of development and much promising research into other techniques of energy storage, the lead-acid battery is still the best choice for low voltage motor vehicle use. This is particularly so when cost and energy density are considered. Incremental changes over the years have made the sealed and maintenance-free battery now in common use very reliable and long lasting.

The basic construction of a nominal 12V lead-acid battery consists of six cells connected in series. Each cell, producing about 2V, is housed in an individual compartment within a polypropylene, or similar, case. Below is a cut-away battery showing the main component parts. The active material is held in grids or baskets to form the positive and negative plates. Separators made from a micro-porous plastic insulate these plates from each other.

[14] There is a useful SOH calculator (estimator) here: https://www.geotab.com/blog/ev-battery-health/

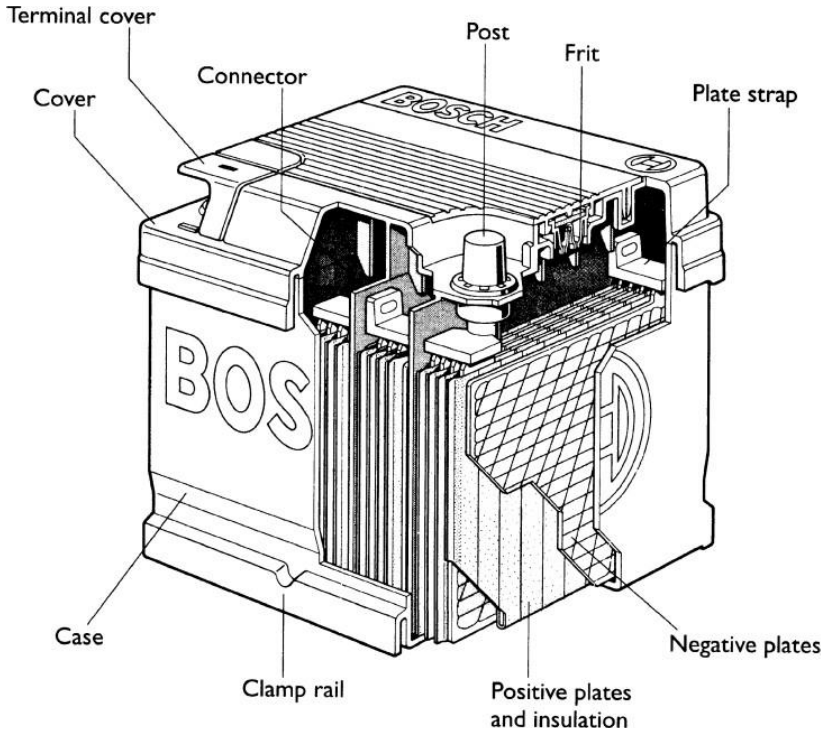


Figure 128 Lead-acid battery

However, even modern batteries described as sealed do still have a small vent to stop the pressure build-up due to the very small amount of gassing. A further requirement of sealed batteries is accurate control of charging voltage.

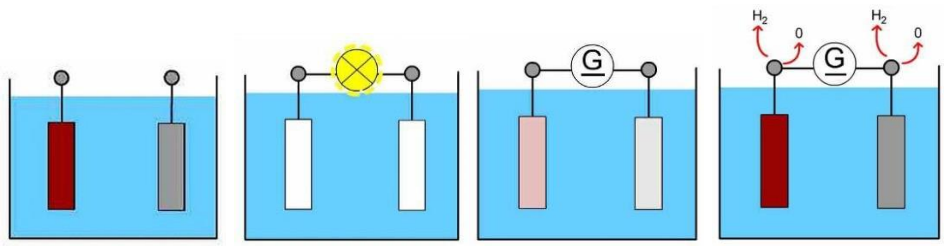


Figure 129 Battery discharge and charging process (left to right): Fully charged; discharging; charging; charging and gassing

In use, a lead-acid battery requires very little attention other than the following when necessary:

- Clean corrosion from terminals using hot water.
- Terminals should be smeared with petroleum jelly or Vaseline, not ordinary grease.
- Battery tops should be clean and dry.
- If not sealed, cells should be topped up with distilled water 3mm above the plates.
- The battery should be securely clamped in position.

4.2.2. Alkaline (Ni-Cad, Ni-Fe and Ni-MH)

The main components of the nickel-cadmium (NiCad) cell for vehicle use are as follows:

- positive plate – nickel hydrate (NiOOH)
- negative plate – cadmium (Cd)
- electrolyte – potassium hydroxide (KOH) and water (H_2O).

The process of charging involves the oxygen moving from the negative plate to the positive plate, and the reverse when discharging. When fully charged, the negative plate becomes pure cadmium and the positive plate becomes nickel hydrate. A chemical equation to represent this reaction is given next but note that this is simplifying a more complex reaction.

- $2NiOOH + Cd + 2H_2O + KOH == 2Ni(OH)_2 + CdO_2 + KOH$

The $2H_2O$ is actually given off as hydrogen (H) and oxygen (O_2) as gassing takes place all the time during charge. It is this use of water by the cells that indicates they are operating, as will have been noted from the equation. The electrolyte does not change during the reaction. This means that a relative density reading will not indicate the state of charge.

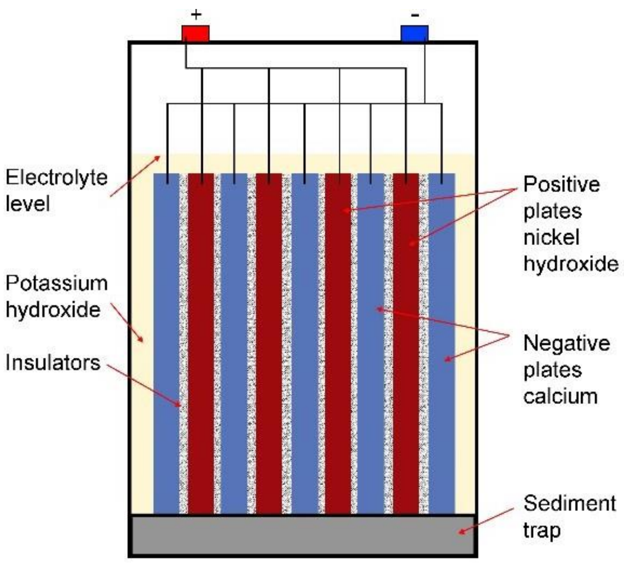


Figure 130 Simplified representation of a NiCad alkaline battery cell

Ni-MH or nickel-metal-hydride batteries are used and have proved to be very effective by some electric vehicles. Toyota in particular has developed these batteries. The components of NiMH batteries include a cathode of nickel-hydroxide, an anode of hydrogen absorbing alloys and a potassium-hydroxide (KOH) electrolyte. The energy density of NiMH is more than double that of a lead acid battery but less than lithium-ion batteries.

Toyota developed a cylindrical NiMH battery in 1997 that powered the Rav4EV as well as the e-com electric vehicle. Since then, Toyota has continually improved its NiMH batteries by reducing size, improving power density, lowering weight, improving the battery pack/case, and lowering costs. The current NiMH battery, which powers the third generation Prius, costs 25% that of the 1st generation.

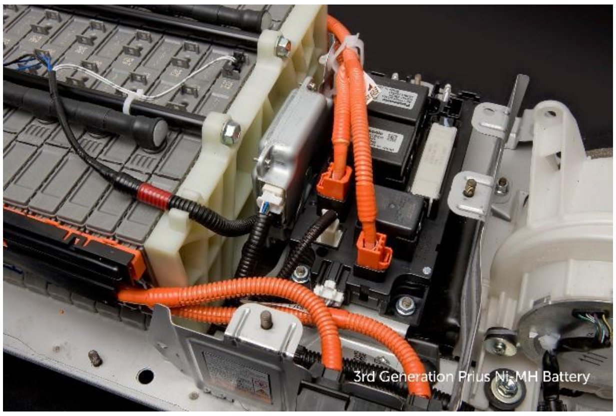


Figure 131 Toyota NiMH battery and management components (Source: Toyota)

Nickel-metal batteries are ideal for mass producing affordable conventional hybrid vehicles due to their low cost, high reliability, and high durability. There are first-generation Prius batteries still on the road with over 200,000 miles and counting. That is why NiMH remains the battery of choice for Toyota's conventional hybrid line up.

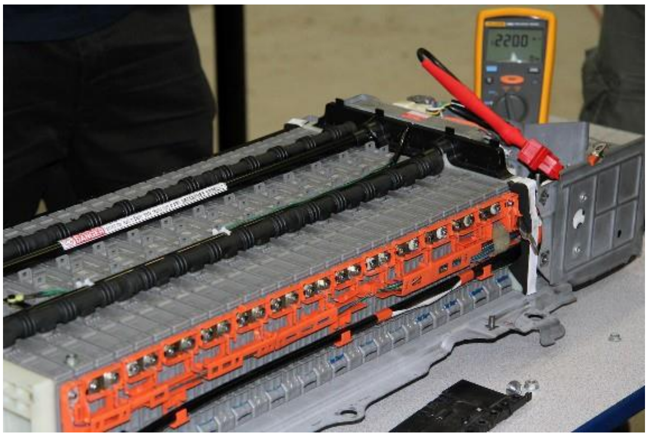


Figure 132 Ni-MH battery

4.2.3. Sodium-nickel Chloride (Na-Ni-Cl)

Molten salt batteries (including liquid metal batteries) are a class of battery that uses molten salts as an electrolyte and offers both a high energy density and a high-power density. Traditional 'use-once' thermal batteries can be stored in their solid state at room-temperature for long periods of time before being activated by heating. Rechargeable liquid metal batteries are used for electric vehicles and potentially also for grid energy storage, to balance out intermittent renewable power sources such as solar panels and wind turbines.

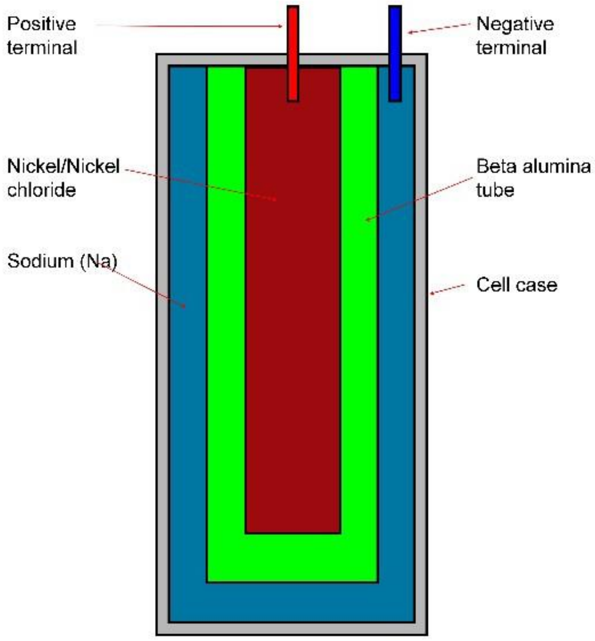


Figure 133 Sodium-nickel-chloride cell

Thermal batteries use an electrolyte that is solid and inactive at normal ambient temperatures. They can be stored indefinitely (over 50 years) yet provide full power in an instant when required. Once activated, they provide a burst of high power for a short period (a few tens of seconds) to 60 minutes or more, with output ranging from a few watts to several kilowatts. The high-power capability is due to the very high ionic conductivity of the molten salt, which is three orders of magnitude (or more) greater than that of the sulfuric acid in a lead-acid car battery.

Significant development has been done relating to rechargeable batteries using sodium (Na) for the negative electrodes. Sodium is attractive because of its high potential of 2.71V, low weight, non-toxic nature, relative abundance and ready availability and its low cost. In order to construct practical batteries, the sodium must be used in liquid form. The melting point of sodium is 98 °C (208 °F). This means that sodium-based batteries must operate at high temperatures between 400–700 °C, with newer designs running at temperatures between 245–350 °C.

4.2.4. Sodium Sulphur (Na-S)

The sodium-sulphur or Na-S battery consists of a cathode of liquid sodium into which is placed a current collector. This is a solid electrode of alumina (a form of aluminum oxide). A metal can that is in contact with the anode (a sulfur electrode) surrounds the whole assembly. The major problem with this system is that the running temperature needs to be 300–350°C. A heater rated at a few hundred watts forms part of the charging circuit. This maintains the battery temperature when the vehicle is not running. Battery temperature is maintained when in use due to current flowing through the resistance of the battery (often described as I^2R power loss).

Each cell of this battery is very small, using only about 15g (half an ounce) of sodium. This is a safety feature because, if the cell is damaged, the sulfur on the outside will cause the potentially dangerous sodium to be converted into polysulphides – which are comparatively harmless. Small cells also have the advantage that they can be distributed around the car. The capacity of each cell is about 10Ah. These cells fail in an open circuit condition and hence this must be considered, as the whole string of cells used to create the required voltage would be rendered inoperative. The output voltage of each cell is about 2V.

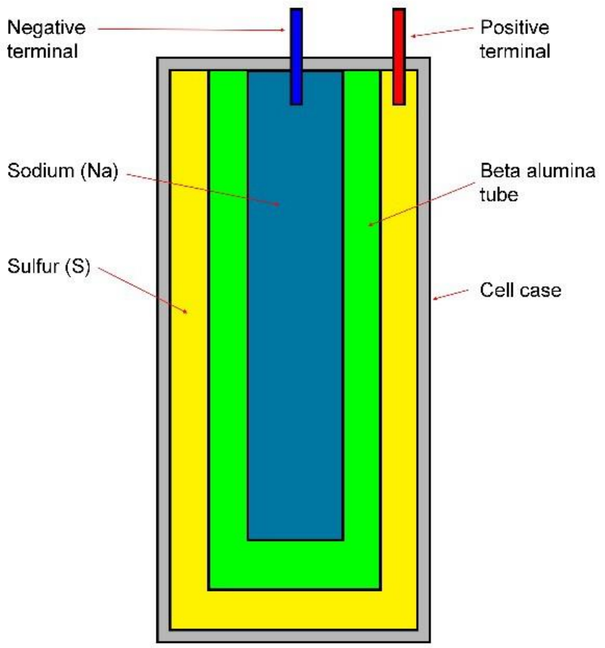


Figure 134 Sodium sulfur cell

4.2.5. Lithium-ion (Li-ion)

Lithium-ion technology is the battery technology of choice for almost all pure EVs. Today's batteries have an energy density of 100-265 Wh/kg but have the potential to go as high as 280Wh/kg. Much research in cell optimization is taking place to create a battery with a higher energy density and increased range. Lithium-ion technology is currently considered the safest.

The Li-ion battery works as follows. A negative electrode (anode) and a positive electrode (cathode) are part of the individual cells of a lithium-ion battery together with the electrolyte and a separator. The anode is a graphite structure, and the cathode is layered metal oxide. Lithium-ions are deposited between these layers. When the battery is charging, the lithium-ions move from the anode to the cathode and take on electrons. The number of ions therefore determines the energy density. When the battery is discharging, the lithium-ions release the electrons to the anode and move back to the cathode.

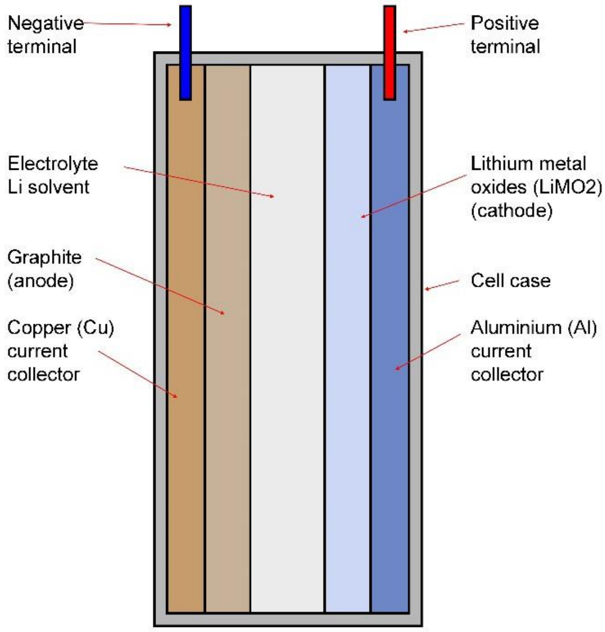


Figure 135 Lithium-ion cell

Useful work is performed when electrons flow through a closed external circuit. The following equations show one example of the chemistry, in units of moles, making it possible to use coefficient *X*.

- The cathode (positive terminal) half-reaction is: $\mathrm{Li}_{1-x}\mathrm{CoO}_2 + x\mathrm{Li}^+ + x\mathrm{e}^- \leftrightarrows \mathrm{LiCoO}_2$
- The anode (negative terminal) half reaction is: $x\mathrm{LiC}_6 \leftrightarrows x\mathrm{Li}^+ + x\mathrm{e}^- + x\mathrm{C}_6$

One issue with this type of battery is that in cold conditions, the lithium-ions movement is slower during the charging process. This tends to make them reach the electrons on the surface of the anode rather than inside it. Also, using a charging current that is too high creates elemental lithium. This can be deposited on top of the anode covering the surface, which can seal the passage. This is known as lithium plating. Research is ongoing and one possible solution could be to warm up the battery before charging.

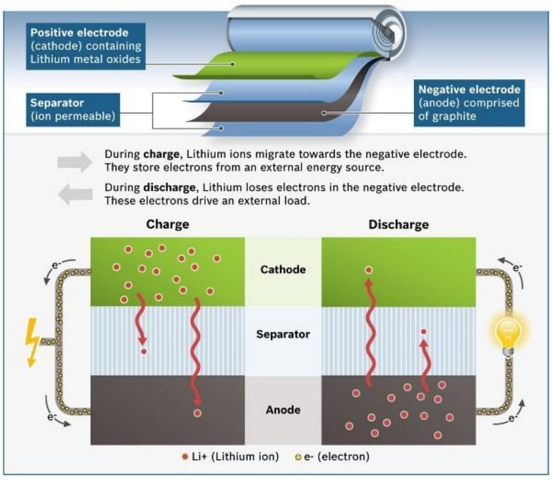


Figure 136 Operation of a lithium ion battery Source: Bosch Media)

Bosch and other companies are working on post-lithium-ion batteries, such as those made using lithium-sulfur technology, which promises greater energy density and capacity. The company estimates that the earliest the lithium-sulfur battery will start series production is the middle of the 2020s.

There are several ways to improve battery performance. For example, the material used for the anode and cathode plays a major role in the cell chemistry. Most of today's cathodes consist of nickel-cobalt manganese (NCM) and nickel-carboxyanhydrides (NCA), whereas anodes are made of graphite, soft or hard carbon, or silicon carbon.

High voltage electrolytes can further boost battery performance, raising the voltage within the cell from 4.5 to 5V. The technical challenge lies in guaranteeing safety and longevity while improving performance. Sophisticated battery management can further increase the range of a car by up to 10% – without altering the cell chemistry.

Figure 137 Battery developments are ongoing (Source: Bosch Media)

4.2.6. Fuel cells

The energy of oxidation of conventional fuels, which is usually manifested as heat, can be converted directly into electricity in a fuel cell. All oxidations involve a transfer of electrons between the fuel and oxidant, and this is employed in a fuel cell to convert the energy directly into electricity. All battery cells involve an oxide reduction at the positive pole and an oxidation at the negative during some part of their chemical process. To achieve the separation of these reactions in a fuel cell, an anode, a cathode, and electrolyte are required. The electrolyte is fed directly with the fuel.

It has been found that a fuel of hydrogen when combined with oxygen proves to be a most efficient design. Fuel cells are very reliable and silent in operation but are quite expensive to construct.

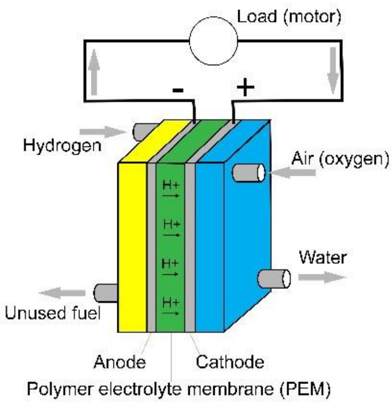


Figure 138 Fuel cell operation

Operation of a fuel cell is such that as hydrogen is passed over an electrode (the anode), which is coated with a catalyst, the hydrogen diffuses into the electrolyte. This causes electrons to be stripped off the hydrogen atoms. These electrons then pass through the external circuit. Negatively charged hydrogen anions (OH) are formed at the electrode over which oxygen is passed such that it also diffuses into the solution. These anions move through the electrolyte to the anode. Water is formed as the by-product of a reaction involving the hydrogen ions, electrons, and oxygen atoms. If the heat generated by the fuel cell is used, an efficiency of over 80% is possible, together with a very good energy density figure. A unit consisting of many individual fuel cells is often referred to as a stack.

The working temperature of these cells varies but about 200°C is typical. High pressure is also used, and this can be of the order of 30 bar. It is the pressures and storage of hydrogen that are the main problems to be overcome before the fuel cell will be a realistic alternative to other forms of storage for the mass market.

Many combinations of fuel and oxidant are possible for fuel cells. Though hydrogen--oxygen is conceptually simple, hydrogen has some practical difficulties, including that it is a gas at standard temperature and pressure and that there does not currently exist an infrastructure for distributing hydrogen to domestic users. More readily usable, at least in the short term, would be a fuel cell powered by a more easily handled fuel. To this end, fuel cells have been developed which run on methanol. There are two types of fuel cell that use methanol:

- Reformed methanol fuel cell (RMFC)
- Direct methanol fuel cell (DMFC)

In the RMFC, a reaction is used to release hydrogen from the methanol, and then the fuel cell runs on hydrogen. The methanol is used as a carrier for hydrogen. The DMFC uses methanol directly. RMFCs can be made more efficient in the use of fuel than DMFCs but are more complex.

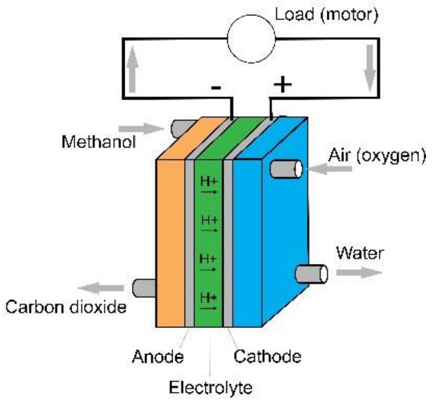


Figure 139 Direct methanol fuel cell operation

DMFCs are a type of proton exchange membrane fuel cell (PEMFC). The membrane in a PEMFC fulfils the role of the electrolyte, and the protons (positively charged hydrogen ions) carry electrical charge between the electrodes.

Because the fuel in a DMFC is methanol, not hydrogen, other reactions take place at the anode. Methanol is a hydrocarbon (HC) fuel, which means that its molecules contain hydrogen and carbon (as well as oxygen in the case of methanol). When HCs burn, the hydrogen reacts with oxygen to create water and the carbon reacts with oxygen to create carbon dioxide. The same general process takes place in a DMFC, but in the process the hydrogen crosses the membrane as an ion, in just the same way as it does in a hydrogen fueled PEMFC.

The real benefit of methanol is that it can easily fit into the existing fuel infrastructure of filling stations and does not need highly specialized equipment or handling. It is easy to store on-board the vehicle, unlike hydrogen which needs heavy and costly tanks. The big downside is that carbon dioxide is produced.

4.2.7. Super-capacitors

Super- or ultra-capacitors are very high capacity but (relatively) low size capacitors. These two characteristics are achieved by employing several distinct electrode materials prepared using special processes. Some state-of-the art ultra-capacitors are based on high surface area, ruthenium dioxide (RuO_2) and carbon electrodes. Ruthenium is extremely expensive and available only in very limited amounts.

Electrochemical capacitors are used for high-power applications such as cellular electronics, power conditioning, industrial lasers, medical equipment, and power electronics in conventional, electric and hybrid vehicles. In conventional vehicles, ultra-capacitors could be used to reduce the need for large alternators for meeting intermittent high peak power demands related to power steering and braking. Ultra-capacitors recover braking energy dissipated as heat and can be used to reduce losses in electric power steering.

Figure 140 Ultracapacitors (Source: Skeleton)

One system in use on a hybrid bus uses 30 ultra-capacitors to store 1600kJ of electrical energy (20 farads at 400V). The capacitor bank has a mass of 950kg (2100lbs). Use of this technology allows recovery of energy when braking, which would otherwise have been lost because the capacitors can be charged in a very short space of time. The energy in the capacitors can also be used very quickly for rapid acceleration.

4.2.8. Flywheels

As discussed previously, recovering the energy that would otherwise be lost when a vehicle brakes is an extremely effective way to improve fuel economy and reduce emissions. However, there are some concerns about the environmental impact of widespread battery manufacture and end-of-life disposal. Flywheel technology is one possible answer. A company known as Flybrid produces a mechanically compact kinetic energy recovery system (KERS).

Flywheel technology itself is not new. Flywheel energy storage has been used in hybrid vehicles such as buses, trams, and prototype cars before, but the installation tended to be heavy and the gyroscopic forces of the flywheel were significant. The new system overcomes these limitations with a compact and relatively lightweight carbon and steel flywheel.

Figure 141 Carbon fiber flywheel (Source: Flybrid)

KERS captures and stores energy that is otherwise lost during vehicle deceleration events. As the vehicle slows, kinetic energy is recovered through the KERS continuously variable transmission (CVT) or clutched transmission (CFT) and stored by accelerating a flywheel. As the vehicle gathers speed, energy is released from the flywheel, via the CVT or CFT, back into the driveline. Using this stored energy to reaccelerate the vehicle in place of energy from the engine reduces engine fuel consumption and CO_2 emissions.

Figure 142 The Flybrid® hybrid system

(Source: www.flybridsystems.com)

Flywheel systems offer an interesting alternative to batteries or super-capacitors. In a direct comparison they are less complex, more compact, and lighter weight. However, the technology challenges involved in a flywheel that can rotate at speeds up to 64,000 rpm, extracting the energy and keeping it safe, should not be underestimated.

4.3. Battery developments and other issues

4.3.1. Introduction

Every year, motor vehicles which have reached the end of their useful lives create between 8 and 9 million tons of waste in the European Union. The figures are similar in the USA. These can be described as End of Life Vehicles (ELV).

Electric vehicles (EVs) pose similar environmental risks to any other ELV (End of Life Vehicles) in that they contain components and fluids which can initiate fires, pollute the environment and/or cause harm to human health. However, EVs will generally create a lower liquid leakage risk, as they will not contain the same quantities of potentially polluting fluids as other types of ELVs (End of Life Vehicles) (diesel, petrol/ gasoline, and engine oil for example). The additional environmental risk from EVs comes from the management of the high voltage batteries that all EVs contain.

It is important to be able to access information specific to the manufacturer and the vehicle being worked on. This is needed because it is recommended that the high voltage system be deactivated on arrival. This will reduce the risk of electric shock, short circuits, and fires. Different systems are de-energized in different ways so always refer to the manufacturer's information. This process should only be carried out by a trained person.

Figure 143 End of life vehicles

Most electric vehicle batteries are lithium-ion. These rely on a mix of materials such as cobalt, manganese, nickel, and graphite. The batteries can be found in different locations on the vehicle. For hybrid EVs they are usually under the rear seats, behind the rear seat or in the boot/trunk. For full EVs, the batteries are often under the floor.

It is already recommended that lead acid vehicle batteries are disconnected shortly after arrival at the ELV site. This significantly reduces the risk of fires and the same approach therefore applies to the de-energization of EVs. The earlier Toyota Prius have nickel metal hydride batteries. These are a strong alkali so must not be stored with lead acid batteries. If in doubt, check the manufacturer's data and the battery labels to identify the battery chemistry.

Figure 144 Lithium-ion battery

Lithium Ion batteries (Li-ion) batteries involved in fires present a serious fire risk and can re-ignite if not adequately cooled. In extreme cases thermal runaway is a risk in EVs using these batteries if they are overheated or overcharged. In the UK, lead acid and Ni-Cd batteries are classified as hazardous waste so consignment notes must be completed, and hazardous waste producer records kept for their removal from the site. Li-ion and NiMH batteries are not currently classed as hazardous waste. This is because they were not widely used when the Lists of Waste codes were drafted. This is likely to change in future.

4.3.2. Other batteries on the vehicle

EVs contain more than just the batteries used to power the electric drive motor. Hybrids (and some pure EVs) still contain 12V lead acid-based batteries. Batteries are used for emergency assist systems (OnStar for example), infotainment systems, tire pressure sensors, and more.

Figure 145 Some tire pressure sensors contain small mercury-based batteries.

Figure 146 Access to emergency systems is usually by a button under the rear-view mirror

In end of life vehicles this means there could be a number of batteries to disconnect and remove - before the vehicle goes into crusher/shredder! Manufacturer’s information or another trusted sources should be used to determine the locations of all these batteries.

Figure 147 OnStar battery

The battery shown above is for the OnStar system on a General Motors vehicle. It is 15.5V and uses a Lithium-Manganese Dioxide chemistry. If damaged, it can cause heat and a potential fire. It should be treated as hazardous material, particularly when still charged.

The location of these batteries varies considerably across different types of vehicle. Use appropriate data to locate them, and they should be removed and stored safely.

4.3.3. Battery life and recycling

It is certainly possible to extend the life of a battery by carrying out repairs and refurbishment. However, please note that:

BATTERY REPAIRS MUST ONLY BE COMPLETED BY TRAINED AND COMPETENT ENGINEERS USING THE CORRECT TOOLS AND PERSONAL PROTECTIVE EQUIPMENT

Manufacturers usually consider the end of life for a battery to be when the battery capacity drops to 80% of its rated capacity. This means that if the original battery has a range of 100km from a full charge, after 8 to 10 years of use the range may reduce to 80km. However, batteries can still deliver usable power below 80% charge capacity. Several vehicle manufacturers have designed the battery to last the lifetime of the car.

The main sources of lithium for EV batteries are salt lakes and salt pans, which produce the soluble salt lithium chloride. The main producers of lithium are South America (Chile, Argentina, and Bolivia), Australia, Canada, and China. Lithium can also be extracted from sea water. It is expected the recycling will become a major source of lithium. Estimates of worldwide reserves is about 30 million tons. Around 0.3kg (10oz) of lithium is required per kWh of battery storage. There is a range of opinion, but many agree this will last over a thousand years!

The volume of lithium recycling at the time of writing is relatively small, but it is growing. Lithium-ion cells are considered non-hazardous and they contain useful elements that can be recycled. Lithium, metals (copper, aluminum, steel), plastic, cobalt, and lithium salts, can all be recovered.

Lithium-ion batteries have a lower environmental impact than other battery technologies, including lead-acid, nickel-cadmium, and nickel-metal-hydride. This is because the cells are composed of more environmentally benign materials. They do not contain heavy metals (cadmium for example) or compounds that are considered toxic such as lead or nickel. Lithium iron phosphate is essentially a fertilizer. As more recycled materials are used the overall environmental impact will be reduced.

All European battery suppliers must comply with ‘The Waste Batteries and Accumulators Regulations 2009’. This is a mandatory requirement, which means manufacturers take batteries back from customers to be reused, recycled, or disposed of in an appropriate way.

At the time of writing (2020), battery cells make up about 30% the price of a pure electric vehicle. A problem to solve is growth in demand for raw materials, which is expected to be x25 by 2030 compared to 2015. Reuters reported that prices for key elements such as cobalt, lithium, nickel, and copper, could increase exponentially (May 2019). One way forward is the 5R solution as shown here.

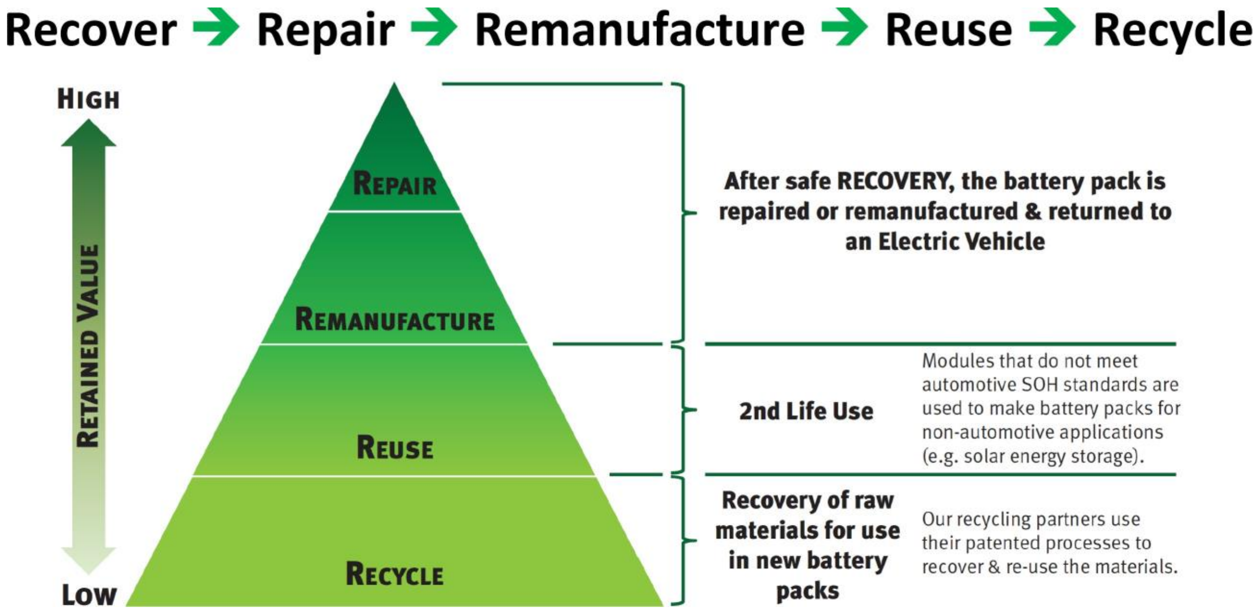


Figure 148 5R solution (Source: Autocraft EV Solutions)

Cells age differently so only a proportion will be unusable at the end of a battery pack life. These cells (or modules) can be sorted and repurposed. Through cell replacement (5% to 30% of the cells), EV battery packs can theoretically be remanufactured to a state of health (SOH) of 100%, multiple times.

The Autocraft EV battery system identifies, grades, and produces different grades of packs:

- Grade A packs (Repair) for use in vehicle within original new spec
- Grade B packs (Remanufacture) for use in vehicle to a lower capacity spec
- Grade C packs (Reuse) for use in alternative markets
- Grade D packs (Recycle) made safe for material recycling partners

(Source and more information: Autocraft Solutions: www.autocraftsg.com)

4.3.4. Temperature

A recent study by the AAA[15] showed that the impact of temperature on EVs is significantly more than was expected. The organization tested five models:

- BMW i3
- Chevrolet Bolt EV
- Nissan Leaf
- Tesla Model S
- Volkswagen e-Golf.

AAA (the American Automobile Association, Inc.) https://www.aaa.com

Each car was operated at -7°C and 35°C. All had a similar response, and on average, lost about 12% range at the low temperature. This was a quite small loss but, did not include the use of any cabin heating. When HVAC systems were activated, the range loss averaged 41%. This did not include seat or steering wheel heaters or headlights, which would impact the range further.

Another study conducted by Consumers Union[16], focused on two EVs:

- Tesla Model 3 with a 310-mile range rating
- Nissan Leaf with a 151-mile range rating.

Testing was done on a track when the outside temperature averaged between -18°C and -12°C. The Tesla used up the equivalent of 121 miles to cover 64 actual miles, leaving a displayed range remaining of 189 miles. The Nissan used 141 miles of stated range to travel 64 miles, leaving just 10 miles showing on its range display.

Figure 149 Tesla (Roadster) in cold conditions…

Lithium-ion battery components develop increased resistance at low temperatures, and this limits how much power they can hold, as well as how fast they can be charged or discharged.

4.3.5. Fast charging

Electrical current flow in battery cells and the associated connections causes heat, cooling is therefore vital. This heating effect is proportional to the square of the current flowing, multiplied by the internal resistance of the cells and connections (I^2R). Internal resistance of the cells rises when cold.

Consumers Union: https://www.consumersinternational.org

Figure 150 Lithium-ion battery pack

Many lithium battery cells should not be fast charged when their temperature is below 0℃. Battery management systems can handle this low temperature issue, but lithium cells also begin to degrade quickly if their temperature is too high (typically over 45℃) and there are safety concerns with operation at high temperatures.

The temperature of cells also needs to be kept constant across the pack. Uneven temperatures can lead to degraded performance and potential thermal events.

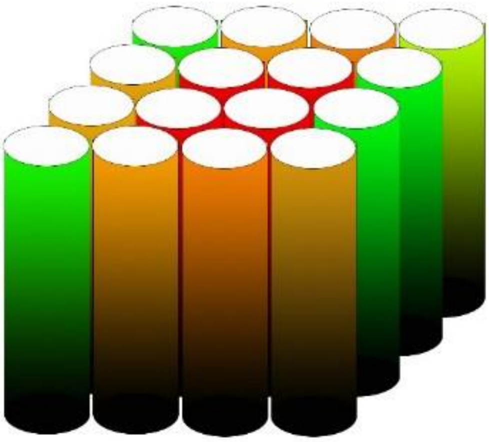


Figure 151 Representation of heat generated inside a battery pack (the penguin effect!)

For efficient liquid cooling, there are two options:

- Indirect cooling. using a liquid that is pumped around the battery and passed through a cooler radiator or similar
- Direct immersion cooling where the battery cell components are covered in a cooling agent.

Cooling the battery with a dielectric oil (the cooling agent) which is then pumped out to a heat exchanger system is an effective solution and offers good control. Figure 105 shows an example of this.

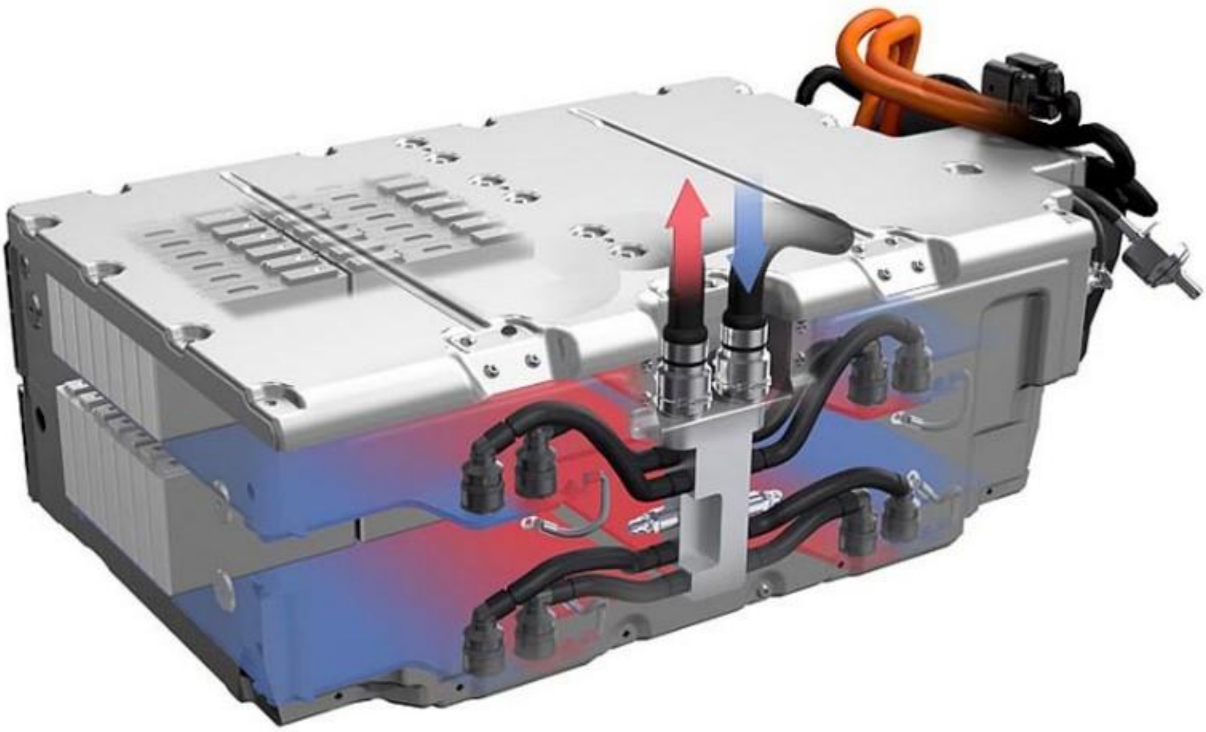


Figure 152 Battery pack with coolant flow connections (Source: Porsche Media)

Currently, the most widely used cooling approach is the indirect cooling method using a traditional cooling agent. As the demand of energy volumetric density, safety, and power density increases, there is an urgent need for a safer, more efficient cooling system design, and cooling agents. Direct immersion cooling is the safe recommendation.

Direct liquid cooling/heating is more effective and takes up less volume, provided that the heat transfer fluid is a safe and stable dielectric. Direct immersion cooling offers a safe, efficient, simplified design that enables more compact packaging.

Selection of the liquid for direct immersion cooling of electronics must not be made based on heat transfer characteristics alone. Chemical compatibility of the coolant with the cells, electronics (control units) and other packaging materials must be a prime consideration to help avoid:

- Short circuits
- Corrosion
- Cross contamination
- Flammability risk

There are several materials factors to be considered for fast charge of cells, because fast charging has four main limiting factors:

- lithium plating
- particle cracking
- atomic rearrangement
- temperature rise

These four main factors must be taken into consideration when determining the optimal fast charge profile. If this is not done, then significant reduction in cell capacity will be the result. Increasing the charging time by changing cell chemistry or design will have a cost to either lifetime or energy density.

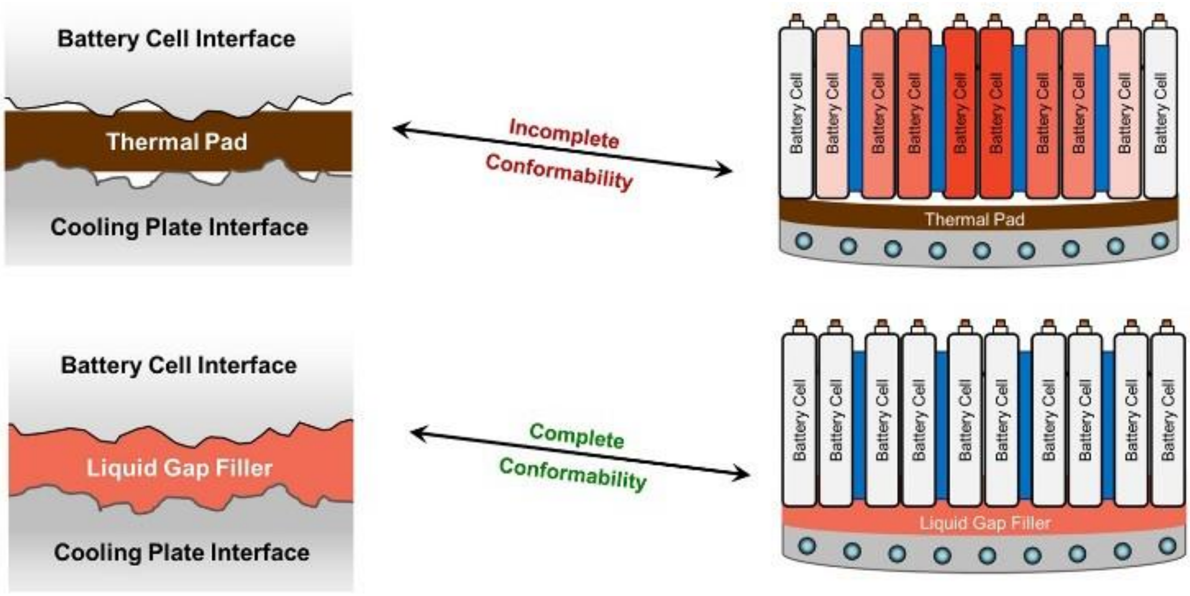


Figure 153 Gap fillers can have a huge impact on thermal conditions in a lithium-ion battery (Source: Solvay)

Claimed charging times on some new battery designs vary from a few minutes to a few hours. The more ambitious fast charge times would have to overcome significant barriers to become a reality. As a bare minimum, a highly efficient thermal management system and detailed attention to component to packaging is needed.

4.3.6. Solid-state batteries

Bosch is working on a new battery technology for electric cars that could be production-ready by 2024. Bosch has crucial knowledge in innovative solid-state cells for lithium batteries. Solid-state cells could be a breakthrough technology as the batteries charge faster and are smaller than current technologies.

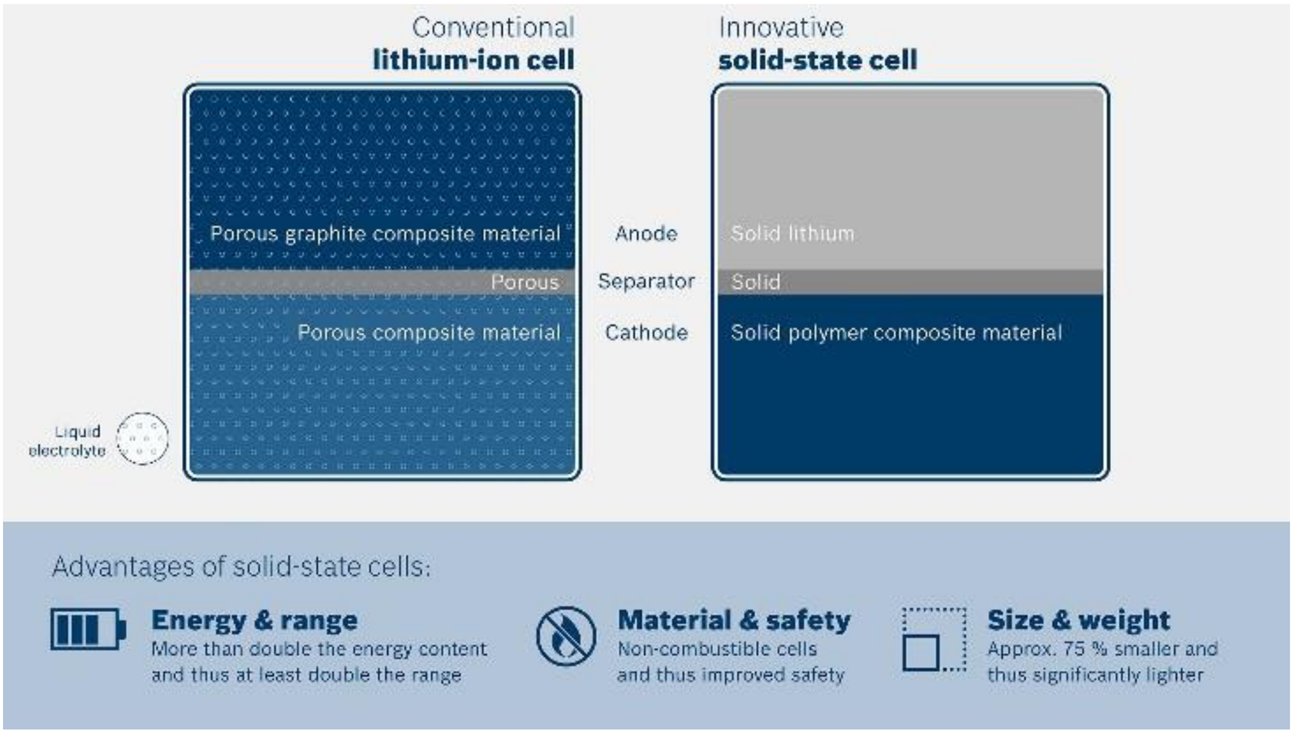


Figure 154 Potential of solid-state batteries for EVs (Source: Bosch Media)

Up to now, the declared industry target has been to double battery energy density and halve costs by the end of this decade. With the new solid-state cells, there is the potential to more than double energy density by 2030, and at the same time reduce the costs further. A comparable electric car that has a driving range today of 150 km would be able to travel more than 300 km without recharging at a lower cost. Engineers are working on further refining the technology, and in doing so, making electromobility a more practical proposition. By 2025, the company forecasts that roughly 15 % of all new cars built worldwide to have at least a hybrid powertrain.

Figure 155 Solid state cells (Source: Bosch Media)

The performance of an energy storage device can be improved by various methods. For example, in cell chemistry, the material that the positive and negative poles (cathode and anode) are made of plays a major role. In current lithium-ion batteries, one of the reasons energy capacity is limited is because the anode consists to a large degree of graphite. Using solid-state technology means the anode can be made from pure lithium, which increases storage capacity. In addition, the new cells function without ionic liquid, which means they are not flammable.

4.3.7. Chemical hazards

When dealing with a high-voltage traction battery leaking electrolyte following an accident, extreme caution must be observed, and appropriate PPE always used. This is because electrolytes tend to be irritating, flammable and potentially corrosive.

Any fluids leaking from high-voltage traction battery packs tend to be refrigerant and not electrolyte. There are only small amounts (milliliters) of electrolyte throughout the individual cells. However, skin exposure to electrolyte and the inhalation of released gases resulting from chemical reactions with leaking electrolyte should be avoided at all costs.

Figure 156 Dead battery leaking

If your skin becomes exposed to the contents of the high-voltage traction batteries or their gases, the affected areas need to be flushed with lots of water. Soiled clothing needs to be taken off and cleaned. Medical attention should then be sought as soon as possible.

Nickel metal hydride (NiMH) batteries contain potassium hydroxide in the battery electrolyte. It is a strong alkaline and is colorless and odorless. A potential spillage of battery electrolyte can be checked by using litmus paper. It can be neutralized using diluted acid.

4.3.8. Battery storage

There are a few simple rules for storing batteries:

- Do **not** mix different types (lead-acid, NiMH, Li-ion)
- Do **not** stack batteries, they should be isolated on separate benches or shelves
- Use insulated boxes or benches or shelves
- Only allow access to trained personnel
- Do **not** allow customers access to the storage area
- Keep the area/building secure
- Keep the batteries dry
- Do **not** expose them to high temperatures
- Use lifting equipment where appropriate, with insulation if needed.

As well as the safety aspects that must be followed when storing batteries, another consideration is important especially for dismantlers. Batteries have a value that can be considered at three main levels:

- High value: still functional and can be reused as it is
- Medium value: can be reused after repairs or individual components can be reused
- Lower value: content of the pack and cells can be recycled

If batteries are not stored correctly, and the system for moving them on is not run properly, their value will drop from high, to medium to low.

Figure 157 Warning sign

Batteries should be stored in a secure place that is signed appropriately as a high voltage area, where no untrained people are allowed to enter. The extreme allowable temperature is -40°C to 50°C (-40°F to 122°F) for most types of battery. However, the ideal storage temperature is about 15°C (59°F). Keep the cells at a relative humidity of about 50%. Do not freeze any battery, as this may change the molecular structure.[17]

[17] The Battery University: https://batteryuniversity.com/learn/article/how_to_store_batteries

Remember, even a damaged and discharged battery, could still be at a voltage level that will kill or injure.

For nickel batteries, the recommended storage method is at around 40% state-of-charge (SoC). This minimizes age-related capacity loss while keeping the battery operational and allowing for some self-discharge. Nickel-metal-hydride (NiMH), such as most Toyota Prius batteries, can be stored for 3–5 years but of course that would not be ideal, better that they are reused, repaired, or recycled as soon as possible.

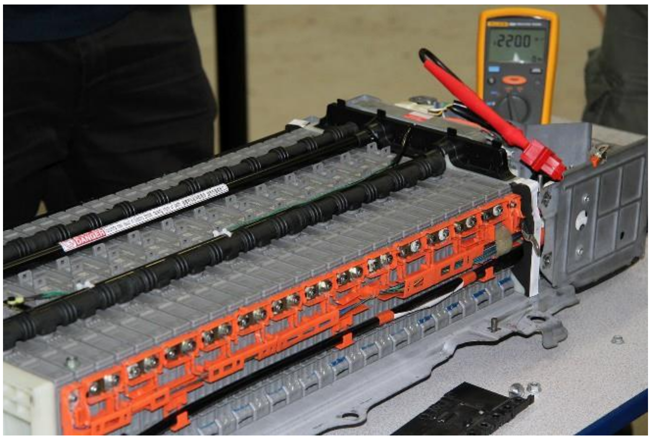


Figure 158 NiMH battery pack

With lithium batteries (Li-ion), such as most Pure EVs and PHEVs, there is almost no self-discharge below about 4.0V at 20°C (68°F). Storing at 3.7V yields amazing longevity for most Li-ion systems. Finding the exact 40–50% SoC level to store Li-ion is not that important. At 40% charge, most Li-ion batteries have an open circuit voltage of about 3.8V per cell at room temperature.

Figure 159 Li-ion battery pack

If Li-ion cells drop below 2V for any length of time, copper shunts form inside the cells that can lead to increased self-discharge or a partial electrical short. When recharged, the cells could become unstable, causing excessive heat, or showing other problems. Li-ion batteries that have been under stress sometimes function normally but are more sensitive to mechanical abuse.

If a battery is damaged, then it should be stored away from other batteries and in a plastic tray that will catch any leakages. EV batteries do not contain large quantities of electrolyte. Large fluid leaks are more likely to be coolant; however, this should still be treated with caution.

4.3.9. Battery disposal

Items such as smartphones have small lithium-ion batteries but because of their size they are often thrown into general household rubbish and probably end up in landfill.

Batteries used in electric vehicles are much bigger and of much higher voltage, so it is especially important that they are correctly recycled to avoid damage to the environment. The EU and China have introduced rules that make vehicle manufacturers responsible for recycling their batteries. The US is likely to do the same. However, this responsibility is likely to involve dismantlers at some point.

The process of recycling EV batteries is complex and expensive for a variety of reasons. Not least of which is that most were not designed with recycling in mind as other factors such as crash tests had to be considered first.

Currently, recycling facilities for lithium-ion batteries, are few and far between. This is a significant challenge as they need to be transported as hazardous materials under the Carriage of Dangerous Goods Regulations (CDR) in the UK and the International Carriage of Dangerous Goods by Road (ADR) in mainland Europe. This is both costly and complex in terms of customs regulations and necessary documentations (see next section).

Figure 160 International hazard symbol

In the USA, the Environmental Protection Agency (EPA) regulates hazardous materials as they may impact the community and environment, including specific regulations for environmental clean-up and for handling and disposal of waste hazardous materials. For instance, transportation of hazardous materials is regulated by the Hazardous Materials Transportation Act. The Resource Conservation and Recovery Act was also passed to further protect human and environmental health.

Always refer to and follow the guidance appropriate to the region you are working in.

Lithium-ion batteries use a variety of chemical processes making it difficult to develop standardized recycling. Extracting lithium in a reusable form is difficult. Some recyclers use hydrometallurgy but most heat old batteries to high temperatures to retrieve metals. This is a process known as pyrometallurgy, and generally only produces cobalt and nickel. Lithium is more difficult to extract. There is concern that the supply of lithium will struggle to keep pace with demand as electric vehicle sales increase. This will, however, increase its value and the recycling market will react accordingly.

Vehicle manufacturers, where they have the responsibility to dispose of end of life batteries, provide detailed information. For example: www.toyota-tech.eu/hvb/userguidance.aspx

4.3.10.Battery transportation

Specialist shipping companies should generally be used to transport batteries that have been removed from a vehicle, especially if the battery is damaged. This section is only intended as an overview of the issues.

A battery that is in perfect working order and undamaged still poses risks when transporting. However, a battery that is properly packaged and insulated can be transported by a trained person. It should be secured to prevent movement during normal driving and in particular in the case of an accident. This would be no different from transporting a heavy item such as an IC engine, other than the high voltage of the battery.

New lithium-ion battery handling labels and shipping marks have been effective, under changes to the International Air Transport Association (IATA) dangerous goods transport regulations since 1st Jan 2017. However, under the 60th edition of the regulations, (1st January 2019), labels such as the one shown below, are mandatory.

Figure 161 Mandatory label

From 1st January 2020, manufacturers and subsequent distributors of lithium cells or batteries and equipment powered by lithium cells and batteries manufactured after 30th June 2003 must make available the test summary as specified in the UN Manual of Tests and Criteria, Revision and amend. 1, Part III, subsection. This can be achieved using the company website. Before lithium cells/batteries can be transported, they must have successfully passed certain tests. These tests simulate transport conditions like pressure, temperature, crush, and impact, and are described in the UN manual of tests and criteria.

Types of packaging are also specified in regulations[18] as outlined in this instruction (please refer to the full documentation for further information):

An interesting question to complete this section: Is the recycler required to ensure that a customer transports these batteries correctly before they sell one? Customers collecting from vehicle recyclers and salvage agents has always been an issue. We have had long discussions over many years on how customers should remove salvage vehicles, engines, transmissions, batteries and more from vehicle recyclers and salvage agents – I am sure we all have horror stories to tell!

There are a number of options and sharing best practice is the answer. Ultimately it is the recyclers decision, however:

- the recycler may insist that any purchaser of these components must have them delivered by the recycler (who will transport the components correctly)
- if the customer insists that they are collecting the battery then the recycler should advise on best practices
- if the customer decides to do it their way then they should sign a disclaimer to confirm that they have been advised on best practices and transportation is at their risk.

[18] UNECE: https://www.unece.org/trans/danger/danger.html

P908	PACKING INSTRUCTION	P908

This instruction applies to damaged or defective lithium ion cells and batteries and damaged or defective lithium metal cells and batteries, including those contained in equipment, of UN Nos. 3090, 3091, 3480 and 3481.

The following packagings are authorized provided the general provisions of 4.1.1 and 4.1.3 are met:

For cells and batteries and equipment containing cells and batteries:

Drums (1A2, 1B2, 1N2, 1H2, 1D, 1G)

Boxes (4A, 4B, 4N, 4C1, 4C2, 4D, 4F, 4G, 4H1, 4H2)

Jerricans (3A2, 3B2, 3H2)

Packagings shall conform to the packing group II performance level.

1. Each damaged or defective cell or battery or equipment containing such cells or batteries shall be individually packed in inner packaging and placed inside an outer packaging. The inner packaging or outer packaging shall be leak-proof to prevent the potential release of electrolyte.
2. Each inner packaging shall be surrounded by sufficient non-combustible and electrically non-conductive thermal insulation material to protect against a dangerous evolution of heat.
3. Sealed packagings shall be fitted with a venting device when appropriate.
4. Appropriate measures shall be taken to minimize the effects of vibrations and shocks, prevent movement of the cells or batteries within the package that may lead to further damage and a dangerous condition during carriage. Cushioning material that is non-combustible and electrically non-conductive may also be used to meet this requirement.
5. Non combustibility shall be assessed according to a standard recognized in the country where the packaging is designed or manufactured.

For leaking cells or batteries, sufficient inert absorbent material shall be added to the inner or outer packaging to absorb any release of electrolyte.

A cell or battery with a net mass of more than 30 kg shall be limited to one cell or battery per outer packaging.

Additional requirement:

Cells or batteries shall be protected against short circuit.

Figure 162 Lithium-ion packaging instructions taken from United Nations Economic Commission for Europe (UNECE) documentation

Figure 163 Overloaded?

5. Maintenance, repairs and replacement and dismantling

5.1. Information

5.1.1. Introduction

Before carrying out any practical work on an EV, you should be trained or supervised by a qualified person. Refer to previous content for procedures on safe working and PPE and making the system safe for work. Key aspects of diagnostics, repairs, service, or dismantling work on EVs (and any other vehicles for that matter) are as follows:

- observation of Health & Safety procedures
- correct use of PPE
- correct use of tools and equipment
- following the correct repair procedures
- following workplace procedures
- referral to manufacturer specific information

Figure 164 Safety clothing and equipment (Source: EINTAC, www.eintac.com)

5.1.2. Technical information

There are many sources of technical and other information but in the case of EVs, it is essential to refer to manufacturers' data, safety data sheets, and workshop manuals. You should also be aware of the appropriate technique for gathering information from drivers/customers. For example, asking questions about when, where, or how a problem developed can often start you on the road to the solution. Likewise, if dismantling, then this can be a good guide to the condition of potentially valuable components. General sources of information include the following:

- paper based, electronic
- on vehicle data/warnings
- wiring diagrams

- repair instructions
- bulletins
- verbal instructions
- International Dismantling Information System (IDIS)

Always the most reliable source of information is that directly from the vehicle manufacturer. All this data is available to everyone, at a cost, but registration on several websites is needed. Some companies aggregate this data so may be a better option. Whatever way you access data, make sure it is the latest and vehicle specific. An example a manufacturer’s data about component location is shown in the following figure.

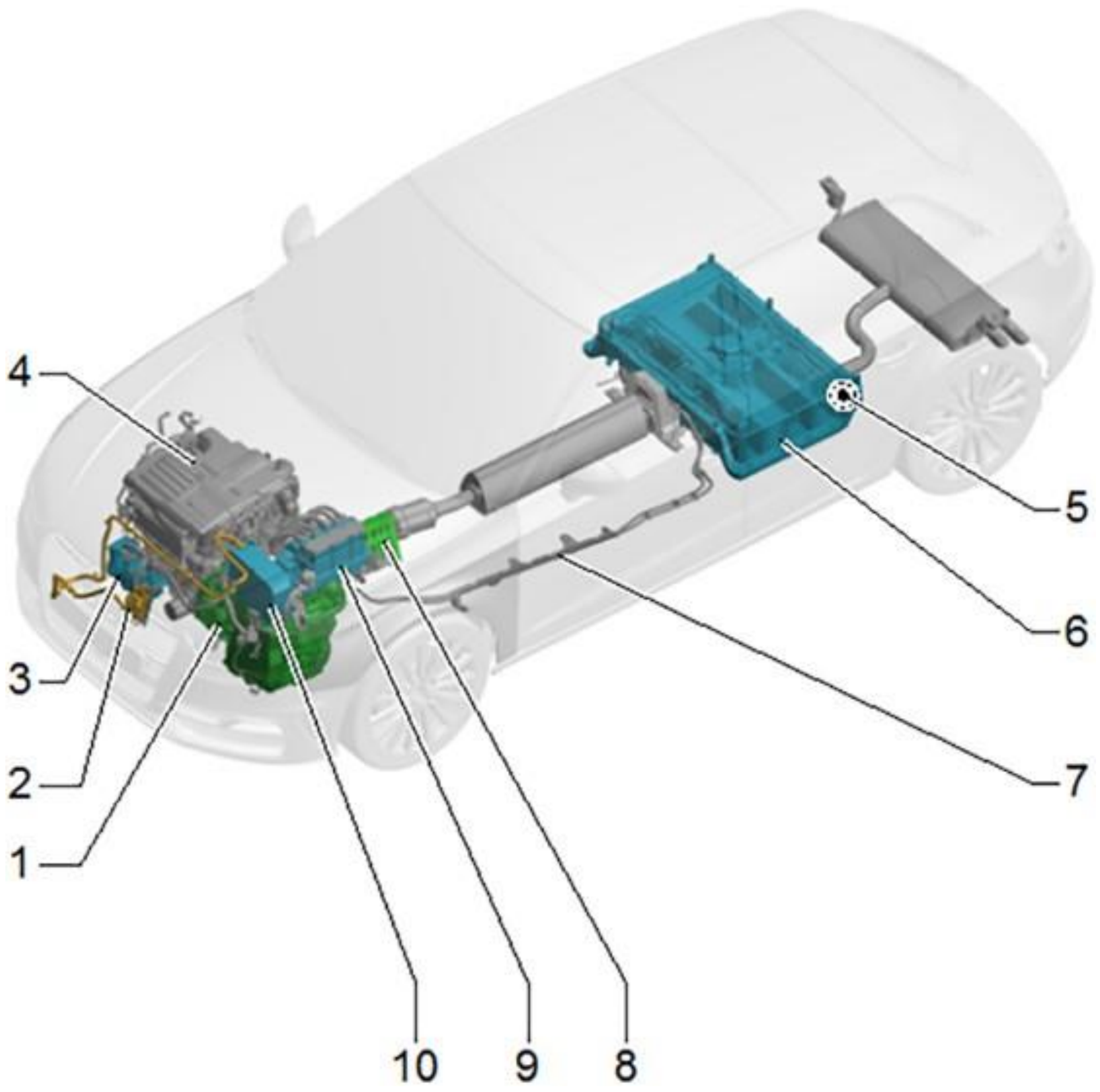


Figure 165 Components on a Golf GTE: 1. Three-phase current drive (Electric drive motor, Drive motor temperature sender), 2. High-voltage battery charging socket, 3. Electrical air conditioner compressor, 4. Combustion engine, 5. Battery regulation control unit, 6. High-voltage battery, 7. High-voltage cables, 8. High-voltage heater (PTC), 9. Power and control electronics for electric drive (Control unit for electric drive, Intermediate circuit capacitor, Voltage converter, DC/AC converter for drive motor), 10. Charging unit 1 for high-voltage battery (Source: Volkswagen Group)

An additional example showing a cutaway image of a vehicle that is very useful for learning the layout and position of the main components is shown here:

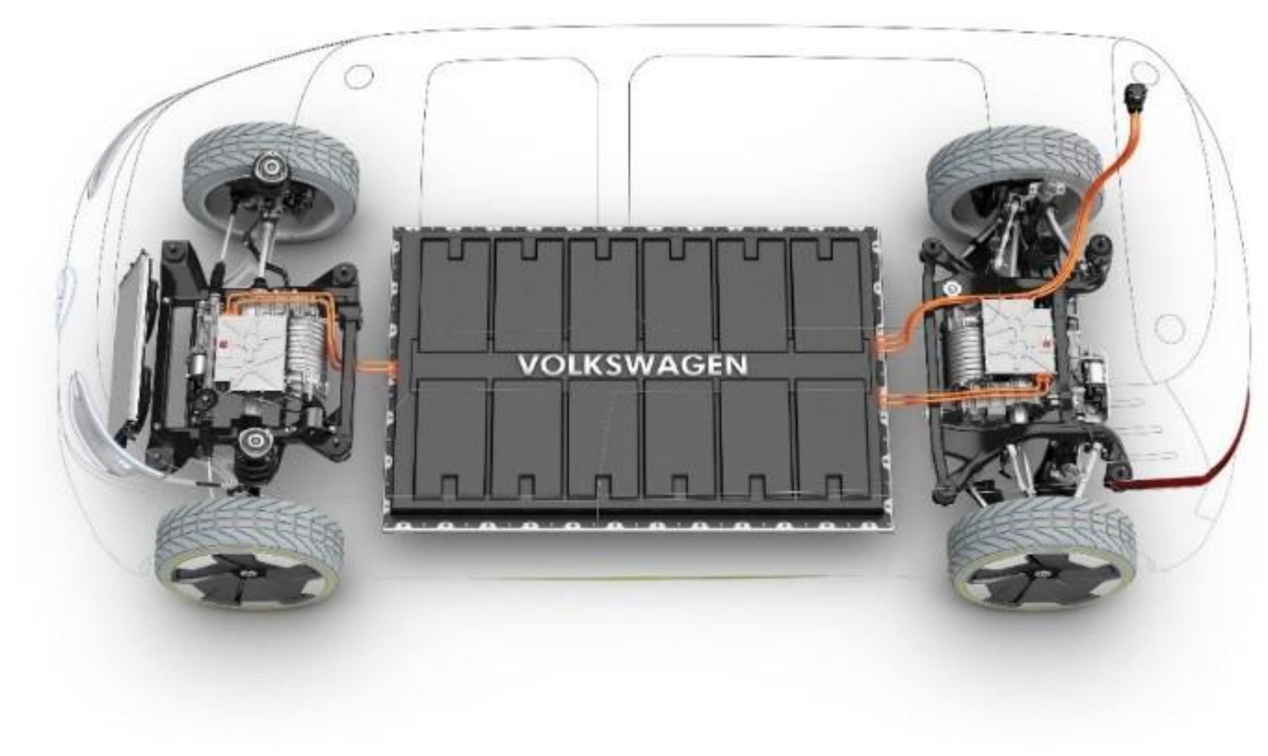


Figure 166 Example of manufacturer image (Source: Volkswagen)

5.1.3. Maintenance intervals

Maintenance intervals on electric and hybrid vehicles vary between models and manufacturers. Always refer to the manufacturer's data. Using an eGolf as an example, inspections depend on the length of time and the mileage. The first inspection takes place after 30,000 km (18,600 miles) or 24 months, followed by every 12 months or 30,000 km after that, depending on which comes first. A brake fluid inspection is recommended after 3 years, followed by every 2 years.

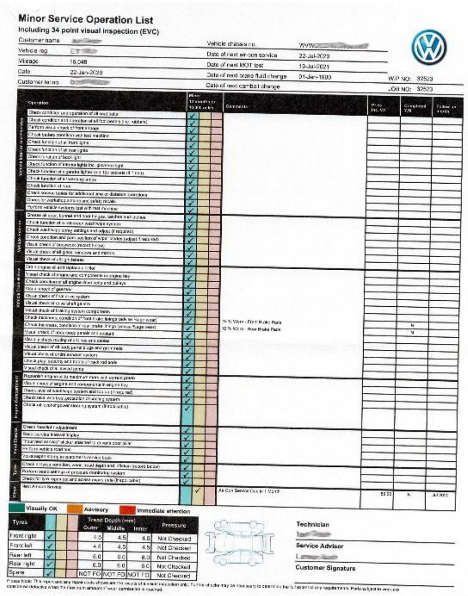


Figure 167 Example of a maintenance check list

Note that for most normal servicing procedures it is not necessary to de-energize the high voltage system. However, check data and if in doubt, switch it off!

5.1.4. Dismantling

Clearly before any form of dismantling or salvage work takes place an EV should be made safe. This is the same procedure as for normal service and repair. You must also remember that even after de-energization, the HV battery is still live. It should be the first component to be removed from the vehicle and it should be disconnected in the recommended sequence.

As mentioned in earlier sections, there are several other batteries on the vehicle that should also be removed before other work and before crushing or shredding.

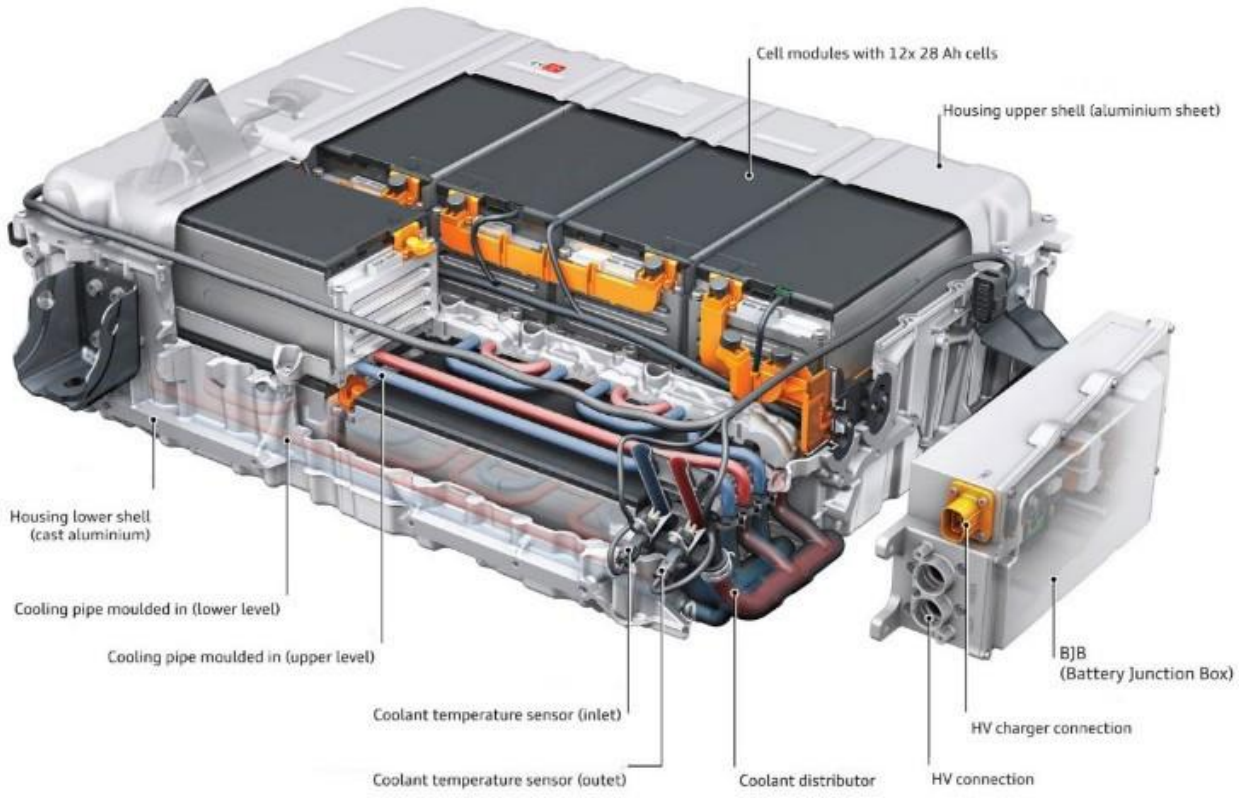


Figure 168 High voltage battery components (Source: Audi Media)

5.2. Before work

5.2.1. De-energizing

Different manufacturers have different ways to de-energize the high-voltage system (you must refer to specific data for this operation). Below I have presented a typical but generic example of a de-energization process:

1. Always use appropriate PPE
2. Place high voltage warning signs, and a fence around the vehicle with posts and barrier tape or similar
3. Disconnect the charging plug (if in use)
4. Switch ignition ON, connect scanner and check for faults, complete scan of battery modules and record battery data
5. Follow manufacturers recommendations to disconnect HV system, two different options below

Option 1

1. Connect scanner and check High Voltage readings are normal
2. Switch OFF the ignition and remove the key to a safe place
3. Open the service connector
4. Lock service connector to prevent accidental re-connection
5. Switch ON the ignition
6. Check dashboard warnings
7. Connect scanner and check High Voltage readings are ZERO

Figure 169 Maintenance connector (green item, top left)

Option 2

1. Switch OFF the ignition and remove the key to a safe place (at a distance if a remote key)
2. Disconnect 12v Battery
3. Remove High Voltage Service Disconnect (orange plug) and wait 10 minutes for capacitors to discharge
4. Check correct operation of multimeter on a low voltage source
5. Check for ZERO voltage at invertor using a Cat III (1000v) multimeter and leads

6. Re-check voltmeter on the same low voltage source

Figure 170 Service Disconnect Plug

In some cases, a technician qualified in high voltage may carry out the de-energization process for others to then continue with the ‘During work’ phase.

5.2.2. Repairs affecting other vehicle systems

If care is not taken, work on any one system can affect another. For example, removing and replacing something as simple as an oil filter can affect other systems if you disconnect the oil pressure switch accidentally or break it by slipping with a strap wrench.

For this reason, and of course it is even more important when dealing with high energy system, you should always consider connections to other systems. A good example would be if disconnecting a 12V battery on an HEV, the system could still be powered by the high voltage battery and DC-DC converter. Manufacturers’ information is therefore essential.

Figure 171 Electronic control unit (ECU)

Electro-magnetic radiation (or interference) can affect delicate electronics. Most ECUs are shielded in some way but the very high strength magnets in the rotor of some EV motors could cause damage.

5.2.3. Inspect high voltage components

During any service or repair operation it is important to inspect high voltage components. This includes the charging cables shown here.

Figure 172 Domestic mains and charge point cables

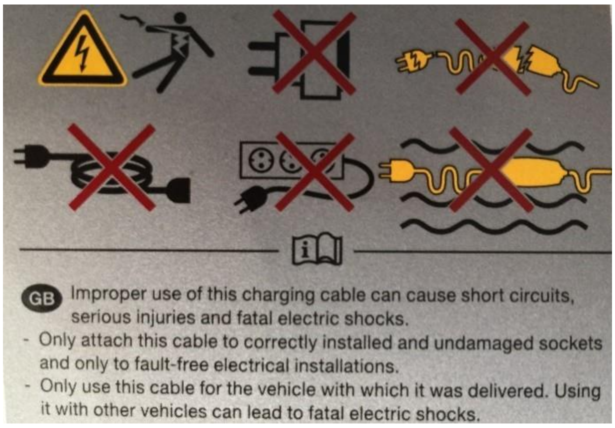


Figure 173 Warning and information supplied as part of the charging cables

Cables

High voltage components and high-voltage cables should undergo a visual check for damage and correct routing as well as security.

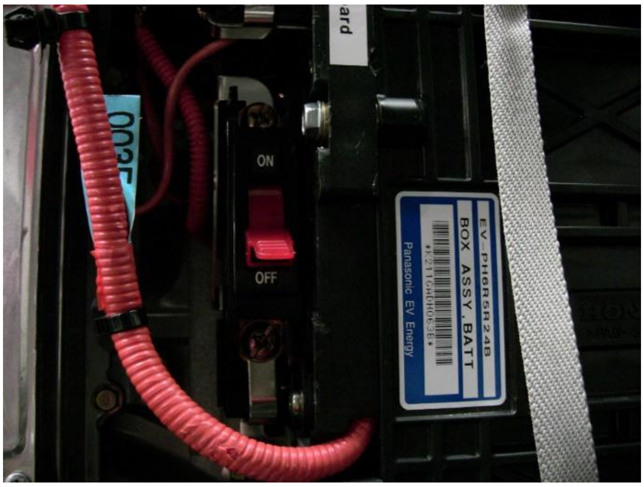


Figure 174 Battery switch and high voltage cable (red, but most are orange!)

Pay attention to the following during the visual check:

- The high-voltage components must not reveal any external damage
- Insulation of high-voltage cables must not be defective or damaged
- Unusual deformations of cables

Figure 175 High voltage cables

Battery

Check high-voltage batteries for:

- Cracks in upper part of battery housing or battery tray
- Deformation of upper part of battery housing or battery tray
- Color changes due to temperature and tarnishing of housing
- Escaping electrolyte
- Damage to high-voltage contacts
- Fitted and legible information stickers
- Fitted potential equalization line

- Corrosion damage

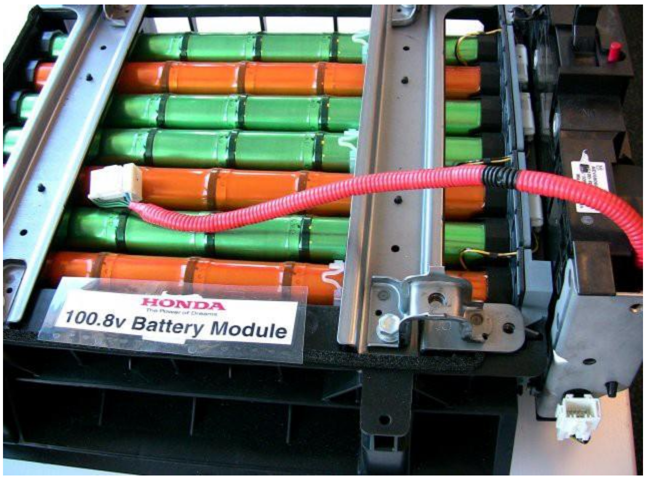


Figure 176 Honda battery pack

Other components

Engine compartment area: check the condition of the power and control electronics for electric drive, high-voltage cables for battery and air conditioning compressor, high-voltage cable for electric drive as well as high-voltage charging socket in radiator grille or in tank cap as appropriate.

Underbody: check high-voltage battery as well as high-voltage cables for battery.

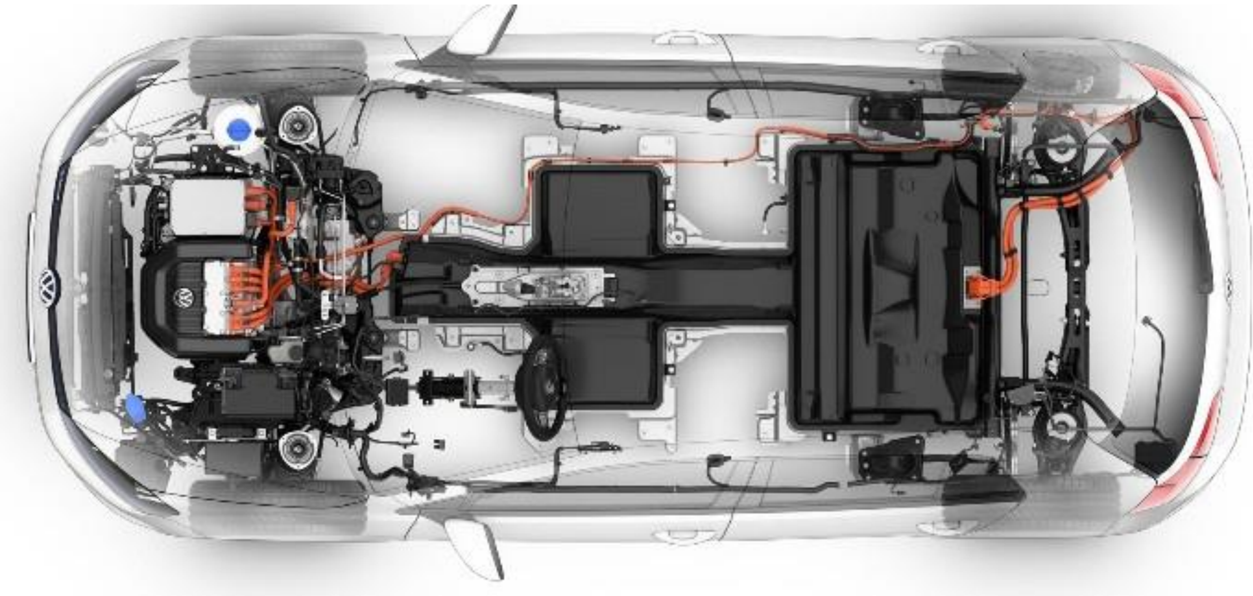


Figure 177 High voltage and other components (Source: Volkswagen Media)

5.3. During work

5.3.1. High voltage components

The main high voltage (also described as high energy) components are classified as:

- cables (orange!)
- drive motor/generator
- battery management unit
- power and control units (includes inverter and converter)

- charging unit
- electric heater
- air conditioning pump.

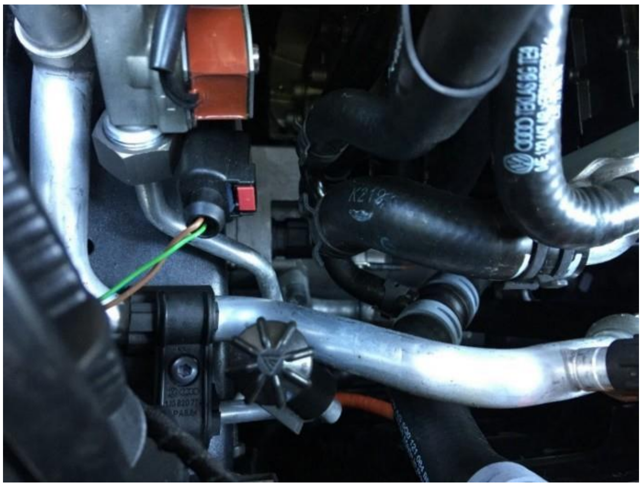


Figure 14 The AC compressor on this car is driven by a high voltage motor but still deep down on the side of the engine. You can just make out the orange supply cable here!

General safety points to note with this type of work:

- Poisonous dust and fluids pose a health hazard
- Never work on high-voltage batteries which have short-circuited
- Danger of burns from hot high-voltage battery
- Hands may sustain burns
- Wear protective gloves
- Cooling system is under pressure when the engine is hot
- Risk of scalding to skin and body parts
- Wear protective gloves
- Wear eye protection
- Risk of severe or fatal injury due to electric shock

All high voltage remove-and-replace jobs will start with the de-energizing process and after completion, the re-energizing process.

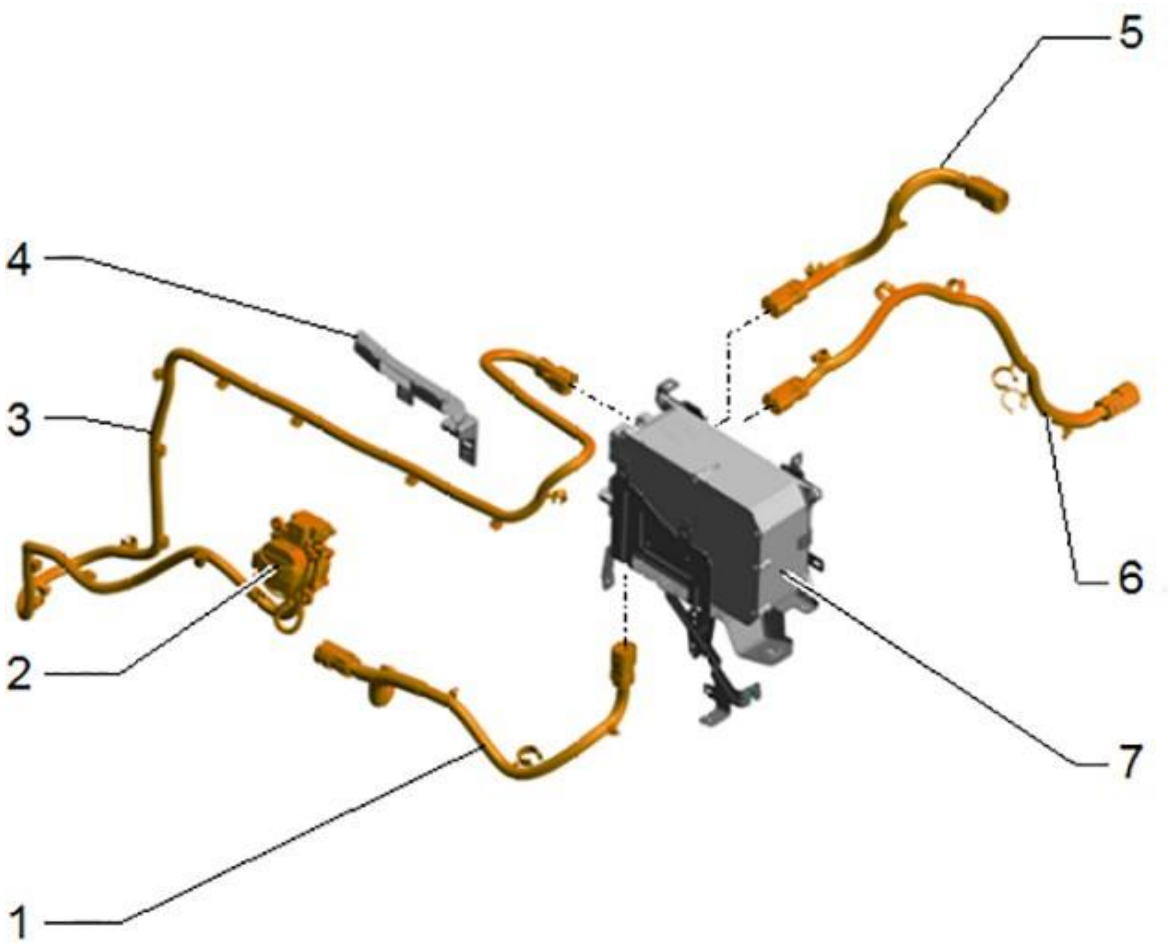


Figure 178 High voltage cables: 1. AC compressor cable, 2. Charging socket, 3. Charging socket cable, 4. Guide, 5. Battery charger cable, 6. High voltage heater cable, 7. Charging unit.

Manufacturers' information is essential for any remove and replace job that involves high voltage. Generic instructions for any component would be something like the following, but more detailed:

1. De-energize the system
2. Drain coolant if appropriate (many high voltage components require cooling)
3. Remove any covers or cowling
4. Remove high voltage cable connections (for safety reasons, some connectors are double locked, the figure below shows an example)
5. Remove securing bolts/nuts as necessary
6. Remove the main component.

Figure 179 Toyota Prius engine bay

Figure 180 Golf GTE engine bay

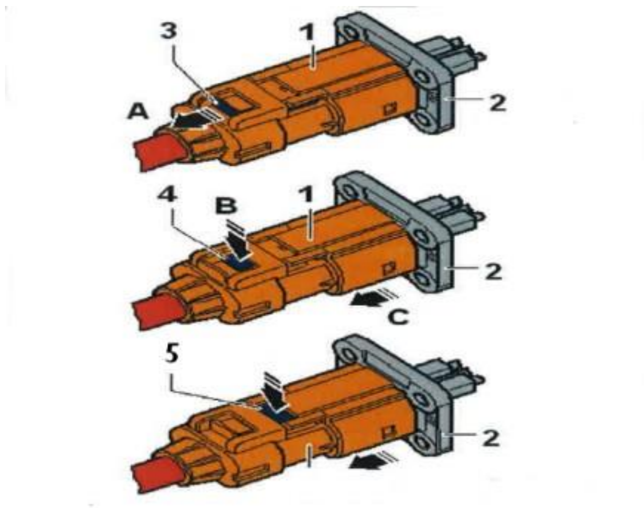


Figure 181 Locking connectors: Pull out lock 3 in direction A, Push mechanism 4 in direction B and pull off connector 1 until it is against the second lock, Push mechanism 5 in direction D and the connector can now be removed completely

5.3.2. Insulation testing

Clearly an important skill when working in salvage is to be able to determine the value of components. How and if the vehicle drives into the yard is a good indicator but sometimes additional tests may be useful. For example, the stator of an EV motor is heavy and contains a lot of copper as well as iron. It therefore has a scrap value. However, as a working component that could be sold, its value is likely to be a lot higher. One way of checking a component such as this is to carry out an insulation test

An insulation tester is mostly used on electric and hybrid vehicles to check that the high voltage cables and components are safe.

The device shown below is known as a Megger and can supply up to 1000V to test the resistance of insulation on a wire or component. A reading well in excess of 10MΩ is what we would normally expect if the insulation is in good order – but as always, check manufacturers' recommendations. The high voltage is used because it puts the insulation under pressure and will show up faults that would not be apparent if you used an ordinary ohmmeter.

Figure 182 Megger insulation tester

To test the insulation resistance on the stator shown, the Megger should be connected between one of the three phase windings and the iron body.

Figure 183 Stator from a hybrid motor

Take care when using insulation testers, the high voltage used for the test will not kill you, because it cannot sustain a significant current flow, but it still hurts!

5.3.3. Battery pack

For most battery removal jobs, special tools and workshop equipment may be necessary, for example:

- Hose clamps
- Scissor-type lift platform
- Drip tray
- Protective cap for power plug.

Typical removal process:

1. De-energize high-voltage system
2. Remove underbody covers
3. Remove silencer
4. Remove heat shield for high-voltage battery
5. Open filler cap on coolant expansion tank
6. Set drip tray underneath.
7. Remove potential equalization line
8. Disconnect high-voltage cables
9. Fit protective cap onto high-voltage connection
10. Clamp off coolant hoses with hose clamps
11. Lift retaining clips, remove coolant hoses from high-voltage battery, and drain coolant
12. Preparing scissor-type lift assembly platform with supports
13. Raise lift assembly platform to support the high voltage battery

14. Remove mounting bolts
15. Lower high voltage battery using lift assembly platform.

Installation is carried out in the reverse order; note the following:

- Tighten all bolts to specified torque
- Before connecting high voltage, cable pull protective cap off high-voltage connection
- Refill coolant
- Re-energize high-voltage system.

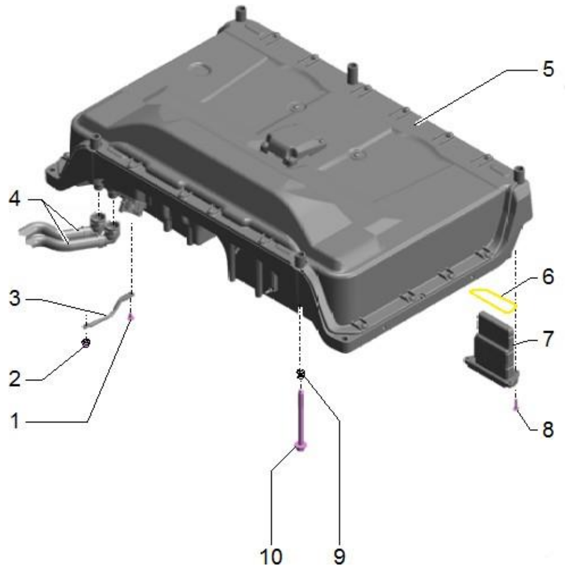


Figure 184 Battery pack: 1. Bolt, 2. Nut, 3. Potential equalization line, 4. Coolant hoses, 5. High-voltage battery, 6. Gasket, 7. Battery regulation control unit, 8. Bolt, 9. Captive nut, 10. Bolt

Figure 185 48V Battery (Source: Bosch Media)

5.3.4. Low voltage components

As well as high voltage, a large part of our work on EVs will be working on the low voltage systems. Sometimes these are described as 'low energy' to distinguish them from the 'high energy' components such as the drive motor – but do remember components such as a starter motor are low voltage but not low energy! Low voltage systems will include:

- control units/fuse boxes
- low energy components associated with interior heating
- wiring harness/cabling
- battery
- starter motor
- alternator
- switches
- lighting
- low energy components associated with air conditioning
- alarm/immobilizer
- central locking
- electric windows/wipers/washers
- central locking

Figure 186 Standard 12V starter motor (Source: Bosch Media)

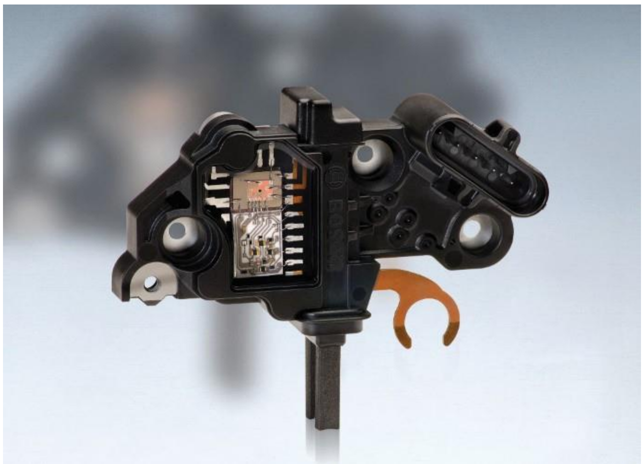


Figure 187 Alternator regulator (Source: Bosch Media)

5.4. Interrupted work

5.4.1. Procedures

When carrying out repair work, diagnostic, or dismantling work, it is quite normal for the process to be interrupted. This could be if waiting for parts for example. However, in many cases the work will be interrupted because of breaks or the workshop closing until the following day. If this happens, the vehicle should be secured so that it cannot be accidentally touched, moved, or switched on.

Suitable signage and fencing should be used. The vehicle keys and the key used to secure the maintenance connector, should be stored securely.

Figure 188 Warning notice icons

Figure 189 Danger signs (Source: EINTAC, www.eintac.com)

5.4.2. Safety

Specified lockout and tagging procedures may be used. If your company operates these then you must comply with them. For example:

- Keys stored in a specific location
- Lockout tags of specified type to be used
- Records to be kept

- Dedicated workshop areas may be allocated to high voltage operations
- General security.

Figure 190 Insulated tools

5.5. Dismantling

5.5.1. Introduction

When a high voltage vehicle is presented, you should have a designated area for them to be placed. Once the car is identified as a hybrid or an EV, tag the vehicle with a high voltage sign. This sign should only be removed when a qualified person has de-energized it, inspected, and removed the high voltage parts.

Figure 191 Scrap components

A high voltage vehicle is safe for anyone to work on when the HV battery pack, inverter with capacitors and the drive unit with high energy permanent magnet motors have been removed. This can now be dismantled by anyone with dismantling experience and training.

Unbolting or cutting a part out of a car is usually quite simple. However, it takes training and experience to know what parts are good and bad, how to work and how to stay safe. Testing and evaluating the components is an important part of a salvage technician's work.

Figure 192 Cars stacked for storage

5.5.2. Accident damage

The battery is the main cause of concern if an EV has been in a serious accident. A direct mechanical impact means the high voltage battery may become damaged. In some cases, it may disintegrate or become detached from the vehicle. In this situation it is extremely dangerous. Signs of damage are:

- the battery becomes warm
- the presence of smoke, noises, or sparks
- there is deformation of the housing.

An accident is classified as serious if there is clearly recognizable deformation of the vehicle structure, which goes beyond external damage to sheet metal, the bodywork or attached parts. Serious accidents are usually accompanied by airbag activation, which causes the high voltage system to be disconnected.

Figure 193 Serious accident damage

However, it should be noted that only those components are activated that can act in the direction of the impact. Front airbags in frontal impacts, side airbags in side impacts, for example. This only occurs if they have been installed in the vehicle of course. In the case of a pure rear impact, the accident may be serious, and no airbags may have been activated.

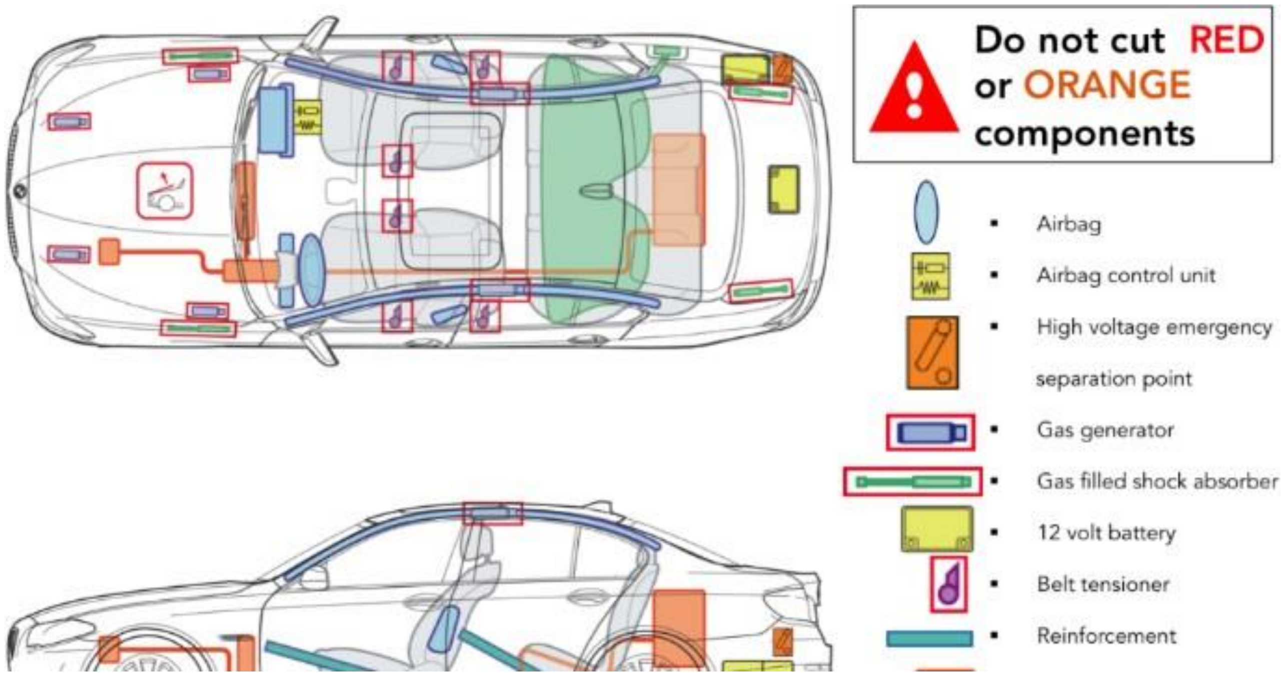


Figure 194 Emergency separation point in the rescue data sheet

A separation point is a cut-off device for the high-voltage system, which can be recognized by rescue personnel. These points are described in the rescue data sheet and may also be found in the manufacturer's rescue guidelines.

A parked vehicle that has been in an accident can still pose an electrical hazard. Under certain circumstances a vehicle's high-voltage system can be active while the vehicle is not in motion (e.g. air-conditioning during parking). When a stationary electric vehicle is involved in a crash, the airbags are generally not activated, which means it is not possible for their deployment to switch off the high-voltage system.

After a serious accident, the vehicle's high-voltage system should be assumed to be active and therefore de-energized manually.

Figure 195 High voltage battery damaged during an accident

5.6. After work

5.6.1. Introduction

After work on a high voltage vehicle has been completed, it will be re-energized, checked, and returned to the customer. Of course, this is only relevant if the car is going back into service. However, for dismantlers this could be important for two main reasons:

- The working vehicle, after assessment, is deemed to have a resale value greater that the dismantled parts
- The vehicle needs to be driven to a different work area

Figure 196 Parking area

5.6.2. Re-energizing

Different manufacturers have different ways to re-energize the high-voltage system (you must refer to specific data for this operation). Below is a typical generic example of a re-energization process:

1. Always use appropriate PPE
2. Unlock service connector
3. Replace the service connector
4. Switch ON the ignition
5. Check dashboard warnings
6. Connect scanner and check for faults
7. Remove the fencing and high voltage warning signs

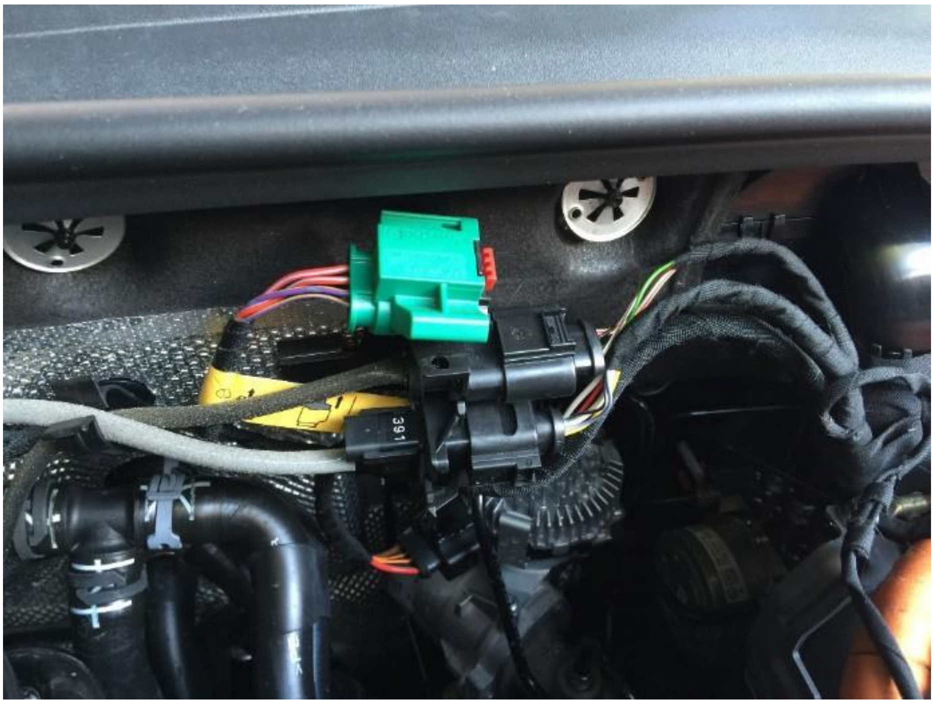


Figure 197 Maintenance connector

5.6.3. Results, records, and recommendations

This section is often overlooked but it is very important make a final check of any test results, keep a record of them and then where appropriate, make recommendations to the customer.

Volkswagen
Service record

Complete record

Vehicle data	
Vehicle identification number	WV[illegible]
Type designation	Golf 1.4 GTEBM[illegible]
Date of delivery	2018-07-19
Workshop remark	
Date	2020-06-22
Mileage/km	16048 mi
93f7	
Carried out by	[illegible]
Authorised Volkswagen service partner	Yes
Inspection with oil change	
Date	2020-06-22
Mileage/km	16048 mi
Order number	32523
Carried out by	[illegible]
Authorised Volkswagen service partner	Yes

Figure 198 Service record printout

It is essential that proper documentation is used and that records are kept of the work carried out. For example:

- job cards
- stores and parts records
- manufacturers' warranty systems

These are needed to ensure the customer's bill is accurate and so that information is kept on file in case future work is required or warranty claims are made. Recommendations may also be made to the customer, such as the need for:

- further investigation and repairs
- replacement of parts

In a dismantling situation, records should be kept of the work carried out and the parts and components salvaged.

Figure 199 Electronic data can be accessed online using this diagnostic tool

Results of any tests or work carried out will be recorded in a number of different ways. The actual method will depend on what test equipment was used or what system is in place. Some equipment will produce a printout for example. However, results of all work should be recorded on the job card. In most cases this will now be done electronically.

Figure 200 Electronic records (Source Garage Hive)

5.7. End note

5.7.1. Life cycle of a vehicle

Understanding about the whole life cycle of a vehicle (sometimes called cradle to grave) is not essential knowledge for a salvage technician. However, it is interesting and is why our industry is so important.

Life-cycle assessment or life cycle assessment (LCA) is a way of assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service. For instance, for a vehicle, environmental impacts are assessed from raw material extraction and processing (cradle), through the product's manufacture, distribution, and use, to the recycling or final disposal of the materials it is made from (grave). To determine the carbon footprint of a vehicle, its life is divided into three phases:

1. Production
2. Use
3. Recycling

For most manufacturers (Volkswagen is the example company used here), the carbon footprint of the battery-powered electrically propelled variants is already better than those of the corresponding vehicles with internal combustion engines. The same vehicle model but with different powertrains is used for this comparison.

The electric vehicle offers a higher CO_2 saving potential in all phases of the product cycle. Furthermore, it is of crucial importance for CO_2 emissions whether the propulsion energy is generated from fossil or regenerative sources. As an example, at the time of writing (2020), the Golf TDI (Diesel) emits 140g CO_2/km on average over its entire life cycle, while the e-Golf reaches 119g CO_2/km.

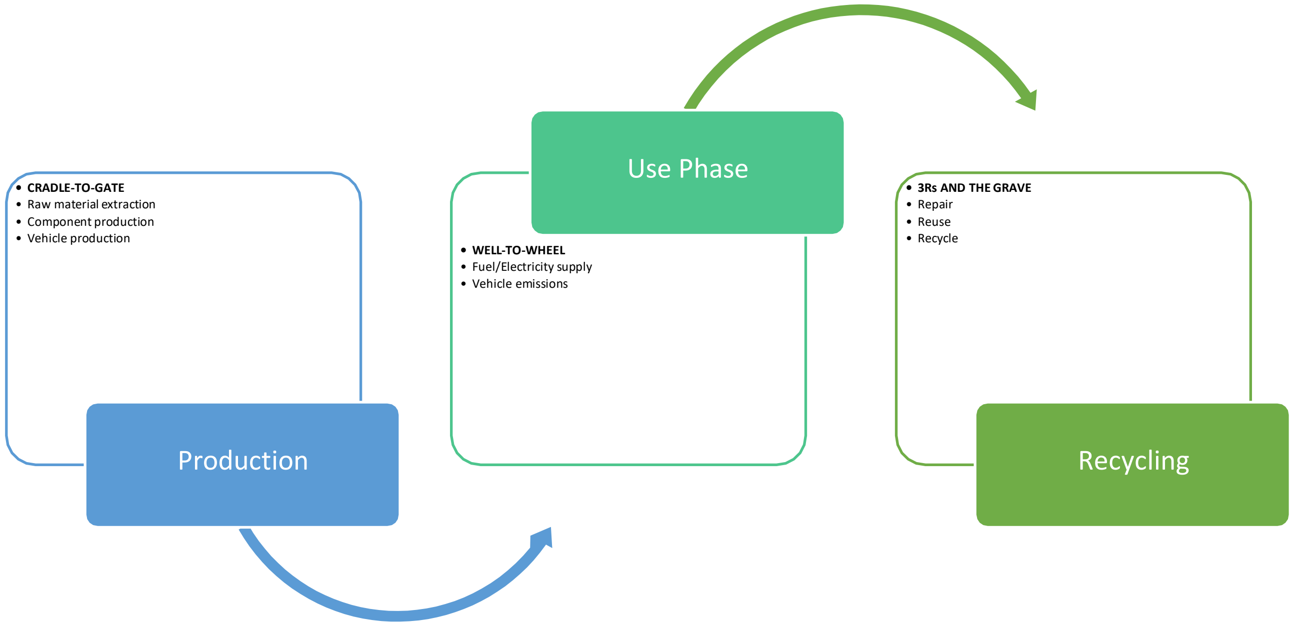


Figure 201 Life cycle assessment

A vehicle with an internal combustion engine creates most of the emissions during the use phase, that is, in the supply chain of the fossil fuel and the combustion. Here the Diesel reaches 111 g CO_2/km. A corresponding vehicle with electric drive emits only 62 g CO_2/km during this phase, which results from energy generation and supply. In contrast, most emissions from the battery-powered electric vehicle are generated in the productions phase. According to life cycle assessment (LCA), a diesel here generates 29 g CO_2/km, while 57 g CO_2/km were determined for a comparable e-vehicle.

The battery production and the complex extraction of raw materials are responsible for this. These emissions account for almost half of the CO_2 emissions of the entire life cycle. During the use phase, CO_2 emissions depend on the sources of energy production. They decrease even more; the more regenerative energies are available.

Life cycle assessment is an intricate, complex, and internationally standardized procedure to research the ecological balance sheet of vehicles. Among other things, the carbon dioxide emissions are investigated during all product stages of the automobile:

- The emissions generated by the extraction of raw materials, the production of components, and the assembly are included in the production.
- The use phase includes both the emissions of the fuel and electricity supply, and especially those of vehicle operation over 200,000 km,
- Recycling evaluates dismantling and potential savings through recycling.

(Source: Volkswagen Media)

Figure 202 Golf TDI and the eGolf compared throughout their life cycle

5.7.2. Benefits of salvage and dismantling

The benefits of running a salvage business are clear; we provide a service and earn a living! Being able to do this safely and successfully for high voltage vehicles does require some additional training and skills, but also offers other benefits to technicians and customers.

The most obvious benefit to customers of salvaged parts is reduced cost. Prices can be 50% or more, cheaper than sourcing from the manufacturer. To get the real value in the sale of EV parts a salvage technician needs to be trained. In this way it will become possible to sell parts with warranties.

Using recycled car parts is very good for the environment. Buying a salvaged part prevents the need for a new part to be manufactured and transported. This saves resources and one estimate suggests that recycled parts save 80 billion barrels of oil per year.

Figure 203 Example of components that can be reused. EV components are likely to have a much higher value

5.7.3. And finally

It does not really matter if we are doing maintenance, repairs, replacements, diagnostics, or dismantling. The high voltages on ICE cars such as from ignitions systems, hurts. However, working on a high voltage vehicle is different from working on a low voltage vehicle because they can kill you by electric shock!

Figure 205 This is a Vauxhall Grandland hybrid – but it is hard to tell without looking very closely for the orange wires, take care!

However, if you are trained and you follow the recommended procedures, they are perfectly safe. As listed a few times in this learning resource, the following points are simple but important guidance:

- Follow H&S procedures
- Use the correct PPE
- Use the correct tools and equipment
- Follow the correct repair procedures
- Follow normal workplace procedures
- Refer to manufacturer specific information.

There is some good salvage value in electric vehicles particularly for those who are well trained and understand their operation. Whether the salvaged vehicle is a hybrid or a full EV it does not matter, following the rules will ensure your safety and produce a profit.

Finally, remember that ERIC will always keep you safe:

1. **E**liminate risks – are there other ways of doing the work
2. **R**educe risks – the amount of time that is spent in potentially dangerous situations

3. **I**nformation on risks – ensure you are aware of the risks and have the right level of instruction, training, and information

4. **C**ontrol risks – wear the correct personal protective equipment (PPE).

Figure 206 Overalls, locks, and barriers (Source: EINTAC, www.eintac.com)