Emergency response to incidents involving vehicles with alternative propulsion

Course book

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1. Preamble

The percentage of vehicle with alternative propulsion on our roads is constantly increasing. More and more vehicle manufactures offer these vehicles in series production and there is also a great range of aftermarket vehicle conversions. More than 520.000 motor vehicles are equipped with an alternative propulsion system already in Germany and the amount is constantly growing.

	Germany	The Netherlands
Gasoline	30.487.578	6.177.413
Diesel	11.266.644	1.334.678
Hybrid-/Electro	39.563	39.962
Compressed Natural Gas	71.519	560
Liquefied Petroleum Gas	418.659	222.838

In the more and more complex environment of modern motor vehicles, emergency responders also need to adapt to the characteristics of vehicles with alternative propulsion. The course "Emergency response to incidents involving vehicles with alternative propulsion" should best possibly prepare responders for those incidents, for instance extrication, burning vehicles or gas leaks. To reach a practical relevance and beside all the background knowledge on alternative fueled vehicles, this course book also includes some ideas how to implement the presence of alternative propulsion into practical training.

The intention of this course book is to provide trainers with the necessary background knowledge about the available vehicles and propulsion systems. However, the focus of this book is not the detailed function of every single system but the aspect that are really important for emergency responders. In particular it is very important to know the safety installations of the different systems and there limitations to adapt incident response if necessary.

This course book should procure trainers with the necessary tools to teach emergency response personnel the things, they really need to know!

2. Introduction

2.1. Propulsion of motor vehicles

- Motor vehicles can either be propelled by a combustion engine or an electric motor.
- A **combustion engine** can be operated with multiple different fuels. Beside the classic fuels like gasoline and diesel, gaseous fuels like compressed natural gas (CNG), liquefied petroleum gas (LPG and hydrogen can also be used.
- **Electric motors** are in need of electricity that can either be provided by a battery or can be produced on-board using a fuel-cell.
- A propulsion system that uses a combination of two different means of propulsion is called **hybrid**. A hybrid vehicle tries to combine the advantages of different means of propulsion, such as a combustion engine and an electric motor.
- If a single combustion engine can be operated with multiple fuels, the propulsion system is called **bivalent**. In contrast if only one fuel can be used the propulsion system is calle**d monovalent**, while some vehicles with an 'emergency' fuel tank of less than 15 liters are often also referred to as monovalent.

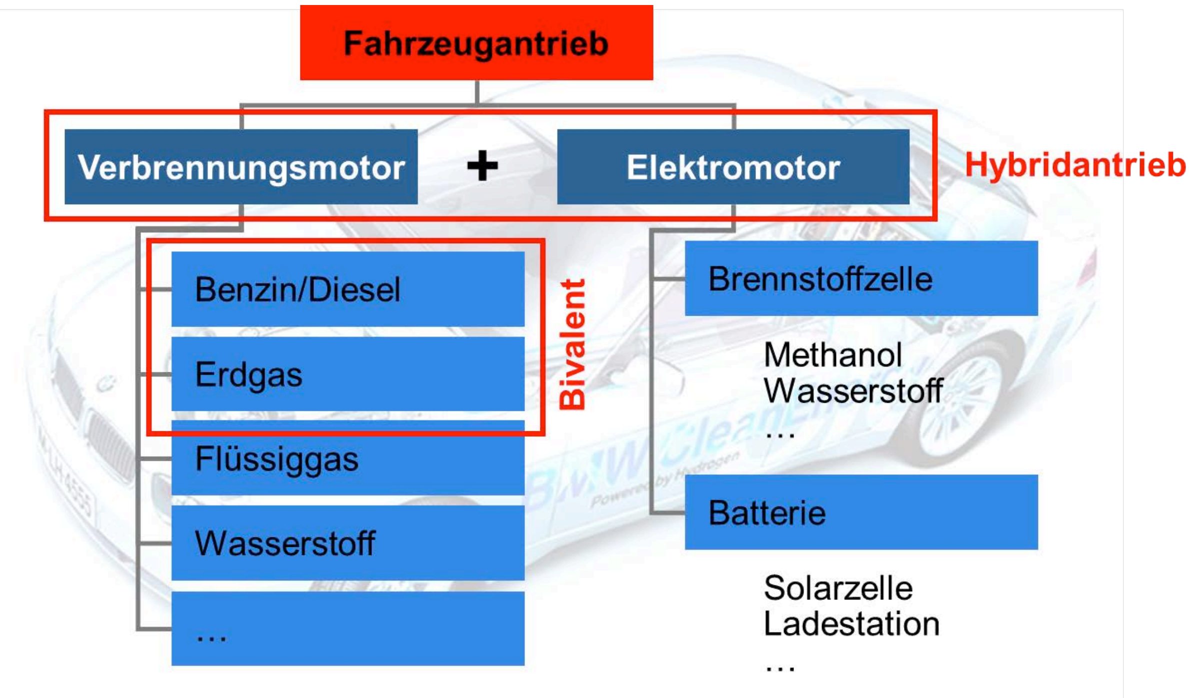


Figure 1: Classification and terminology of motor vehicle propulsion systems.

2.2. Safety of motor vehicle propulsion systems

- The safety of the vehicle as well as the safety of the propulsion system plays a key role during the development of a new vehicle. No vehicle manufacturer on the world can afford to introduce a potentially unsafe vehicle to the market.

- Vehicle manufacturers need to follow a variety of different **legal regulation** during the development of a new vehicle, for instance ECE-R 110 for vehicles with compressed natural gas propulsion or ECE-R 67 for vehicles with liquefied petroleum gas propulsion.

- Those regulations also dictate the necessary safety installations and test methods for the propulsion system components. Furthermore the vehicles are also crash tested to demonstrate their crash-worthiness (for example by following EuroNCAP guidelines).

- Simplified, it is possible to point out three essential principles, to ensure the safety of the propulsion system:

    - **Protected mounting**

      Propulsion system components, such as the fuel tank, high voltage batteries, fuel cell stacks or gas tanks are mounted in locations that are experienced safe in most crashes. In particular the area above and in front of the rear axle, the area behind the rear seat, the center tunnel area as well as the area close to the firewall are considered to be the safest.

    - **Shut-down on detection of hazardous incidents**

      Modern vehicles are most likely equipped with a variety of restrain systems, like seatbelts including seatbelt pretensioners, airbags and other components to protect the occupants in the event of a crash. The control unit of these restrain systems is also intended to shut-down the propulsion system in a lot of different vehicles to ensure that potential hazards are reduced.

      In addition it is possible that the propulsion system will be disabled on detection of gas leak (gas-powered vehicles) or a ground-fault (electric vehicles). All of these measures will only work, oft the detection of the hazardous incidents works properly.

    - **Prevention of explosion**

      Safety installation should prevent the dangers associated with the fuel and the fuel tank. In particular this affects fuel tanks for gaseous fuels, as the internal pressure rises when the tank is exposed to high temperatures, for instance when the vehicle is on fire. To avoid explosion of the tank, it is equipped with a so called pressure relief device (PRD), that should vent the content in case of excessive pressure or excessive temperatures. If the vehicle is burning, the gas will ignite outside of the tank and will burn off.

3. Gasoline- and Diesel

- Motor vehicles are most frequently propelled by means of gasoline or diesel.

- The essential principals mentioned under 2.2. are also valid for vehicles with gasoline or diesel propulsion.

- Mounting the fuel tank above or in front of the rear axle ensures that the tank is not prone to be damaged during accidents and therefore will not leak its content. The fire hazard is low when fuel is not escaping.

- To cut off the further delivery of fuel many modern vehicles will **shut-off the fuel pump** in case an accident is detected. The fuel pump will not be able to further deliver fuel to the engine compartment, where it could be ignited. Furthermore the stand heating will also be shut off.

- To reduce the danger of short-circuit faults in the engine compartment and therefore the danger of fire, many vehicles that have their battery mounted outside the engine compartment utilize so called **battery safety terminal**s. These terminals pyrotechnically disconnect the positive battery cable running from the battery to the engine compartment. The other electrical systems in the vehicle such as the restrain systems and the lightening will be continuously supplied with electricity.

- Some vehicles (especially old ones) are equipped with an **inertia-switch**. This switch is intended to shut-off the fuel pump in case of an accident to stop the flow of fuel. An inertia-switch works independent from the restrain systems and can detect de- or acceleration that exceeds certain limits.

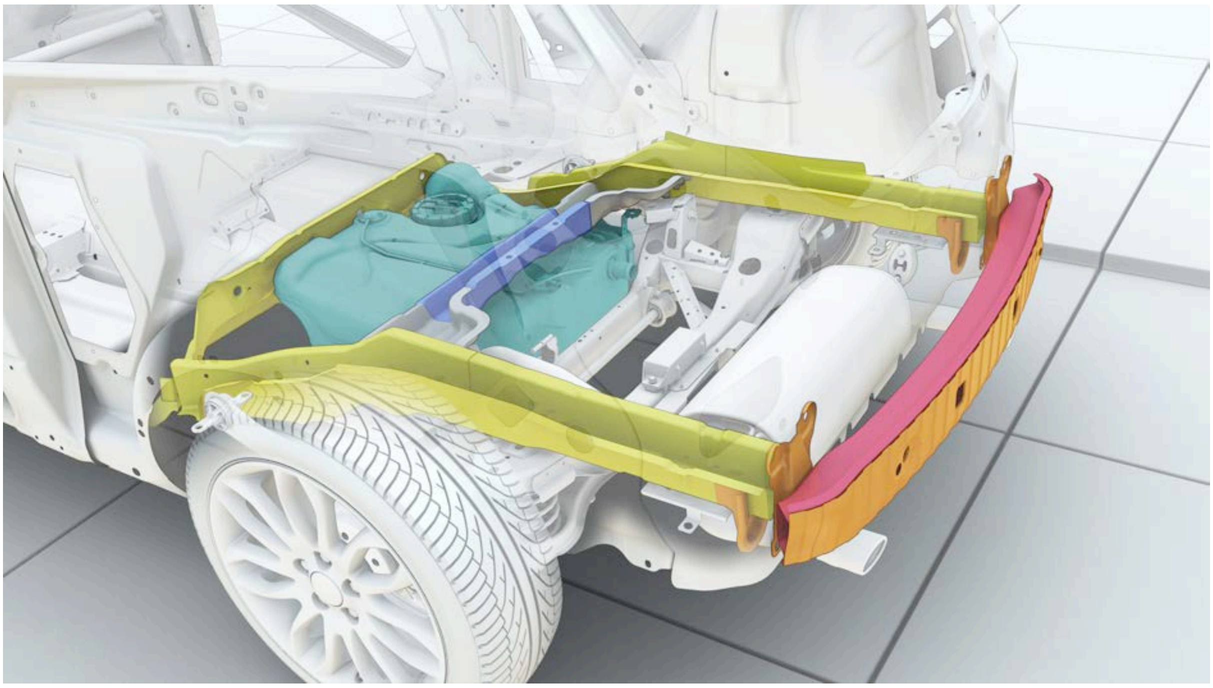


Figure 2: Protected mounting of a fuel tank in the area of the rear axle (courtesy of Volvo).

4. Compressed natural gas (CNG)

4.1. Operating mode of CNG propulsion

Figure 1: CNG powered vehicle, Volkswagen Touran Ecofuel (Courtesy of Volkswagen AG)

- Vehicles powered by compressed natural gas are offered by several vehicle manufacturers as series vehicles and are produced directly on the manufacturers' production lines. Examples:
    - Citroen C3 Bivalent
    - Fiat Doblo Natural Power
    - Ford C-Max CNG (Compressed Natural Gas)
    - Mercedes-Benz B-Class NGT (Natural Gas Technology)
    - Mercedes-Benz Econic NGT Truck
    - Opel Zafira CNG
    - Volvo S60 Bi-Fuel
    - Volkswagen Touran Ecofuel

- The belated retrofitting of a CNG installation in a gasoline vehicle is possible, but not very common.

- CNG powered vehicles are available with monovalent design (no or only an emergency fuel tank) as well as with bivalent design.

- The engine of a CNG powered vehicle is a conventional internal gasoline combustion engine (Otto-cycle engine). Instead of a gasoline-air mixture a conditioned CNG-air mixture is burned within the cylinders. The driver can generally decide, whether the vehicle should be powered by CNG or gasoline with a switch on the dashboard.

- In order to transport a sufficient amount of CNG one or multiple gas tanks are mounted in the vehicle. Usually the CNG is stored there under a pressure of maximum 200 bar (CNG = Compressed Natural Gas, GNC = Gaz Naturel Comprimé).

- The CNG tanks can be made of steel as well as carbon fiber reinforced plastic (CFK). The tanks are very rugged so that a mechanical damage to the tank is highly unlikely.

- The CNG tanks a normally mounted in protected areas of the vehicle and can either be mounted along or cross the vehicle. Common mounting locations are the area of the rear axle, the center tunnel and the trunk. In vans and trucks the chassis frame is often used to mount the tanks.

- The CNG normally reach the pressure regulator in the engine compartment through stainless steel lines mounted along the floor of the vehicle. The regulator will reduce the pressure in order to relay the gas to the engine for combustion.

- If CNG tanks are mounted within the interior of the vehicle, the gas lines are equipped with gas tight plastic tubing. In case of a leak the gas should be dissipated to the atmosphere via the tube.

4.2. Safety installations of CNG vehicles

- Every CNG gas tank is equipped with a special valve (safety valve) which combines several safety functions:

- **Electromagnetic shut-off valve**

  The electromagnetic shut-off valve will be activated and opened by the engine control unit. If there is no current on the valve, it will close automatically. During refueling of the vehicle the valve opens because of the charging pressure of the CNG.

  If the vehicle is operated with CNG, the power supply for the valve will be activated. The magnetic field will pull the valve from the valve seat and will open the gas tank. If gas is not need anymore, the power supply for the valve will be cut and the spring will push the valve back to its seat.

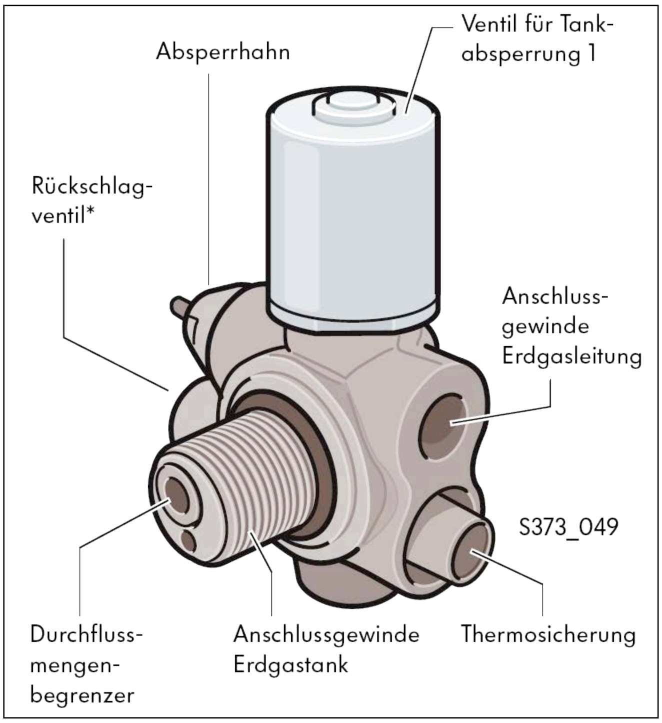


Figure 2: Example for a safety valve on a CNG tank (courtesy of Volkswagen AG)

  The electromagnetic shut-off valve will close (depending on manufacturer of the vehicle) for instance when the vehicle is switched over to gasoline operation, when the engine is switched off, in case of an accident with airbag and/or seatbelt pretensioners activation or when the power supply is interrupted.

- **Excess flow valve**

  The excess flow valve prevents the unintended and abrupt release of CNG in case of a damaged gas line or a damaged pressure regulator.

If the pressure within the gas tank is approx. 2 bar higher than the pressure in the gas line (for instance if the gas line has been ripped off), the conical nipple will be pressed into the seal seat by the tank pressure and only a short amount of gas can escape from the tank. This short amount of leakage is necessary to allow the tank to open again if the pressure difference on both sides of the valve is balancing again. It is an option to completely stop the flow of CNG by using the manual shut-off valve.

In case the excess flow valve has been activated, the complete discharging of the CNG tank may take up to seven hours.

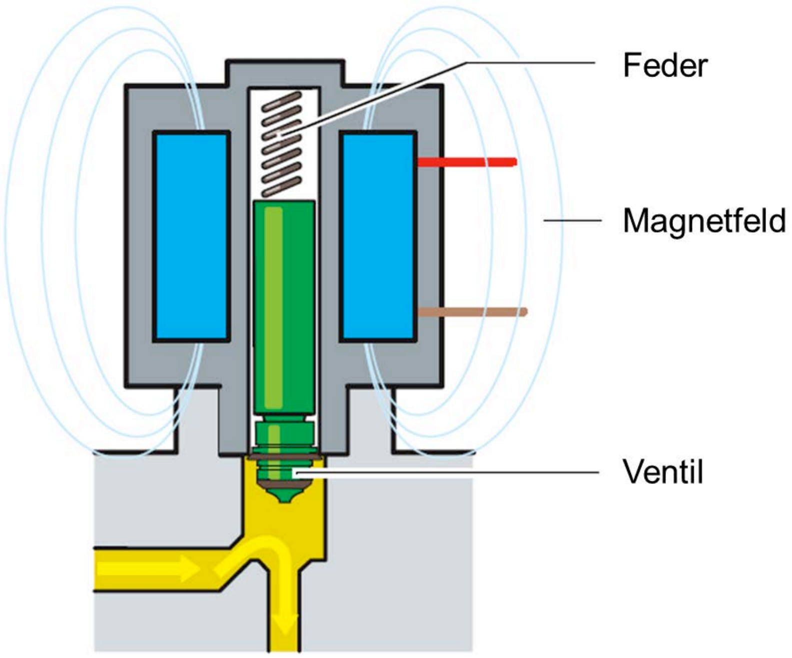


Figure 3: Operating mode of an electromagnetic shut-off valve (courtesy of Volkswagen AG)

- **Pressure relief device**

The pressure relief device (PRD) should avoid bursting of the CNG tank in case of an excessive pressure increase due to high outside temperatures (e.g. vehicle on fire). The PRD is normally integrated into the valve component, while it is possible that a single tank is equipped with PRDs on both ends.

If the temperature in the area of the PRD exceeds 110 °C, the PRD will open a vent and the CNG will be released to the atmosphere. For this reason the PRD may be designed as a fusible safety plug. Some manufacturers also utilize small glass tubes similar to the ones used in fire sprinkler systems. If the process of venting CNG is started once, it cannot be stopped anymore. Total venting of a full CNG tank takes approx. 90 seconds.

- **Rupture disk**

A rupture disk prevents an excessive pressure increase within the fuel tank. A single-use membrane breaks if the pressure exceeds a certain limit (e.g. 300 bar). The content will then be vented to the atmosphere while the process cannot be stopped anymore.

In contrast to a temperature triggered PRD the rupture disk is not mandatory and therefore not always present.

- **Manual shut-off valve**

A manual shut-off valve allows closing the CNG tank, for instance for maintenance work or if a leak occurs in the system. The vent leading to the PRD will not be closed by the manual shut-off valve for safety reasons. The manual shut-off valve can normally be closed by turning it clockwise, while the necessary key to operate the valve is not standardized.

4.3. Physical properties of CNG

- Compressed natural gas (methane, CH_4) is a colorless combustible gas, which is odorless in its original state.
- Compressed natural gas is lighter than air (density ratio CNG/air ~ 0, 6) and volatile. It quickly ascends into the atmosphere!
- CNG is odorized (an odorant is added to the gas), so that a leak can be recognized before the lower explosive limit is reached.
- The explosive range of CNG is between 4 Vol% and 17 Vol% in air.
- The ignition temperature is approx. 640 °C.

4.4. Tactical consideration for emergency response

- A potential danger of CNG powered vehicles arises from the transported gas and the danger of a (burning) gas leak or rather an explosion. If the gas tank is exposed to high temperatures, there is certain danger that the tank is bursting.
- With help of the described safety installation these dangers are effectively reduced. However it is important to know more about the limitation of the safety installations:

Vehicle accidents

- If an accident is detected by the SRS (Supplemental Restraint System) control unit that is severe enough to trigger airbags and/or seatbelt pretensioners the electromagnetic valve will normally be closed automatically. However, not all vehicles are equipped with SRS, not all control units have a connection to the electromagnetic valve and not all types of accidents can be detected by the SRS control unit. Roll over crashes or rear impacted accidents will not trigger any SRS in the majority of cases. In these situations, there will be no signal from the SRS control unit to close the electromagnetic valve.

  Note:
  The safety measures taken by the SRS control unit (e.g. shut-off of the fuel pump, closing of the electromagnetic valves) will only take place, if the SRS control unit can detect the accident.

  Note:
  The presence of deployed airbags is an indicator that the SRS control unit has been able to detect the accident and that safety measures have been taken to secure the propulsion system. A manual deactivation should always be accomplished!

- Even if the accident has not been detected by the SRS control unit, it is like that the electromagnetic valve has been closed by the engine control unit because of the missing engine rpm.

- A gas release is possible in cases where the electromagnetic valve has been damaged in the crash. In this case the excess flow valve will activate and will limit the amount of gas that can exit the CNG tank. A gas release via the excess flow valve can take several hours until the tank is empty.

- There have been cases, where a leak occurred in the area of the safety valve or the CNG lines. It is important to understand that leaks in this area can be closed by using the manual shut-off valve while leaks in the area of the PRD (temperature or pressure controlled) cannot be stopped. The excess flow valve will also not work in the second case.

- It is unlikely that the gas tank of a CNG vehicle will be damaged mechanically that it starts to leak. .Crash tests have shown that the tanks are very rugged.

Vehicle on fire

- In a vehicle fire where the CNG tanks are exposed to temperatures above 110 °C (if the case may be also when the pressure exceeds a certain limit) the PRD will be activated. The gas will be vented to the atmosphere where it will ignite and burn off.

- On a full CNG tank (200 bar) venting till the tank is totally empty will take approx. 90 seconds. It is possible that PRDs are activated time-delayed.

  Note:
  A loud hissing sound usually indicates a PRD release!

  Note:
  If the PRD on a CNG vehicle is activated once, the gas release cannot be stopped.

  Note:
  Depending on the position of the vehicle, the PRD release may create a jet flame.

- It may be difficult for the PRD to detect high temperatures if the gas tank is only exposed to punctual heat source far away from the (temperature activated) PRD. There has been a case where a gas tank exploded on the roof of a bus because heat has only been applied to the center of the tank through an opening in the roof. The punctual flame will also weaken the tank in this location.

Figure 4: Burn test conducted with a CNG powered vehicle. To avoid an explosion of the CNG tank, pressure relief devices mounted on every tank will vent the CNG in case of exposure to high temperatures (courtesy of ADAC).

5. Liquefied petroleum gas (LPG)

5.1. Operating mode of LPG propulsion

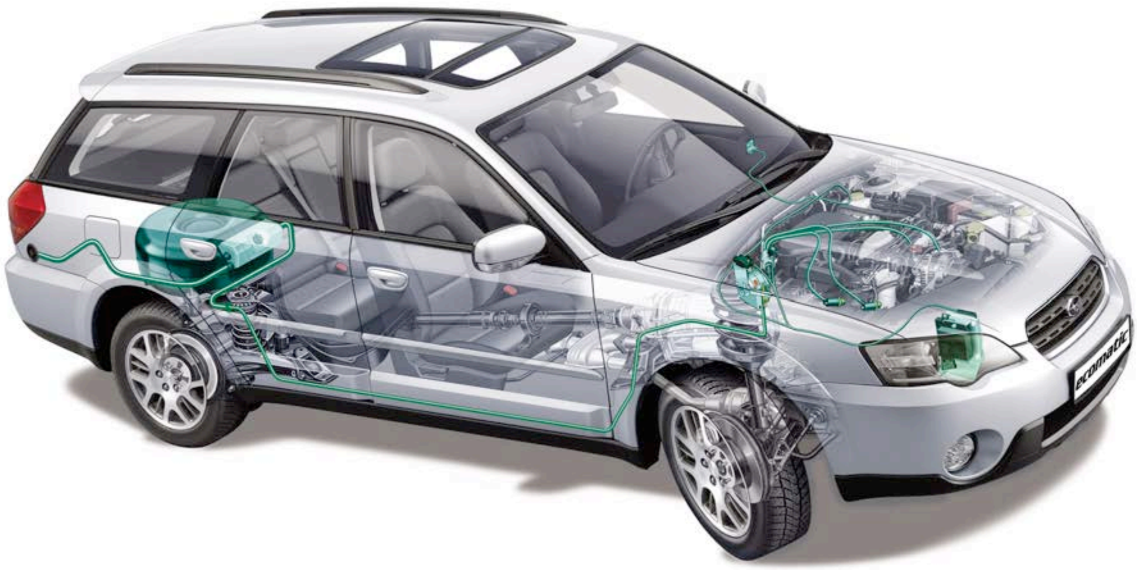


Figure 5: LPG powered vehicle. The LPG tank can be found in the spare wheel well (courtesy of Subaru).

- LPG powered vehicles (LPG = Liquefied Petroleum Gas or GPL= Gaz de Pétrole Liquéfiés) are offered from a variety of manufacturers in series. Examples:
    - Jeep Patriot Eco+
    - Volkswagen Golf BiFuel
    - Volvo S60 Bi-Fuel
- It is also possible and very popular to retrofit a LPG system to a vehicle. Nearly all gasoline vehicles can be retrofitted with an additional LPG system.
- LPG powered vehicles are most of the times bivalent. Normally the vehicle will start on gasoline to bring the vaporizer to its working temperature. Then the driver can decide whether he would like to drive with gasoline or LPG.
- LPG can be stored in tanks of different forms. Toric tanks that can be placed in the spare wheel well of the vehicle are very common but there are also other forms of tanks. Beside the spare wheel well, LPG tanks can also be mounted in the interior of the vehicle or under the floor. LPG tanks are made of steel and have a wall thickness of approx. 3, 5 mm.
- If LPG tanks are mounted inside the vehicle, the gas lines are equipped with gas tight plastic tubing. In case of a leak the gas should be dissipated to the atmosphere via these tubes.
- The LPG filler cap assembly can be found on different places, for instance under the normal fuel filler door but also separately in the area of the bumper or behind the license plate. The LPG filler tube is equipped with one or more one-way safety valves to avoid a gas release in the opposing direction.

- Refueling of the tank is carried out in a closed system. The maximum filling capacity is 80% of the tanks volume to allow the expansion of the gas, when it warms up (e.g. in summer).

- High pressure LPG lines are often made from cooper.

5.2. Safety installations of LPG vehicles

- LPG tanks are equipped with a special valve (safety valve) that combines several safety functions:

Figure 6: Safety valve of an LPG vehicle.

- **Electromagnetic shut-off valve**

  The electromagnetic shut-off valve controls the flow of LPG. It will be opened if the vehicle is operated on LPG. If the operation mode is switched to gasoline, if the engine is switched off, if the electrical power to the valve is lost or maybe also in case an accident has been detected, the valve will close automatically.

  If the vehicle is operated on LPG the electromagnetic valve will be energized. The magnetic field will pull up the valve and the access to the tank is open. If the vehicle should not be operated on LPG anymore, the power supply is cut and the spring will push the valve back down in its seat.

- **80 per cent stop valve**

  The 80 per cent stop valve is a device that limits the filling of the LPG tank at maximum 80 per cent of the tanks capacity. The valve works mechanically with a float lever.

- **Pressure relief (discharge) valve**

The pressure relief (discharge) valve is mounted directly at the LPG tank. It should avoid explosion of the tank due to an excessive pressure increase (e.g. when the vehicle is on fire).

If the pressure in the LPG tank reaches approx. 27 bar, the spring-loaded pressure relief valve opens the tank. The LPG will be vented to the atmosphere where it can burn off.

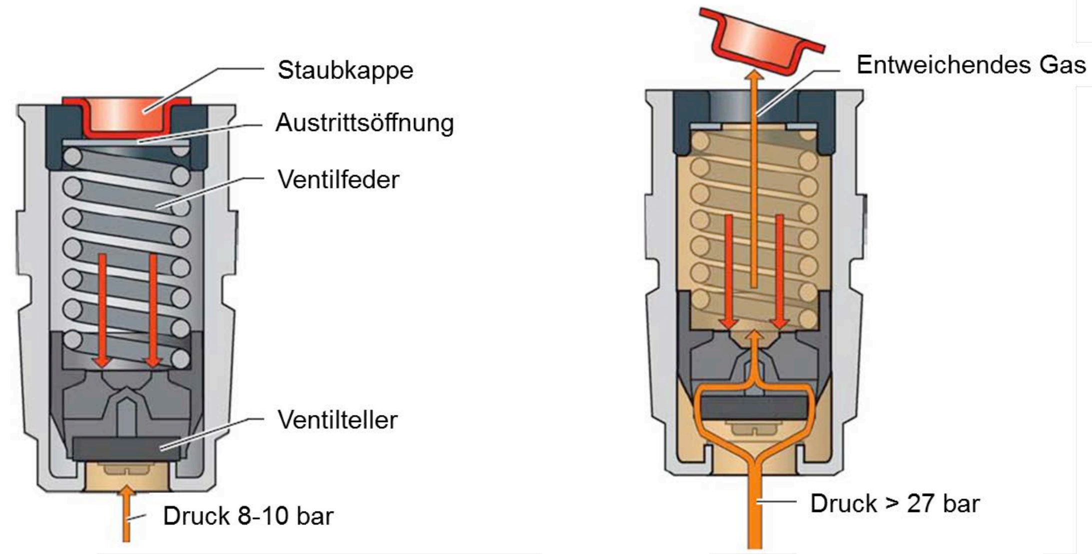


Figure 7: Operating mode of the pressure relief (discharge) valve (courtesy of Volkswagen).

- **Manual shut-off valve**

  A manual shut-off valve allows closing the LPG tank, for instance for maintenance work or if a leak occurs in the system. Not all tanks are equipped with a manual shut-off valve. The function of the PRD is not affected by the manual shut-off valve.

5.3. Physical properties of LPG

- LPG is a mix of Propane (approx. 60%) and Butane (approx. 40%).
- LPG is liquefied at a pressure of 8 bar, while it significantly reduces its volume (1/260 of the original volume).
- Gaseous LPG is heavier than air (density ratio LPG/air ~ 1,55) and therefore will spread on the ground.
- LPG is odorized (an odorant is added to the gas), so that a leak can be recognized before the lower explosive limit is reached.
- The explosive range of LPG is between 1.5 Vol% and 11 Vol% in air.
- The ignition temperature is approx. 460 °C.

5.4. Tactical consideration for emergency response

Vehicle accidents

- During an accident, the electromagnetic shut-off valve shut stop the flow of LPG. The electromagnetic shut-off valve may close for instance if the SRS control unit detects a crash severe enough to deploy airbags and/or seatbelt pretensioners or when the engine is switched off. The valve is closed without current, so disconnecting the 12 volt battery will also close it.

- A release of LPG is possible, if the LPG tank (wall thickness 3,5 mm) is mechanically damaged or if the electromagnetic valve is damaged.

Vehicle on fire

- A vehicle fire that exposes the LPG tank to heat will lead to an activation of the pressure relief (discharge) device as soon as the pressure inside the tank exceeds approx. 27 bar. LPG will be vented to the atmosphere where it will ignite and burn off. If the pressure inside the tank is discharged, the valve will close the tank again.

  Note:
  The pressure relief (discharge) device only opens the tank to discharge the overpressure. The valve will close again if the pressure has been discharged.

  Note:
  A loud hissing sound usually indicates a PRD release!

  Note:
  Depending on the position of the vehicle, the PRD release may create a jet flame.

- There are known incidents where a BLEVE (BLEVE = Boiling liquid expanding vapor explosion) occurred during vehicle fires. In most of these cases, the LPG tank or the LPG installation did not comply with the legal standards, which cannot be recognized easily.

  Note:
  Firefighting should always be carried out with caution and by using all possible coverage.

6. Hybrid- und Electric propulsion

6.1. Operating mode of Hybrid- und Electric vehicles

- Electric motors have the advantage that their efficiency factor is significantly higher than internal combustion engines. Furthermore they have a beneficial torque- and power-characteristic and they are locally emission free.

- Electric motors therefore are (again) experiencing an increase in popularity for vehicle propulsion. They can be found in a variety of different vehicle concepts, whose detailed differentiation is less relevant for emergency responders.

- Generally Hybrid- and Electric vehicle can be distinguished. The Hybrid vehicles (HEV = Hybrid Electric Vehicle) available as series vehicles are combining the classic combustion engine (with fuel tank) with an electric motor/generator as well as a high voltage battery as energy source. An Electric vehicle (EV) is solely propelled by the electric motor. Electric vehicle are not equipped with a combustion engine (Exception: Electric vehicle with Range-Extender).

- Hybrid- and Electric vehicles are increasingly produced in series by the vehicle manufacturers. Additionally there are a couple of manufacturers that convert conventional vehicles to electric propulsion or produce small series of electric vehicles.

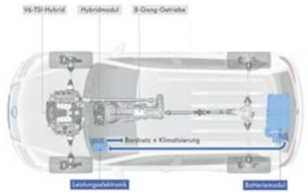
- **Operation mode of a Hybrid vehicle (full hybrid):**

  - If the vehicle is stationary, the combustion engine is not running. The high voltage battery supplies the vehicle (for example, the A/C system) with electricity (depending on the vehicle, with or without the ignition switched to the on position).

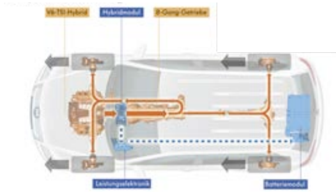
  - During acceleration or while driving with low speeds the vehicle will be solely propelled by the electric motor (provided that the high voltage battery is charged). The combustion engine is not running. The vehicle is running emission free. The electric motor reaches his capacity limit when a certain speed is reached.

  - When the vehicle is driving with constant speed the combustion engine is more efficient. It will take over and will power the vehicle. At the same time, the high voltage battery can be recharged if necessary. When the load requirement is very high (e.g. overtaking), the electric motor supports the internal combustion engine. The torque and power of the internal combustion engine and the electric motor are added together.

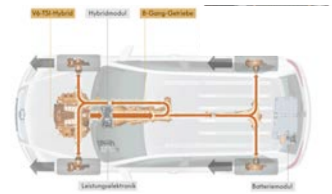
  - While driving downhill or while braking, no operation power is needed. Actually kinetic energy needs to be dissipated. While a conventional vehicle will lose the kinetic energy, the Hybrid vehicle will recover it. The electric motor, which is working as a generator, converts the braking energy into electric energy, which is then used to charge the high voltage battery. If the high voltage battery reaches a low state of charge, it is also possible to raise the engine speed to allow the combustion engine to work with optimal efficiency while recharging the battery via the generator.



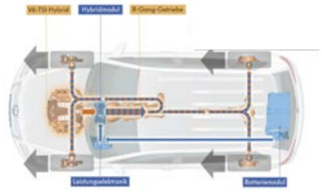
Vehicle stationary



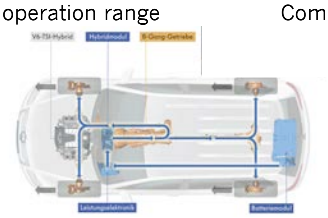
Shifting operation range



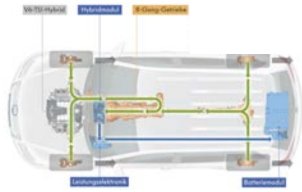
Combustion engine only



E-Boost



Electric drive mode



Brake recovery

- **Micro hybrid**

  Generally speaking a Hybrid vehicle is characterized by two different means of propulsion, which is not the case in the so-called Micro hybrid. Micro hybrid vehicles are equipped with a start/stop automatic and regenerative breaking to charge the starter battery or the starter capacitor.

- **Mild hybrid**

  A mild hybrid uses a compact electric motor to provide extra power assist for the combustion engine. Additionally it can provide auto-stop/start features and regenerative breaking.

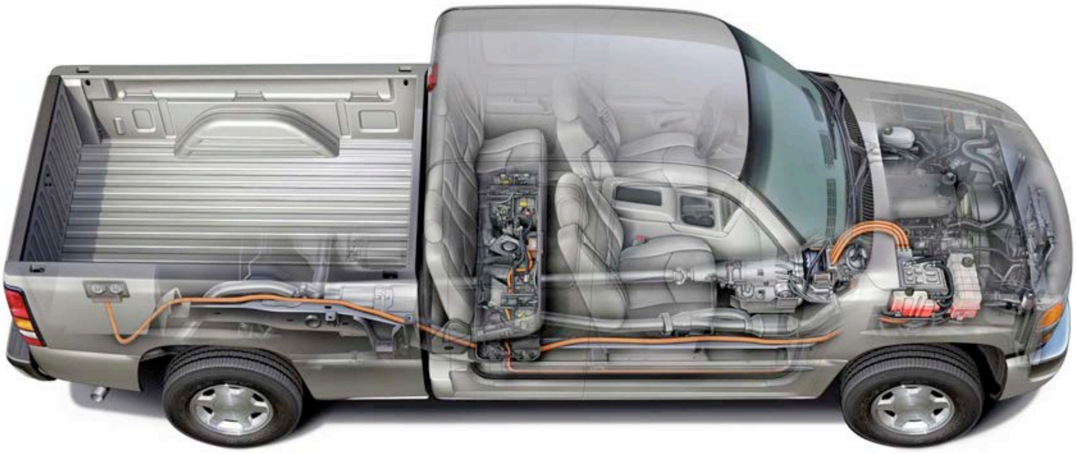


Figure 8: Chevrolet Silverado Hybrid, mild hybrid (courtesy of GM)

Examples:

  - BMW ActiveHybrid 7
  - Honda Civic IMA
  - Mercedes-Benz S400 Hybrid

- **Full hybrid**

  Full hybrids are able to drive solely electromotive. Therefore they are equipped with a powerful high voltage battery, which will be recharged by the generator (e.g. during coasting).

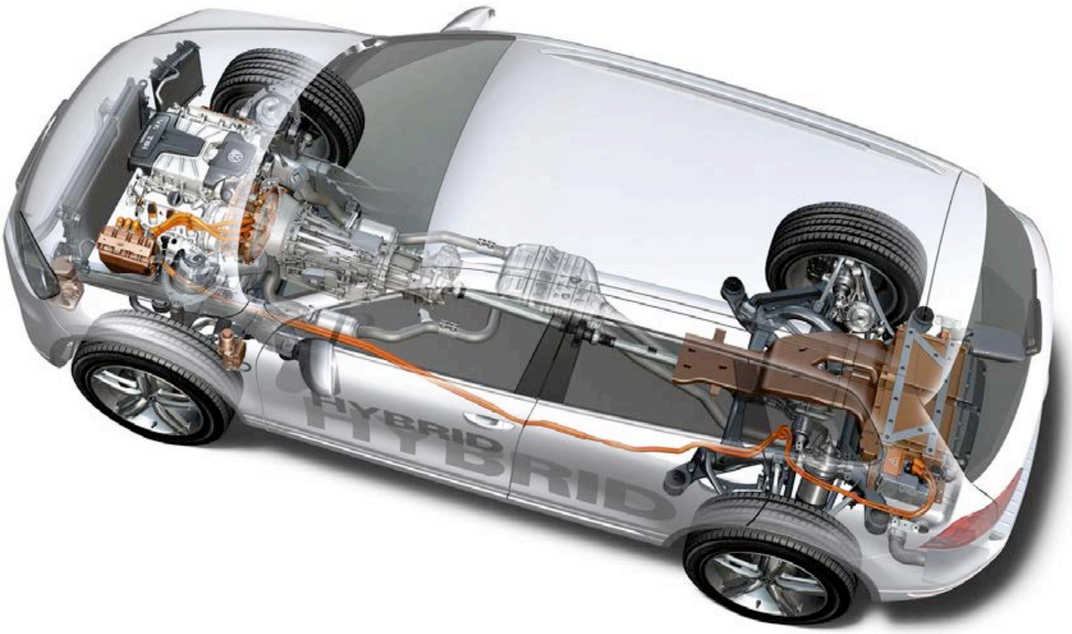


Figure 9: Volkswagen Touareg Hybrid, full hybrid (courtesy of Volkswagen)

Examples:
- Toyota Prius
- Lexus RX450h
- Volkswagen Touareg Hybrid
- Volvo FE Hybrid LKW

- **Plug-in hybrid electric vehicle**

  Hybrid vehicle that can charge their batteries from an external source in the same fashion as Electric vehicles are referred to as Plug-in hybrid electric vehicles (PHEV). Therefore they are equipped with a charge connector to connect the vehicle to charging station.

Figure 10: Toyota Prius PHV, Plug-In electric hybrid (courtesy of Toyota)

Examples:

- Toyota Prius PHV

- **Electric vehicle**

An Electric vehicle (EV) is a vehicle solely powered by an electric motor. This motor draws current from a rechargeable storage battery (high voltage battery) or from another source of electric current. The high voltage battery can be charged from an external source via one or more charge connectors.

Figure 11: Smart electric drive Electric vehicle (courtesy of Daimler)

Examples:

- Nissan Leaf
- Mitsubishi i-MiEV
- Peugeot ION
- Citroen Z-Zero
- Smart EV
- Think City

- **Extended range electric vehicle**

An electric vehicle (solely powered by an electric motor) equipped with an electrical generator powered by an internal combustion engine is called an extended range electric vehicle (EREV). If the battery is empty, the combustion engine starts to power the generator. The generated electricity will power the electric motor. The high voltage battery can also be charged from an external source.

Examples:

Figure 12: Chevrolet Volt, extended range electric vehicle (courtesy of GM)

- Opel Ampera
- Chevrolet Volt

- Components of the Hybrid- and Electric propulsion system are normally mounted in protected areas of the vehicle:

- **High voltage batteries** can often be found in the area in front or above the rear axle. Big high voltage batteries can also be mounted under the floor of the vehicle or in the area of the center tunnel. Small batteries from mild hybrid vehicle can sometimes also be found in the engine compartment.

- Most vehicles utilize Nickel-Metal-Hydride (NiMH) or Lithium-Ion-Batteries (LiIon). Within the high voltage battery the battery cells are connected in series to produce the necessary voltage.

- **High voltage power cables** are normally routed along the floor of the vehicle. They are usually not mounted close to the rocker panel or in the rocker panel as they are running more in the center of the vehicle. It is possible that the cables are not visible because they are covered or are running in conduits.

6.2. Dangers of electricity

- The electric current in Hybrid and Electric vehicles varies depending on the vehicle between 12 Volt and 650 Volt. The high voltage battery supplies direct current (DC) to a converter that transforms it into alternating current (DC/AC converter). At same time another converter (DC/DC converter) also converts the current to 12 Volt DC for the vehicles electrical system.

- Alternating current (AC) of 25 Volt or higher and direct current (DC) of 60 Volt or higher are deemed to be hazardous for the human beings.

- When touching energized high voltage components the current may flow through the human body. Direct current (DC) with amperage of more than 300 mA can lead to reversible disorders of the body's natural electrical signals depending on the period of electrical flow. If the amperage is even higher it is likely to get ventricular fibrillation.

- In addition it is possible that short circuiting the terminals of the high voltage system will produce an arc flash. This can lead to severe burns and flash burn of the eyes.

6.3. Safety of the high voltage system

- The high voltage system of Hybrid and Electric vehicles operates with electric current of up to 650 Volt, which can be potentially dangerous for occupants, service personnel and emergency responders.

  Note:
  The components of the electric propulsion system operate with electric current above 25 Volt DC and 60 Volt AC. Therefore they are more dangerous than the normal 12 Volt electrical system and are referred to as '**high voltage**' (HV) components.

- To reduce the potential dangers of the high voltage system, there are a couple of possible safety measures, such as:

  - Identification labeling and bright orange high voltage cables,
  - Guarding to prevent accidental contact (direct and indirect),
  - Galvanic separation of the high voltage system and the 12 Volt electrical system,
  - High voltage interlock system,
  - Discharge of the high voltage circuit,
  - Shutdown on accident recognition,
  - Service disconnect switch.

- Components of the high voltage system are marked with an **identification label** on their housing or casing, to warn users from the hazardous current and the danger of electric shock.

Figure 13: Identification label for high voltage components

- High voltage power cables (> 60 V) carry a special identification, as identification labels may be easily overlooked for cables with several meters of length. High voltage power cables have a **bright orange insulation**. Additionally HV connecters and the service disconnect switch can also be colored bright orange.

- All high voltage components are mounted in such a way, that it is not possible to directly come in contact with the high voltage. However, following an accident (where the HV system has not been shut off), it is possible that high voltage components have been damaged and that electrical faults are present.

- Therefore high voltage power cables do not only carry the color-coded insulation but are also equipped with a wire braid around the HV cable in the core. This wire braid is used for two purposes: to reduce electromagnetic interference and to monitor if the insulation is intact.

Figure 14: High voltage power cables under the floor pan of Hybrid vehicles (Honda Civic IMA, Lexus RX 400h). In the right photo the wire braid that is used for insulation monitoring is visible.

- The high voltage system is **galvanically separated** from the 12 Volt electrical system and therefore the ground/earth (vehicle body). This means that neither the positive nor the negative high voltage power cables are connected to the vehicle body. (In the 12 Volt electrical system the negative cable is connected to the vehicle body). This sort of network has an increased safety in case of insulation faults.

  Example:
  Because of an electric fault or damage the housing of the high voltage battery is under current. If someone touches the housing, current does not flow through his or her body because the circuit to the voltage source is not closed. In fact, the circuit is not closed even if the person simultaneously contacts vehicle ground by touching the bodywork of the vehicle with some other part of the body. The only situation in which current could flow through the person's body would be if he or she were also to simultaneously touch a second live cable of the high voltage system.

- To recognize faults in the insulation of high voltage components, Hybrid and Electric vehicles are equipped with **ground fault monitoring system** that will also inform the driver via a dashboard control light.

- Many Hybrid and Electric vehicle are also equipped with a so called **high voltage interlock system**. This system ensures that the high voltage system will be shut down as soon as one of the high voltage components will be disconnected from the system. The high voltage interlock system is an electrical circuit, which is closed by different safety plugs and switches. If this circuit is interrupted, for example because a safety plug is removed or a switch of a connected cover is opened by removing the cover, the high voltage system will shut down. A safety plugs for instance needs to be removed before high voltage cables can be disconnected from high voltage components. If the high voltage interlock system is not closed, the electric propulsion system cannot be started.

- In addition to the high voltage battery, the high voltage system has additional power sources, such as the capacitors in the power electronics or the coils of the electrical machines. Even after shutting down the high voltage system, they would be capable of keeping the voltage in the high voltage system at a level high enough to constitute a touch hazard. That is why some manufacturers incorporate an active **discharge function for the high voltage system**, which will discharge the system under certain circumstances (for example accidents detected by the SRS control unit). If a discharge function is not existent or not triggered, it can take several minutes (5 to 10 minutes) until the voltage in the system has been drained.

- The positive and negative high voltage power cables connected to the high voltage battery are controlled by **relay**s (or something similar). The relay is an electromagnetically operated switch that is used to control the flow of high voltage by a low-voltage (12 Volt) signal.

- The relays will be closed for driving and charging. If the SRS control unit **detects an accident** and deploys airbags and/or seatbelt pretensioners or if the high voltage interlock system is opened, the power supply of the relays will be interrupted and the high voltage system will shut-down.

- Vehicles that are not equipped with a comprehensive SRS system (e.g. Tesla Roadster, Think City) the crash deactivation of the propulsion system is activated by an inertia switch. It is not easily possible to recognize if the inertia switch has been triggered.

- Before the high voltage circuit could be closed by the relays for driving, the system will check itself for faults (with the help of the 12 Volt electrical system). The relays can be opened again by switching the ignition to the 'off' position.

- If the **12 Volt battery will be disconnected** while the high voltage system is active (ignition 'on') the HV system may **not shut down**. This is linked to the fact that an onboard converter (DC/DC converter) also supplies the 12 Volt electrical system with electricity. If the 12 Volt battery will be disconnected, the 12 Volt electrical system will still by feed by this converter so that the relays will not open.

- For maintenance work, many vehicles are equipped with a **service disconnect switch**, which intended to interrupt the high voltage circuit. The service disconnect switch often acts as a bridge between parts of the high voltage battery that is connected in series. In addition, the service disconnect switch is often integrated into the high voltage interlock system. If the disconnect switch is released, the interlock system is disconnected and the HV system will shut-down even before the switch can be fully operated or the plug could be removed.

Figure 15: Examples for different service disconnect switches.

Note:
On some vehicles, operating or removing the service disconnect switch is only permitted to specially trained personal and with special personal protective equipment.

6.4. Tactical consideration for emergency response

- On a Hybrid- or Electric vehicle emergency responders need to pay special attention to the high voltage electrical system and the associated dangers of electricity. Additionally it should be noted that a Hybrid- or Electric vehicle can be active, even if it is silent.

Vehicle accidents

- During an accident, the propulsion system should be switched off by means of the relays located at the high voltage battery. This should reduce the danger of the high voltage.

  Note:
  The safety measures taken by the SRS control unit (e.g. shut-off of the fuel pump, open the HV battery relays) will only take place, if the SRS control unit can detect the accident.

  Note:
  The presence of deployed airbags is an indicator that the SRS control unit has been able to detect the accident and that safety measures have been taken to secure the propulsion system. A manual deactivation should always be accomplished!

- The state of propulsion system can be recognized with the so-called 'Ready-Indicator'.

  Note:
  Switching the ignition to the 'off' position is the easiest way to open the HV battery relays. This is necessary if the accident has not been detected by the SRS control unit.

- If the ignition switch is not accessible and the propulsion system is still active, there are vehicle specific deactivation procedures to disable it.

  Note:
  Disconnecting solely the 12 Volt battery on a Hybrid- or Electric vehicle may not lead to the deactivation of the propulsion system.

- If the high voltage system has been disabled, there may be high voltage in the system for some time. The high voltage battery will keep its electric potential at all times and may therefore never be damaged.

  Note:
  High voltage components, especially the high voltage battery should never be damaged. Therefore, it is necessary to know where these components are located.

Vehicle accidents while charging

- On a Hybrid or Electric vehicles that is equipped with a charge port (EV, PHEV) the HV battery relays also need to be closed while the vehicle is connected to an external power source for charging.

- While charging the vehicle is not in an active state (the ignition is not switched to 'on'). For this reason, the SRS control unit is also not active and the vehicle will not recognize an accident.

  Note:
  While charging, the vehicle is most likely not able to detect accidents via the SRS control unit. The HV battery relays will therefore not close in the event of an accident.

- Hence, emergency responders should disconnect the charging connection. Disconnecting the connection at the power source should be preferred over disconnecting the connection at the vehicles charge port.

Vehicle on fire

- If a Hybrid or Electric vehicle is on fire, responders need to keep the high voltage system in mind and expect reaction of a burning high voltage battery.

- Under certain circumstances, it is possible that parts of the high voltage battery may burst under the influence of heat or that there might be a reaction with the water used to extinguish the fire.

  Note:
  Keep the necessary safety distances for fighting fires involving electrical systems with up to 1000 Volt.

  Note:
  A burning high voltage battery may react heavily. To extinguish the fire, copious amounts of water are necessary.

  Note:
  Damaged or burning high voltage batteries should never be opened to apply water. Danger of electric shock. Effective firefighting is not possible when a fire occurs inside the battery. Allow the battery to burn out itself!

Vehicle submersion

- There is no danger of electric shock when touching the vehicle body of a submerged Hybrid or Electric vehicle.

7. Hydrogen propulsion

7.1. Operating mode of hydrogen propulsion

- Driving vehicles with hydrogen propulsion is still a **future technology**. Although a couple of car manufacturers operate a fleet of hydrogen vehicles, there is no real series production yet.

- Generally speaking there are two possibilities to propel a vehicle with the hydrogen. On the first variant, the stored hydrogen will feed an internal combustion engine where it will be burned.

  Example:

  - BMW Hydrogen7

Figure 16: BMW Hydrogen7 test vehicle with hydrogen propulsion. On this vehicle hydrogen will be stored liquefied at -253 °C and burned in an internal combustion engine (courtesy of: BMW).

- On the second variant hydrogen will be utilized to create electricity to operate an electric motor with a fuel cell. As with many Hybrid vehicles batteries are used to provide an energy reserve for times of high power demand and to store excess energy.

  Example:

  - GM Hydrogen4
  - Honda FCX Clarity

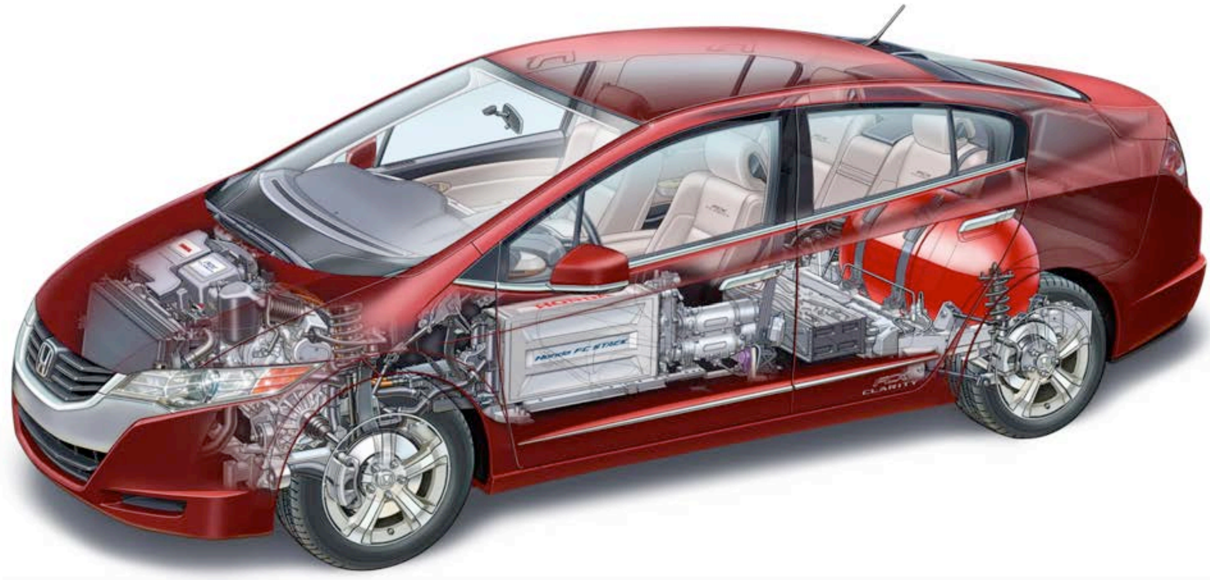


Figure 17: Honda FCX Clarity test vehicle. In this vehicle the hydrogen is stored under pressure (345 bar) and feed a fuel cell. The fuel cell creates electricity to power an electric motor. A high voltage battery is also present (courtesy of Honda).

- Hydrogen can either be stored under pressure (Compressed Hydrogen, CH_2) or liquefied (Liquid Hydrogen, LH_2).

- **Compressed hydrogen** is generally stored in pressure vessels or gas tanks made. The tanks are aluminum- or polymer lined and wrapped with carbon fiber. The technology and the safety devices can be compared to the ones used in CNG powered vehicles. To store a sufficient quantity of hydrogen, the pressure can be up to 700 bar.

- **Liquefied hydrogen** is stored in so called cryogenic tanks at -253 °C. Cryogenic cylinders have a tank within a tank to form a thermos-like insulation protection without the need for external cooling. The insulation of BMWs Hydrogen7 vehicle is 3 cm thick and equals a polystyrene insulation of approximately 17 m (a snowman in the tank would need up to 13 years to totally melt).

- A **fuel cell** is an electrochemical cell that converts chemical energy from a fuel to electric energy. In vehicles hydrogen and oxygen from the air combine in a controlled electrochemical process to form water, while electricity and heat is being generated.

7.2. Safety of the hydrogen and the high voltage system

- The safety devices mounted to the hydrogen storage tanks can be compared to the devices mounted to CNG or LPG powered vehicles. If the pressure or the temperature at the tank exceeds a certain limit the content should be vented to the atmosphere.

- On some vehicles the hydrogen will be transferred to a special vent location (e.g. on the roof of the vehicle) through vent lines. These vent lines can be mounted inside the roof pillars.

- The pressure inside a cryogenic tank will not only increase when the tank is heated but also when the insulation is damaged. In this case, the safety valve will also vent the content to the atmosphere.

- Hydrogen vehicles are often equipped with sensors to detect hydrogen leaks. If a gas concentration will be detected a gas warning indicator will possibly light on the dashboard or in the door pins. Some vehicles will automatically open the windows to vent the interior when gas can be measured.

Note:
Disconnecting the battery will also disable the gas warning system.

- The safety features on the high voltage system of a fuel cell vehicle can be compared with the safety features used on Hybrid- and Electric vehicles.

- Relays to stop the flow of electricity are not only mounted to the high voltage battery but also on the fuel cell (if so equipped). On detection of an accident the generation of electricity will normally also be stopped due to the interruption of the hydrogen supply.

7.3. Physical properties of hydrogen

- Hydrogen (H_2) is a colorless, odorless and tasteless flammable gas.

- The explosive range of hydrogen is between 4 Vol% and 76 Vol% in air.

- Especially in high concentrations, hydrogen can be ignited with minimal energy (0.02 Millijoule) (e.g. by static electricity).

- Hydrogen burns smoke-free and with a nearly invisible flame in daylight.

- Hydrogen boils at -253°C. Below this temperature it is referred to as liquid hydrogen (LH_2).

- Hydrogen is lighter than air (density ratio hydrogen/air ~ 1/15) and volatile. It quickly ascends into the atmosphere as it has the lowest molecular weight and is the smallest molecule of any element.

7.4. Tactical consideration for emergency response

- In principle, the consideration made for gas powered vehicles as well as for Hybrid- and Electric vehicles can also be transferred to vehicle powered by hydrogen. In addition, the following points are important:

- The physical properties of hydrogen (e.g. the barely visible flame) and the missing odorization make it more difficult to detect a hydrogen leak. If a gas warning system is present, emergency responders need to know how to identify a gas alarm.

- Damaging the insulation of a cryogenic tank will (along with heating by fire) lead to a pressure increase in the tank. The pressure relief device will be activated to vent hydrogen from the tank.

- On some vehicles hydrogen will be vented through vent lines within the roof posts to a vent location on the roof (highest point of the vehicle). This should prevent the accumulation of hydrogen in the interior of the vehicle.

  Note:
  Hydrogen vent lines should not be damaged to allow the proper function of the pressure relief device.

- Because of the low ignition energy required, it is possible that the hydrogen will ignite after mixing with atmospheric oxygen, for instance in the area of the vent location

Note:
The area of the vent location should be avoided during emergency response.

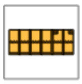
- Burning hydrogen gas may be difficult to recognize. A thermal imaging camera can make the flame visible.

8. Procedures for emergency response

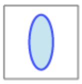
8.1. Introduction

- One of the biggest challenges for the definition of emergency response procedures is to make them universal and applicable to all types of propulsion. While this is possible, it leads to a very extensive collection of procedures.

- For this reason, the procedures in this chapter are marked with symbols to make clear for which type of propulsion they apply.

 **Notes for Electro-, Hybrid- und Fuel cell vehicles**

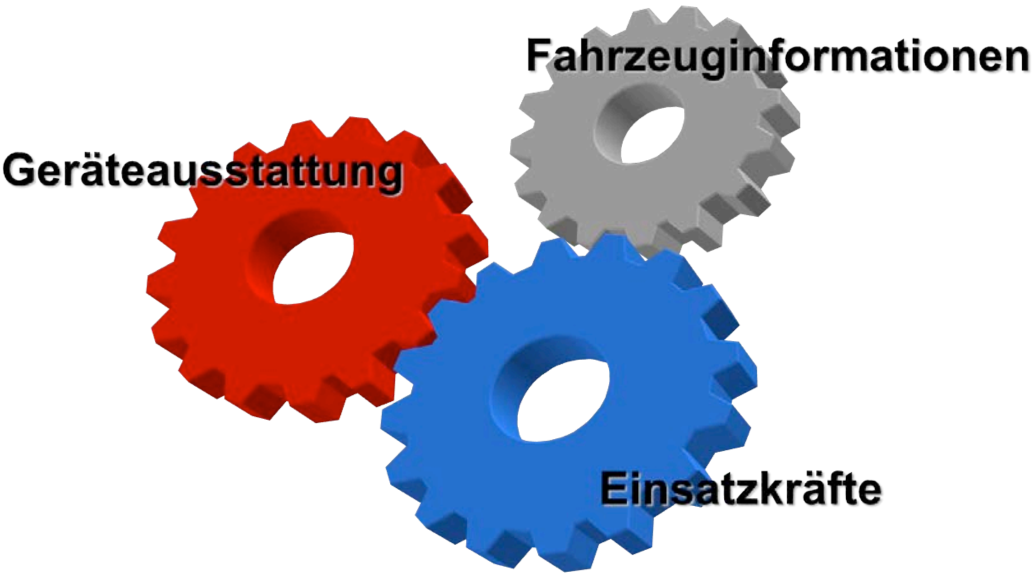
 **Notes for CNG, LPG and Hydrogen vehicles.**

 **Note on restraint systems (airbags, seatbelt pretensioners, roll bars)**

 **Notes on using CRS vehicle information**

- The goal for emergency responders should therefore be, to obtain information about the propulsion system in a very early stage of the incident. This knowledge reduces the necessary measures considerably.

- The challenges related to vehicle propulsion systems can only be solved through a holistic approach. In addition to the right tools (e.g. meters) it is in particular very important to provide emergency response personnel with the necessary knowledge to deal with these vehicles. Vehicle specific knowledge is provided by the Crash Recovery System.



8.2. Approach with caution

- Always approach a crashed or burning vehicle with caution. Pay attention to the following points:

Note:
Hybrid-, Electric- und Fuel Cell vehicles can be operational even if they are silent!

Note:
Burning hydrogen may be invisible or nearly invisible. Burn hazard in the area of the vent location!

- Avoid using non-explosion proof equipment during initial assessment.
- Approach with the wind.
- Stay clear from the vent location.

Note:
The vent location and direction is indicated by the red arrow in the vehicle Crash Recovery System information.

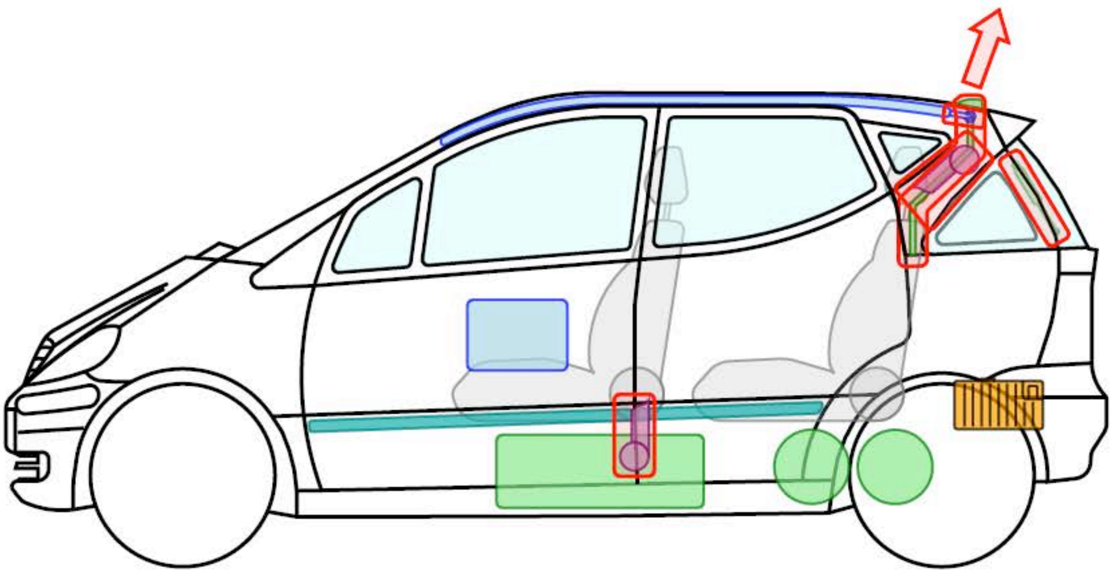


Figure 18: Mercedes-Benz A-Class F-CELL. The vent location and direction is indicated by the red arrow.

- Pay attention to indicators for an activation of the pressure relief device. A loud hissing or rattling sound usually indicates pressure release device activation.

Note:
Burning hydrogen gas may be difficult to recognize. A thermal imaging camera can be utilized to make the flame visible.

8.3. Identify propulsion system

- To reduce the necessary safety measures in dealing with the propulsion system, it is important to obtain information about the type of propulsion system and the fuels used in the vehicle as early as possible.

- There is no definite outer identifying feature for motor vehicles with alternative propulsion!

Note:
The easiest and safety way to gather information about the propulsion system and the rescue relevant vehicle equipment is a request of the vehicles license plate number with the Crash Recovery System.

If the alternative propulsion system has been retrofitted to the vehicle, it cannot be covered by the Crash Recovery System. However, if the propulsion system is registered in the national database, the type of propulsion will be shown in the request result!

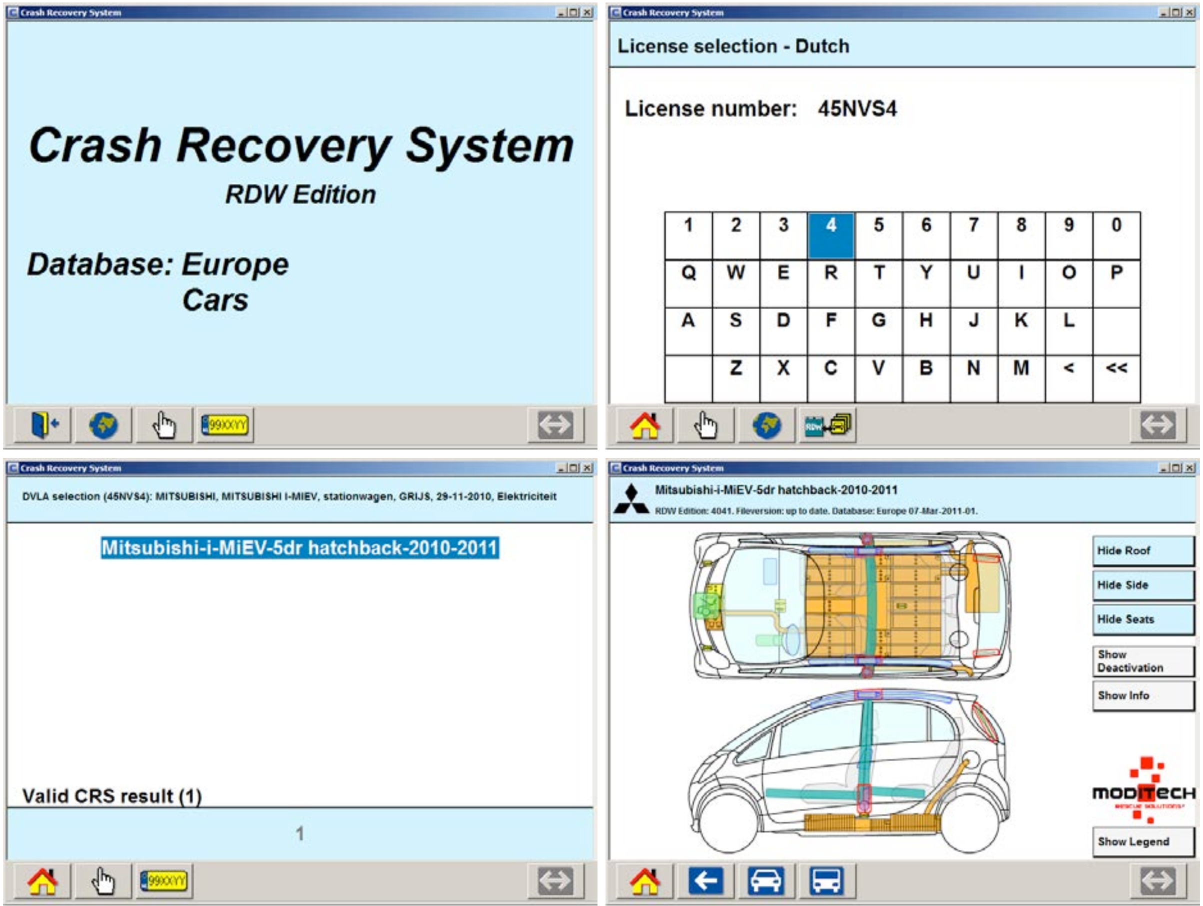


Figure 19: License plate request with the Crash Recovery System. The header in the lower left screenshots shows the result from the national database. In this case, it is a series Electric vehicle, which has then been selected from the CRS database.

Note:
The information window (Info) of the Crash Recovery System gives a first overview about the important things to consider on Hybrid, Electric and Hydrogen vehicles.

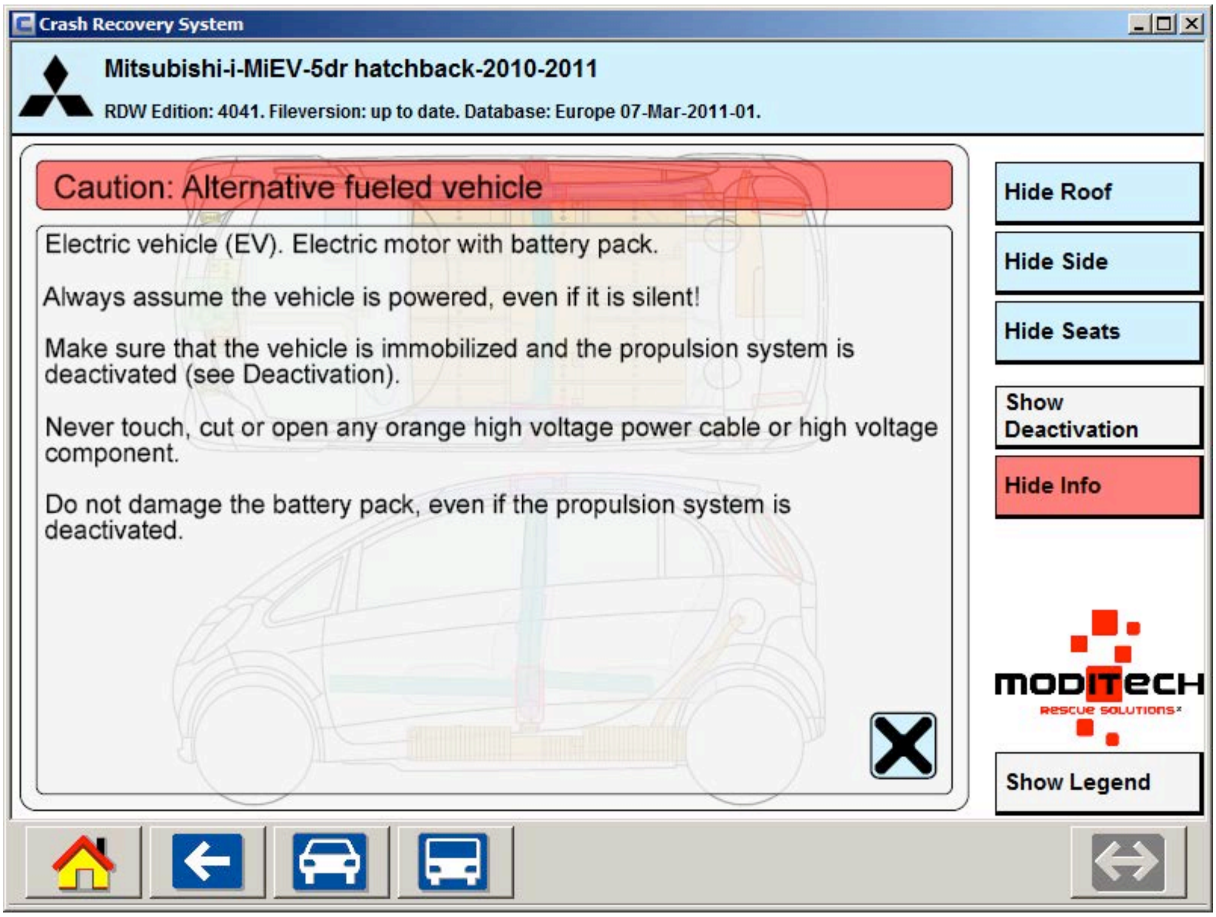


Figure 20: Information window of the Crash Recovery System with important information about Hybrid-, Electric- and Fuel Cell vehicles.

- Information about the type of propulsion can be obtained by **questioning the driver**. In addition the vehicle can be checked for several **propulsion system indicators**, if the license plate cannot be used for a CRS license plate request.

- Escaping fuel:

    - Odor of CNG or LPG.
    - Fog or cloud formed around or under the vehicle.
    - Rattling sound.
    - Hissing sound.
    - Escaping liquid fuel (gasoline/diesel).

- Check underbody

    - Electric cables (orange colored)
    - Warning labels.
    - Gas tanks.
    - Exhaust.

    If necessary, the interior of the front and rear compartment can be checked for additional indicators.

Note:
LPG tanks can be distinguished from CNG tanks as they are often equipped with weld seams.

Figure 21: View on the underbody of the vehicle, a. High voltage power cable, b. Gas tank

- Open filler cap

  Note:
  The filler cap can be found on several locations on the vehicle (among others also on the front of the vehicle or in the front fender area). It is possible to have several filler caps.

  - Form of the filling connector.
  - Number of filling connectors.
  - Inscription on the inside of the filler cap.

Figure 22: Different filler caps. a. bivalent Gasoline/CNG-vehicle, b. Electric vehicle, charge connector in the front fender, c. Electric vehicle, two charge connectors on the front of the vehicle.

- Examine exterior

  - Additional filler caps
  - Uncommon openings
  - Vehicle badges (Hybrid, IMA, CNG, NGT, BiFuel)
  - Advertisement stickers.

Figure 23: Examples for additional filler caps and uncommon openings.

8.4. Detect gas leaks/obviate gas release

Note:
CNG, LPG or hydrogen powered vehicles are not all the same! The physical properties of the gas and the function of the safety features are different.

- If a CNG, LPG or Hydrogen powered vehicles is involved in an incident, it is essential to check if gas is leaking. Check for indicators of a gas release:
    - Hissing or rattling noise.
    - Odor of gas.
    - Fog or cloud.
    - Jet flames.
- It is possible that gas powered vehicles are equipped with a gas warning system. The system may be equipped with indicators to make a gas alarm visible from the outside the vehicle.

Figure 24: Gas warning system of BMWs Hydrogen7 vehicle. The LEDs of the gas warning system are integrated into the door pins and start flashing if hydrogen is detected (courtesy of BMW).

Note:
Information about the indicators for the gas warning system can be found in the Crash Recovery System vehicle information.

- If a gas release (not burning) is detected, the following steps should be taken:
    - Evacuate and cordon of the area around the vehicle.
    - Remove ignition sources.
    - Ensure fire protection.
    - Vehicle may be pushed out of buildings.
    - Evaluate gas concentration with meters; note that gas can accumulate in hollow spaces.

Depending on the measuring result:

- Switch of the engine/motor, do not start the vehicle.
- Switch off the ignition.
- Vent the vehicles interior. Open doors, windows, hood and trunk, if necessary destroy windows from a safe distance.
- If necessary, cross ventilate the vehicle, use power fan.
- If necessary, close the manual shut-off valves.

Note:
Fire Service combustible gas meters are often calibrated for Nonan or methane.

Therefore these measuring instruments show 100% LEL from the level where the actual LEL of hydrogen is 20% or more while measuring hydrogen.

Note:
Opening doors or the trunk of the vehicle may cause electrical sparking!

Note:
Information how to operate the manual shut-off valve can be found in the Crash Recovery System.

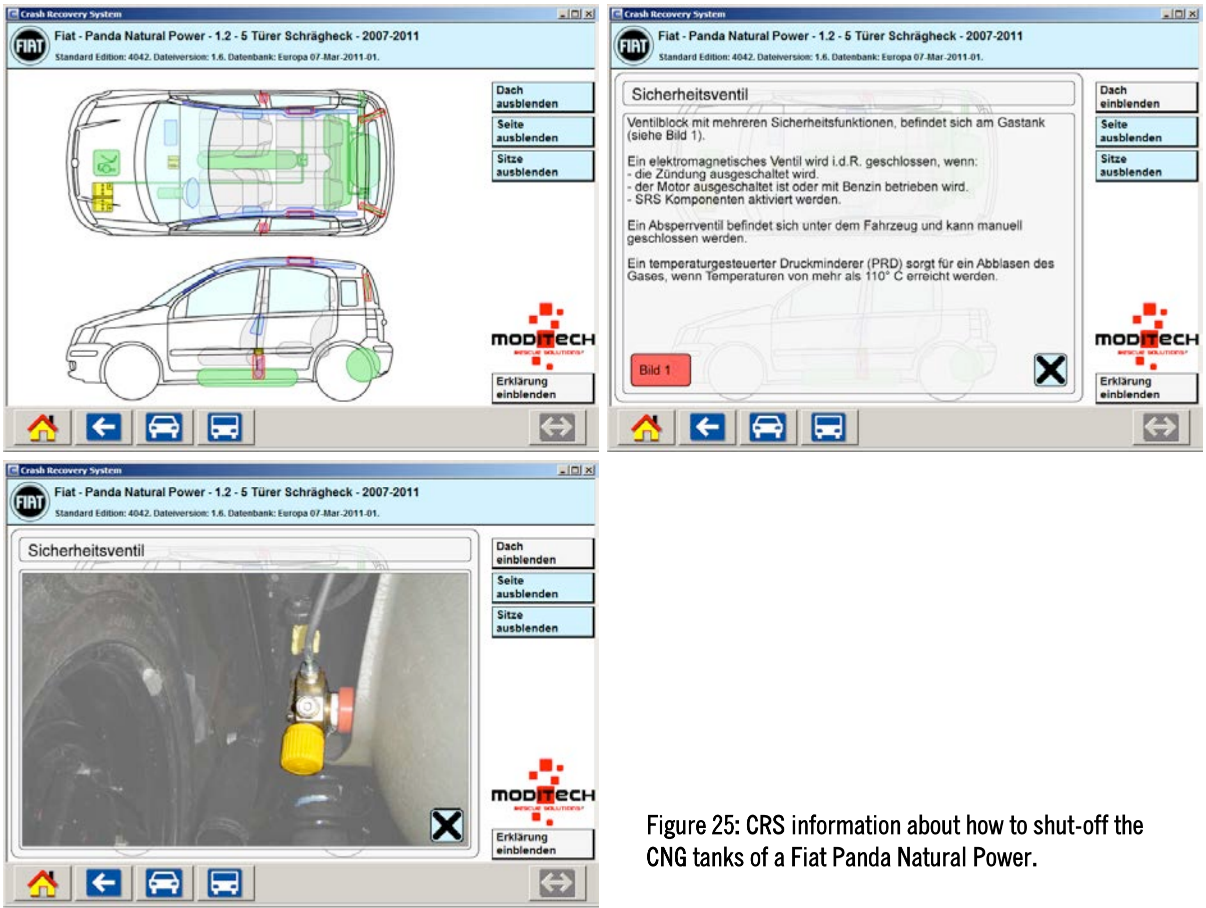


Figure 25: CRS information about how to shut-off the CNG tanks of a Fiat Panda Natural Power.

8.5. Immobilize vehicle

Note:
Hybrid-, Electric- und Fuel Cell vehicles can be operational even if they are silent!

- **All** vehicles should be immobilized in an early stage of the incident to avoid unintended movement:
    - Block the wheels with wheel chocks
    - Shift the gearshift lever to „P“ (Park“)
    - Apply hand brake/electronic park brake

8.6. Deactivate propulsion system

- In order to allow emergency responders to work safely on a crashed vehicle, it should always be ensured that the propulsion system is deactivated.

Note:
The safety measures activated by the SRS control unit (e.g. shut-down of the fuel pump, closing of electromagnetic valves, opening of the high-voltage relays) can only be triggered if the accident could be detected by the SRS system.

Note:
Deployed airbags that are hanging out of their housings are an indication that the SRS control unit has detected the crash and that safety measures have been triggered. A manual deactivation should always be carried out!

Note:
Switching the ignition to the off position is the easiest action to open the high-voltage relays and to disable the propulsion system.

Note:
The high-voltage relays will also be closed during charging (Electric vehicles, Plug-in Hybrid vehicles). To open the relays again, the charging current should be interrupted and the charge connector should be removed from the vehicle!

Note:
Switching the ignition tot he off position will also interrupt power to the SRS control unit and therefore will reduce the risk of accidental airbag deployment. As long as the 12 Volt battery is connected to the vehicles electrical system, restraint systems may still be activated because of short circuits.

- The operational readiness of vehicles with an electric propulsion system can generally be recognized with help of the so-called ‚ready‘-indicator. If the ‘ready’-indicator is illuminated the vehicle is ready to drive and the electric propulsion system is switched on. The ‘ready’-indicator can usually be found in the area of the speedometer.

Figure 26: Examples for ‚ready‘-indicators on different hybrid- and electric vehicles.

- To switch off the ignition, the ignition key should be rotated to the ‚off‘ position.

- Some vehicles do not utilize a conventional ignition key. These vehicles can generally be started and disabled with a start/stop-button. The start/stop-button is located on the dashboard or around the gearshift lever. In order to start the vehicle, an electronic transponder key fob needs to be in the interior of the vehicle.

- To disable the propulsion system (‚ready‘-indicator illuminated) the start/stop-button needs to be pushed once.

Note:
If the propulsion system has already been disabled (for instance by the driver, bystanders or by SRS activation, ‘ready’-indicator off) pushing the start/stop-button my reactivate it.

Figure 27: Start/stop-button, shown on a Toyota Prius

- To prevent the system from inadvertently restarting, the electronic transponder key fob should be removed at least 5 meters from the vehicle if possible.

- The 12 Volt battery should be disconnected. This reduced the chance of short circuits and prohibits restarting of the vehicle.

Note:
The location of the 12 Volt battery is clearly visible in the Crash Recovery System vehicle information.

Note:
The complete deactivation of the propulsion system (including the disconnection of the 12 Volt battery) also reduces the risk of accidental deployment of restraint systems due to short circuits.

- In cases where the ignition key or rather the start/stop-button are not accessible and the electric propulsion system is still active (‘ready’-indicator illuminated) extra (vehicle specific) measures may be needed in addition to disconnecting the 12 Volt battery in order to disable the vehicle.

Note:
On vehicles with an electric propulsion system disconnecting the 12 Volt battery while the vehicle is in an active state may not disable the propulsion system.

Note:
On vehicles powered with CNG or LPG disconnecting the 12 Volt battery will normally close the electromagnetic shut-off valves provided they are not damaged.

Note:
Step-by-step instructions on how to disable the vehicle can be taken from the Crash Recovery System.

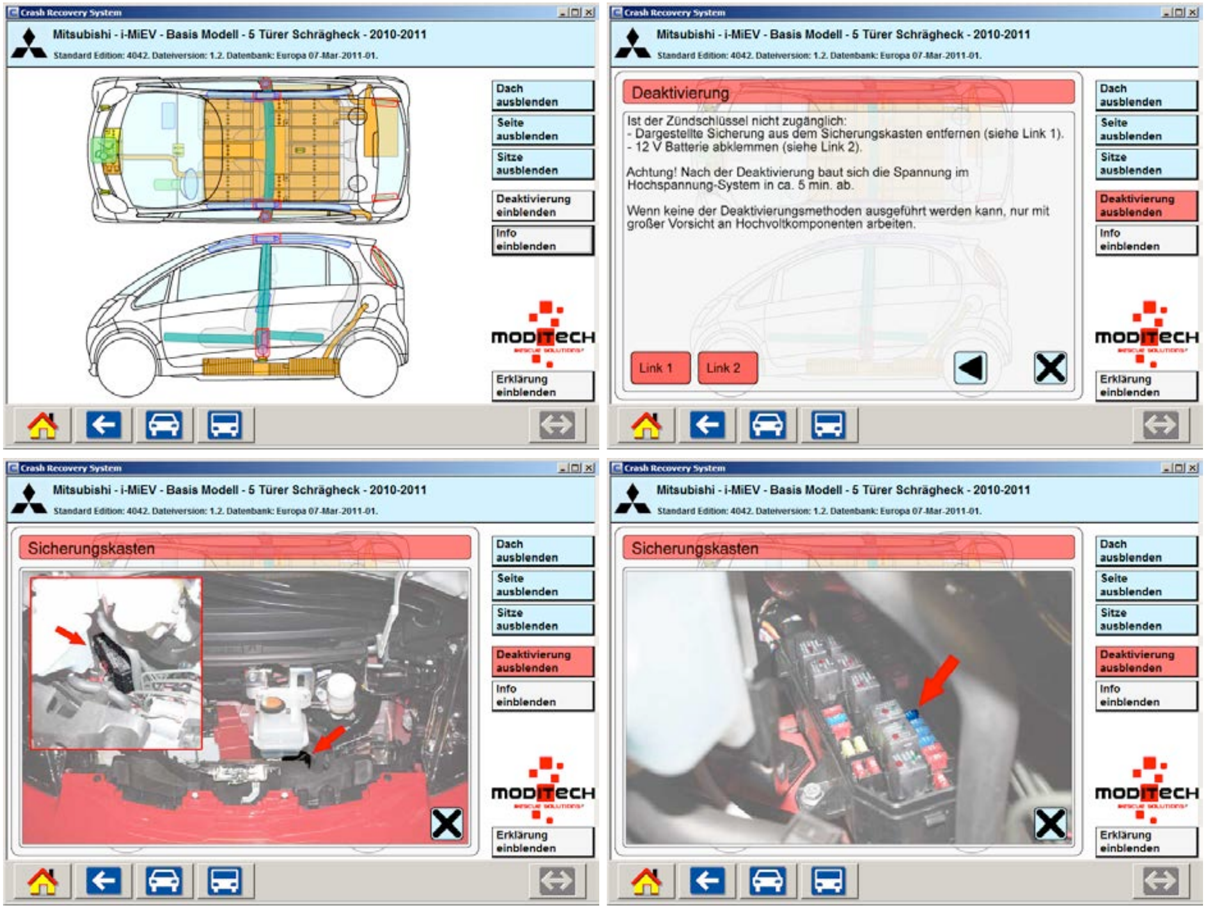


Figure 28: If the ignition key of this Mitsubishi i-MiEV (Electric vehicle) is not accessible, a certain fuse from the fuse box needs to be remove and the 12 Volt battery needs to be disconnected to completely disable the propulsion system.

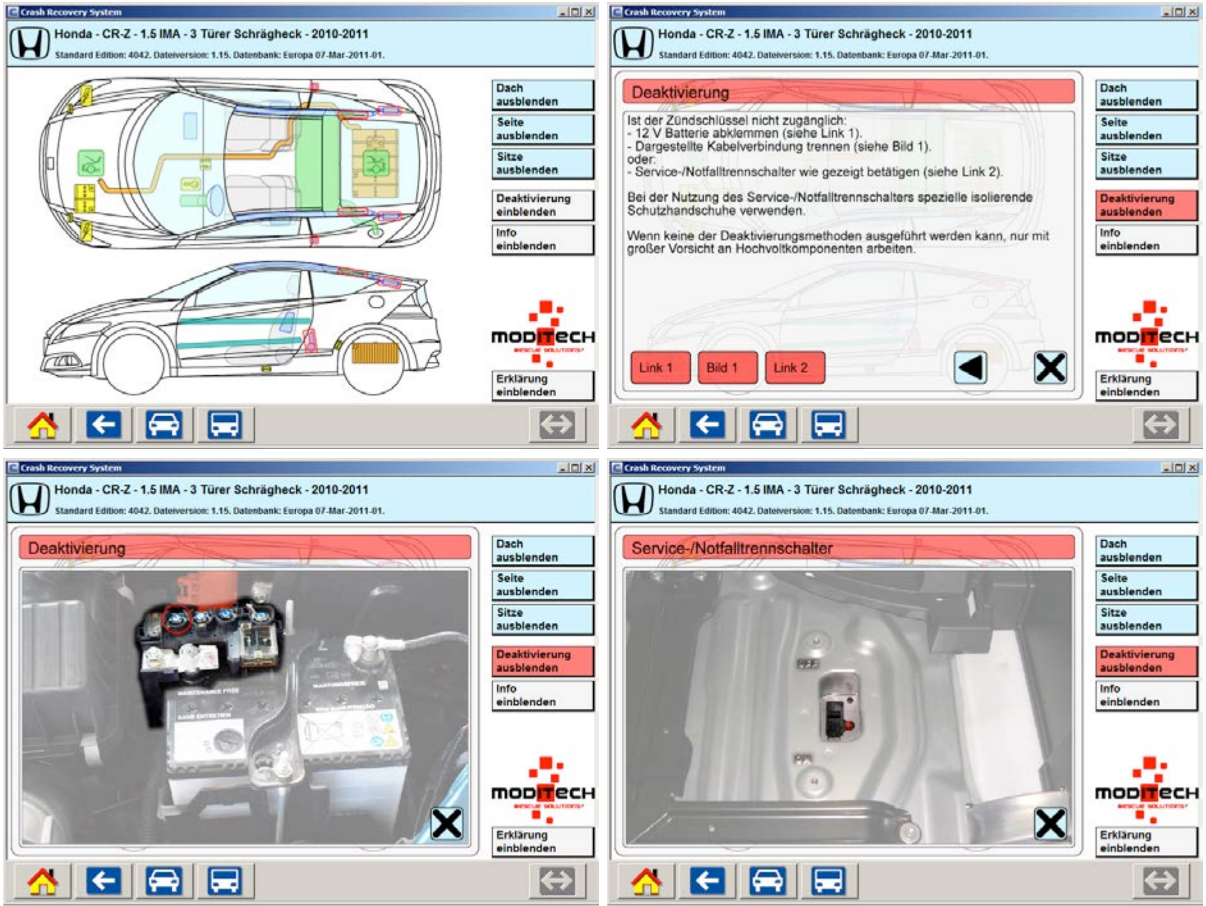


Figure 29: If the start/stop button of this Honda CR-Z (mild Hybrid) is not accessible, an additional cable connection needs to be severed or the service disconnect switch needs to be operated.

8.7. Work with caution

- Even if the propulsion system has been deactivated, there are components on every vehicle that should not be damaged for any reason.

Note:
Every vehicle is equipped with components, which should better be avoided during emergency response operations, such as stored gas inflators, fuel tanks but also high voltage batteries, high voltage power cables, gas tanks and gas lines. The Crash Recovery System keeps you informed on the locations and details of those components.

- The following propulsion system components should not be damaged for any reason:

    - High voltage battery packs
    - High voltage power cables
    - Fuel tanks
    - Gas tanks
    - Gas lines

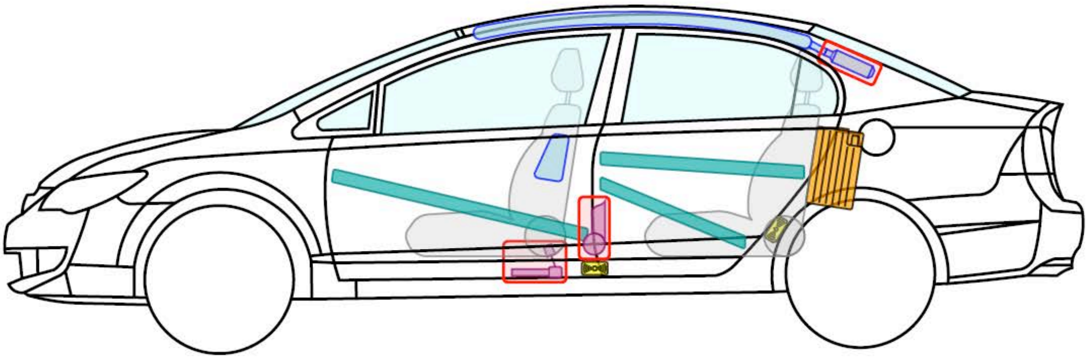


Figure 30: Honda Civic Hybrid, the high voltage battery is located behind the rear seat and should not be damaged for any reason. This also applies for the stored gas inflators for the head impact airbags or the seatbelt pretensioners.

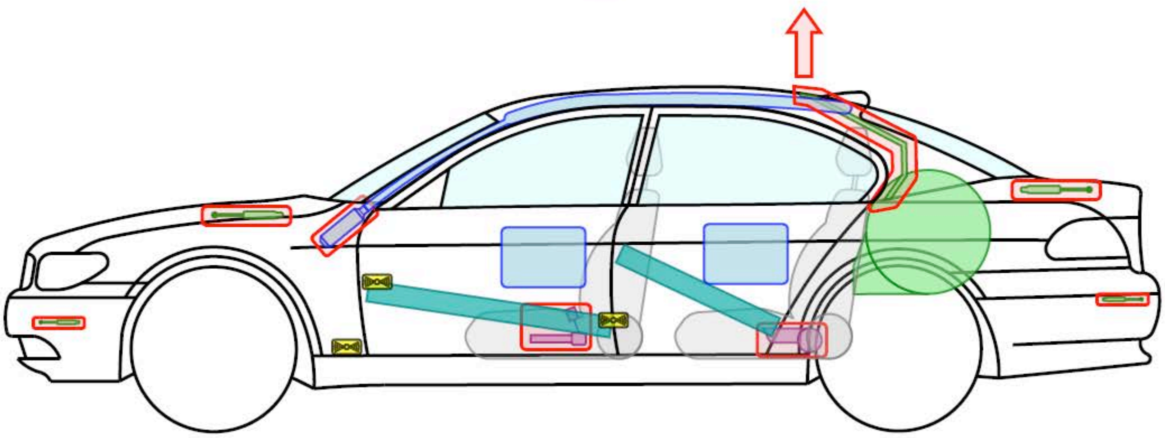


Figure 31: BMY Hydrogen7, the gas tank and the vent line should not be damaged. The same applies for the airbag inflators and the seatbelt pretensioners.

Note:
High voltage power cables (> 60 V) are equipped with an orange insulation for easy identification.

- If the high voltage battery has been damaged, small amounts of electrolyte may leak. Stay away from a broken high voltage battery!

8.8. Vehicle on fire

- The considerations and procedures mentioned in chapters 8.1 to 8.7 also apply for vehicles involved in a fire.

- As soon as flames are visible from the interior if the vehicle, the vehicle can be considered a total loss and is damaged irreparably. Normally it is not worth taking a risk for a total loss.

- Burning vehicles hold a couple of dangers for emergency responders, such as:

  - Deploying airbags with flying debris.
  - Bursting of tires.
  - Bursting of pressurized struts (gas cylinders)
  - Heavy reaction with water and burning light alloys (magnesium).
  - Rolling of the vehicle.

- Fire-fighting measures should **generally** be initiated from a safe distance (use maximum reach of the nozzle). Wearing a self-contained **breathing apparatus is** mandatory!

- Approach the vehicle obliquely from the front when fire-fighting is started!

- Maintaining a safe distance from a fully involved vehicle is very important on every vehicle with an alternative propulsion system.

Figure 32: Vehicle fire involving a Toyota Prius Hybrid vehicle. The vehicle is a total loss and cannot be repaired. It does not make sense to take a risk!

Note:

On all gas powered-vehicles, the danger of a jet flame exists by the sudden activation of the pressure relief devices.

Note:
If the gas tanks are affected by fire, do not extinguish the burning gas. Cool the gas tanks and work out of cover. Burning gas does not explode. To avoid fire extension, cool the vehicle and the surroundings.

Note:
Maintain the necessary nozzle distances for fires in electrical systems below 1000 V.

Note:
Danger of violent reactions if high voltage batteries are burning. Copious amount of water are necessary to extinguish a battery fire.

Note:
Never dismantle or open high voltage batteries, especially if they are burning – danger of electric shock. It may not be possibly to effectively extinguish a fire inside the battery, therefore allow the battery to burn itself out!

Note:
If possible, follow the deactivation procedures shown in the vehicle information system to completely disable the vehicle.

8.9. Vehicle submersion

- The considerations and procedures mentioned in chapters 8.1 to 8.7 also apply for vehicles that are fully or partially submerged in water.
- Due to the layout of the high voltage system, a submerged hybrid or electric vehicle does not have high voltage potential on the metal vehicle body and is safe to touch.

Note:
After removing the vehicle from the water, drain the water from the vehicle if possible.

Note:
If possible, follow the deactivation procedures shown in the vehicle information system to completely disable the vehicle.

9. Training ideas

- It is a particular challenge to include modern vehicle technology and vehicles with alternative propulsion into practical training evolutions. However, only the implementation in the practical training ensures that theoretical knowledge can also be transferred to everyday response operations. If the training session shall include practical exercises on the extrication process and teamwork, it is possible to pretend that the old car from the junkyard is a new vehicle with a little bit of preparation.

- To do this, select a late-model vehicle from the CRS and prepare the old training vehicle with airbag IDs and batteries according to the vehicle information supplied in the CRS.

9.1. Apply airbag labels

Figure 33: Retrofitted airbag label on the upper part of a B-post

Figure 34: Retrofitted deployed driver and passenger airbags

- Airbag locations can be identified by using labels or stickers lettered with words like Airbag, SRS or IC (Inflatable Curtain). It is also possible to prepare the vehicle with already deployed airbags. Just cut out the bag of an already deployed airbag and place it in the old vehicle, to pretend the presence of a deployed passenger airbag, it's pretty easy to pinch the bag in the glove box of the old vehicle.

9.2. ‚Build in‘ a battery

- The battery magnet from the Moditech magnetic label set can be used to simulate the existence and location of a battery in the vehicle, even if the real battery has already been removed. Because of the small thickness of this battery dummy it is possible to place the "battery" under seats or under the trunks floor mat. When performing extrication training, the vehicle's battery should always be disconnected as part of the vehicle preparation.

Figure 35: Battery-Dummy in the trunk of a vehicle

9.3. Simulate an alternative propulsion system

- Another idea is to give the vehicle some of the characteristics of an alternative fueled vehicle in order to visually train emergency responders in the awareness and identification of hybrid components. One possible option is to attach some orange colored 'high voltage' power cable to the floor of the vehicle. Hybrid "labels" can be attached in normal label areas as well.

Figure 36: Retrofitted high voltage power cable on the underbody of a vehicle

9.4. Allow vehicle identification

- During the training drill, emergency responders should be able to identify that the vehicle they are working on is "brand-new", either by applying hints on the vehicle itself or by verbal information from the training officer. It's possible to allow a manual selection within the CRS by adding brand logos and model designations to the vehicle, for instance with a marker pen.

- In countries where the vehicle can be selected by entering the license plate number or the vehicle identification number it is possible to place these numbers on the vehicle.

- A license plate magnet can be used in the front and rear of the vehicle to allow for quick identification of the vehicle. The magnet can be lettered with the desired license number with a board marker.

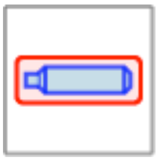
Figure 37: License plate magnet

- A sticker with the desired VIN can be placed in the edge of the windshield or in the doorframe to allow identification.


Figure 38: VIN-Label

Appendix A: Crash Recovery System component overview

Dangerzone



Dangerzone
The components outlined in **red** indicate components that are potentially dangerous during the rescue process.

Dangerzone driver and passenger airbag
Driver and passenger airbags outlined in **red** indicate dual stage airbags that are a potential risk during the rescue process.

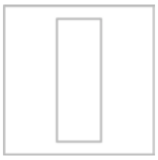
Seats

Front seat top view

Back seat top view

Front seat / back seat side view

Truck seat side view

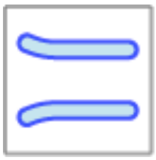


Truck bed top view

Truck bed side view

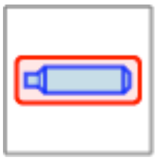
Airbags

Driver airbag



Curtain airbag
Head impact airbag

In dashboard:
Passenger airbag
In seat:
Anti-submarining Airbag



Stored gas inflator
(for curtain airbags)

Side impact airbag (seat)

Knee airbag driver

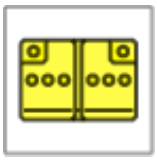
Side impact airbag (side)

Knee airbag passenger

Electrical components


Sensor front / side


Sensor front/ side (mechanical)


Battery (12 V)


Backup power-supply
Ultra capacitor


Truck battery (24 V)


Start/Stop Button
Engine stop


SRS control unit
Roll bar control unit

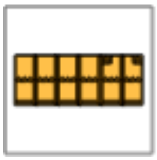

Main battery switch


Seat occupancy sensor

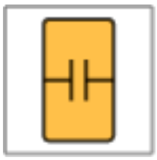

Gas warning indicator


Xenon lights

Electrical components > 30 V


Battery pack


High voltage power cable

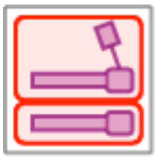

Ultra capacitor


Service/Emergency disconnect switch


Fusebox

Seatbelt pretensioners

Seatbelt pretensioner (Retractor)



Seatbelt buckle or lap belt pretensioner

Miscellaneous

Cylinder to support engine hood or trunk lid

Automatic roll bar

Hydrogen vent stack (Arrow indicates venting direction)

Fuel cell stack

Engine hood opening (rear hinges)

Engine hood opening (front hinges)

Trunk lid opening

Grill opening

Cabin suspension (only trucks)

Chassis suspension (only trucks)

Air system (only trucks)

Steering column adjustment

Fuel tank

Truck fuel tank

Gas tank (CNG, LPG, Hydrogen)

Safety valve

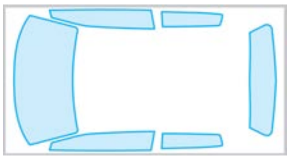
Seat adjustment
(only trucks)

Pedestrian protection system

Reinforcements

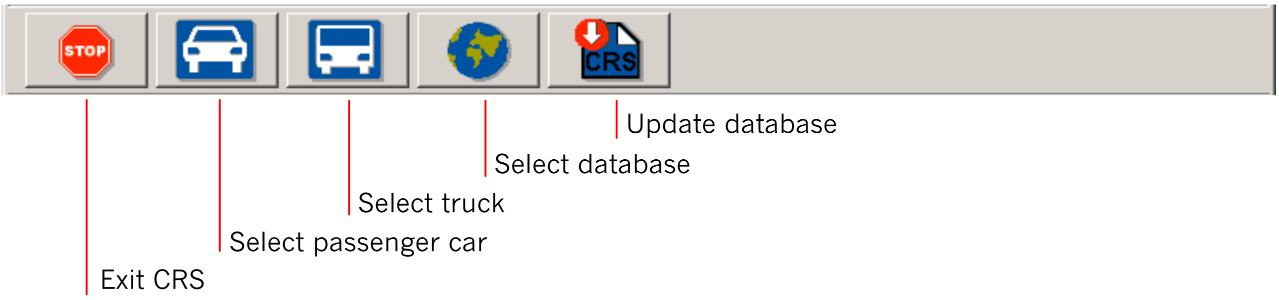
Reinforcement components in bodywork

Glazing



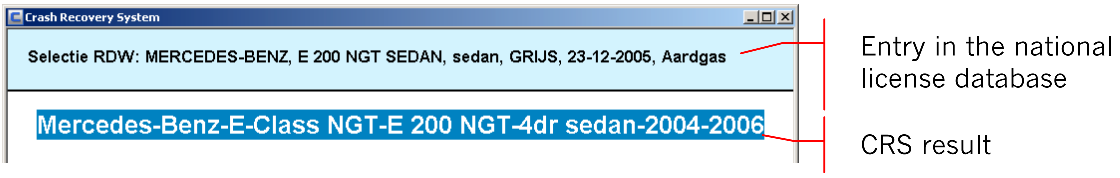
Glazing, glass or plastic, tempered glass or laminated glass

Appendix B: Crash Recovery System quick manual

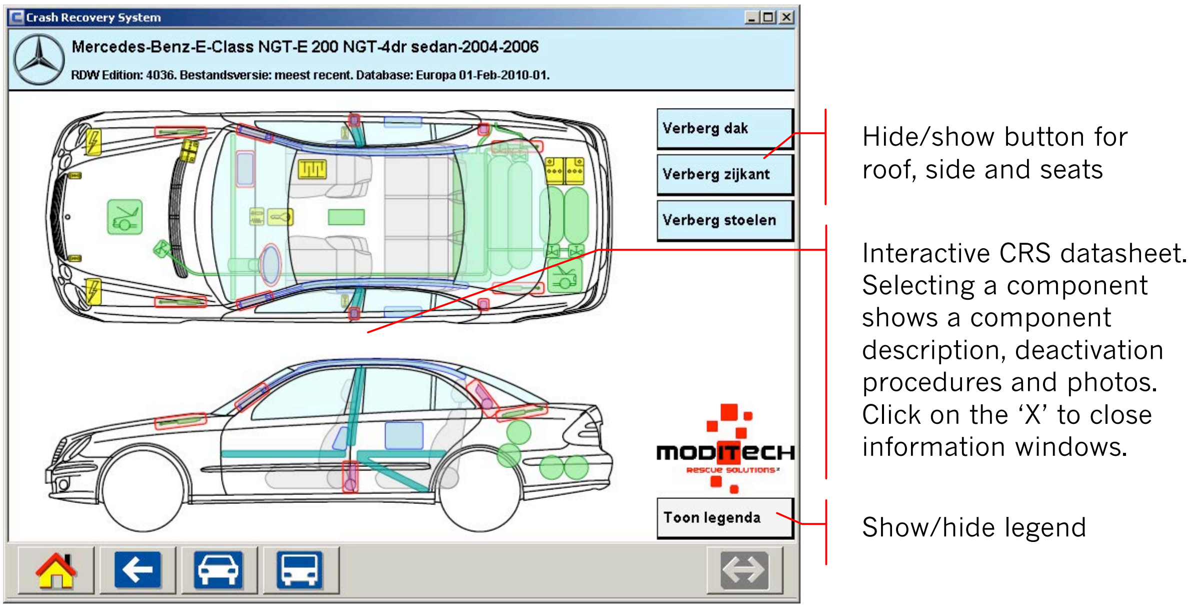


Vehicle selection

1. Select . This opens a new passenger car selection.
2. Select 99XXYY to select a vehicle model using the license plate number.
3. Enter the license plate. Using < << the number can be edited.
4. Press RDW. The license is then retrieved from the license database. The correct vehicle model is selected from the CRS database. The vehicle details will also be shown, incl. color, date of registration and type of propulsion.



5. Click on CRS result to open CRS datasheet.



1. Select . This allows the selection of an additional passenger car.
2. If a license plate request is not possible select . Choose vehicle selecting make, model, engine type, body style and model year.
3. Press on to switch between active datasheets.
4. closes the CRS datasheet. closes the document.

Appendix C: Scenarios for practical training

Scenario 1: LPG powered vehicles involved in a rear impact accident, LPG tank is damaged

Situation:
At the end of a traffic jam a van has rear-ended a passenger car. The car has sever rear-end damaged. The LPG tank retrofitted into the trunk of the vehicle has been damaged due to the impact, LPG is leaking. The driver has been able to escape the vehicle, he is sitting at the side of the road and complains of back and neck pain.

Simulation:
- Scrap car, possibly with rear-end damage.
- License plate magnet, license plate of a LPG vehicle.
- Activated sizzling LPG tank in the trunk of the vehicle.
- Oder of gas, THT liquid.
- Explo-Trainer, danger of explosion inside and around the vehicle.

Objectives:
- First aid to the injured driver.
- Identification of vehicle and type of fuel (CRS).
- Check for airbag deployment.
- Detect and evaluate gas release.
- Take measures to reduce danger of explosion and fire.
- Immobilize vehicle.
- Disable vehicles propulsion system (CRS).
- Stop gas release with manual shut-off valve (CRS).

Scenario 2: Hybrid vehicle on its side after rollover accident. No airbags deployed.

Situation:
A Hybrid vehicle has left the road and rolled over several times due to speeding. The vehicle ends up on its side. The driver is still trapped in the vehicle. No airbags have been deployed.

Simulation:
- Scrap car, possibly with rollover damage, placed on its side.
- License plate magnet, license plate of a Hybrid vehicle.
- Hybrid vehicle badging on the vehicle.
- High-voltage cable ‘mounted‘ to the floor pan.

Objectives:
- First aid to the injured driver.
- Identification of vehicle and type of fuel (CRS).
- Check for airbag deployment.
- Detect and exclude gas release.
- Immobilize vehicle.
- Disable vehicles propulsion system (CRS).
- Preplan extrication (CRS, CRS magnet set)

Appendix D: Show-and-tell checklist

CNG or LPG powered vehicle

- ❒ Vehicle identification via license plate
- ❒ Conventional vehicle identification
- ❒ Identification of potential dangers
    - ❒ Gas tank in the vehicle
- ❒ Identification of vehicle components using CRS
    - ❒ Gas tank
    - ❒ Safety valve
    - ❒ 12 Volt battery
- ❒ Demonstration of the manual shut-off valve
- ❒ Pre-planning of extrication

Hybrid and Electric vehicles

- ❒ Vehicle identification via license plate
- ❒ Conventional vehicle identification
- ❒ Identification of potential dangers
    - ❒ Active high voltage system
    - ❒ High voltage battery
    - ❒ Silent operation
- ❒ Identification of vehicle components using CRS
    - ❒ Start/Stop-Button, Ready-Indicator
    - ❒ High voltage battery
    - ❒ High voltage power cable
    - ❒ Fuse box
    - ❒ Service-/Emergency disconnect switch/cable
    - ❒ 12 Volt battery
- ❒ Disconnect 12 Volt battery with active HV system
- ❒ Measure HV system
- ❒ Demonstration of propulsion system deactivation
- ❒ Pre-planning extrication