HANDOUTS AND REFERENCE MATERIAL

Introduction to Fuel Cell Vehicles
January, 2018

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Reference Material

MIRAI INSTRUMENT CLUSTER

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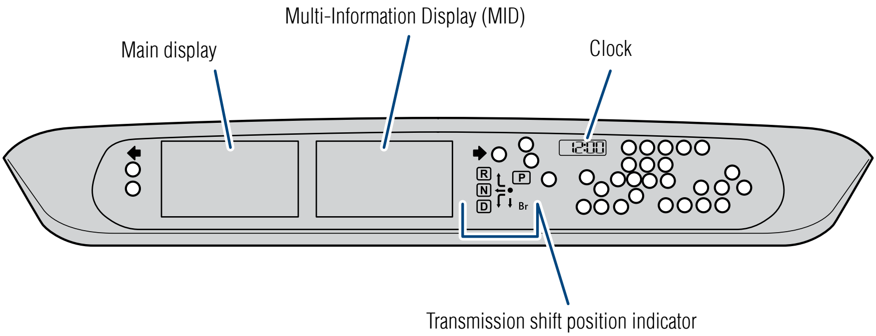
Instrument cluster



○ Service indicators and reminders

Instrument symbols

For details, refer to "Indicators and warning lights," Section 3-3, 2017 Owner's Manual.

- H2 — Hydrogen leak warning
- High coolant temperature warning
- Low fuel level warning
- Master warning[1]
- Low tire pressure warning[1]
- READY — READY indicator
- Security indicator
- PASSENGER AIRBAG OFF / AIRBAG ON — Airbag ON/OFF
- Driver seat belt reminder (alarm will sound if speed is over 12 mph)
- Supplemental Restraint System warning
- Open door warning

[1] *If indicator does not turn off within a few seconds of starting Hydrogen Fuel Cell System, there may be malfunction. Have vehicle inspected by your Toyota dealer.*

FUEL CELL VEHICLE COMPONENT LOCATION

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January, 2018

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Fuel Cell Vehicle Component Locations & Descriptions

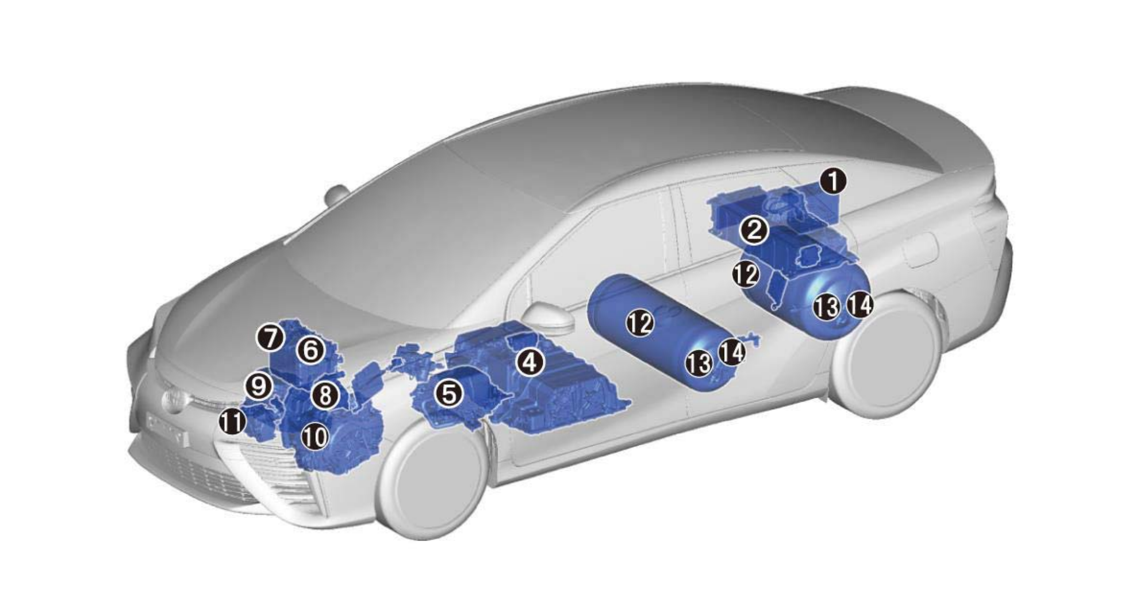
<table>
<tr><th colspan="2">Component</th><th>Function</th></tr>
<tr><td colspan="2">12 Volt Auxiliary Battery ❶</td><td>A lead-acid battery that supplies power to the low voltage devices.</td></tr>
<tr><td colspan="2">EV Battery ❷</td><td>244.8 Volt Nickel Metal Hydride (NiMH) battery pack consisting of 34 low voltage (7.2 Volt) modules connected in series.</td></tr>
<tr><td colspan="2">Power Cable ❸</td><td>• Orange colored power cable is a high voltage, high current electrical line.
• It is primarily used between the EV battery and FC inverter input junction block assembly, between the inverter with converter assembly and FC air compressor with motor assembly, and between the inverter with converter assembly and FC converter assembly.</td></tr>
<tr><td colspan="2">FC Stack Assembly ❹</td><td>Generates electrical energy by causing a chemical reaction between hydrogen fuel from the hydrogen tank and oxygen from the FC air compressor with motor assembly.</td></tr>
<tr><td colspan="2">FC Converter Assembly ❺</td><td>• Boosts the voltage of the electrical energy generated in the FC stack assembly to a maximum of DC 650 Volt.
• According to requests from the EV control ECU, connects and disconnects the FC main relay and controls the electric power to match the value specified by the electric power request.</td></tr>
<tr><td rowspan="2">Inverter with Converter Assembly ❻</td><td></td><td>Based on the requested output value from the EV control ECU, controls the electrical power provided to the traction motor and FC air compressor with motor assembly.</td></tr>
<tr><td>DC-DC Converter ❼</td><td>Steps down the voltage of the high voltage system to approximately DV 14 Volt and provides it to accessory components and the 12 Volt auxiliary battery.</td></tr>
<tr><td colspan="2">FC Cooling Water Pump Assembly ❽</td><td>Circulates the FC stack coolant, which cools the FC stack assembly and the air compressed by the FC air compressor with motor assembly.</td></tr>
<tr><td colspan="2">FC Air Compressor with Motor Assembly ❾</td><td>• Supercharges the air that has passed the air cleaner and provides it to the FC stack assembly.
• Driven by the inverter of the inverter with converter assembly.</td></tr>
<tr><td colspan="2">FCV Transaxle with Motor Assembly ❿</td><td>Based on driving conditions, uses the electrical energy from the FC stack assembly and the electrical energy from the EV battery assembly to generate driving force. Also, uses regenerative braking to generate electricity when decelerating.</td></tr>
<tr><td colspan="2">Compressor with Motor Assembly ⓫</td><td>3-phase high voltage AC electrically driven motor compressor.</td></tr>
<tr><td colspan="2">Hydrogen Tank ⓬</td><td>Employs a hydrogen tank made chiefly of carbon fiber reinforced plastic that can with stand high pressure of 70 MPa (713.8 kgf/cm2, 10150 psi).</td></tr>
<tr><td colspan="2">Hydrogen Tank Valve Assembly ⓭</td><td>Installed to each hydrogen tank, and opens and closes the hydrogen channels.</td></tr>
<tr><td colspan="2">Hydrogen Tank Temperature Sensor ⓮</td><td>Detects the hydrogen fuel temperature inside the hydrogen tank and transmits it to the hydrogen fuel control ECU.</td></tr>
<tr><td colspan="2">Hydrogen Supply Regulator Assembly ⓯</td><td>Installed between the hydrogen tank and FC stack assembly, and reduces the pressure of the hydrogen fuel from the hydrogen tank to between 1.0 MPa and 1.5 MPa (10.2 kg/cm2 to 15.3 kg/cm2, 145 psi to 218 psi).</td></tr>
</table>

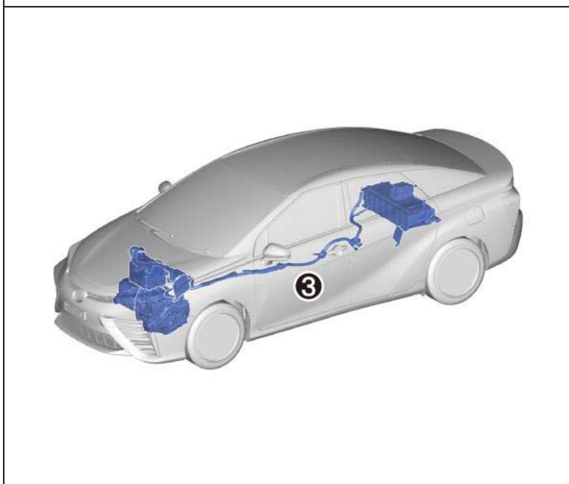
*Numbers in the component column apply to the illustrations on the following page.

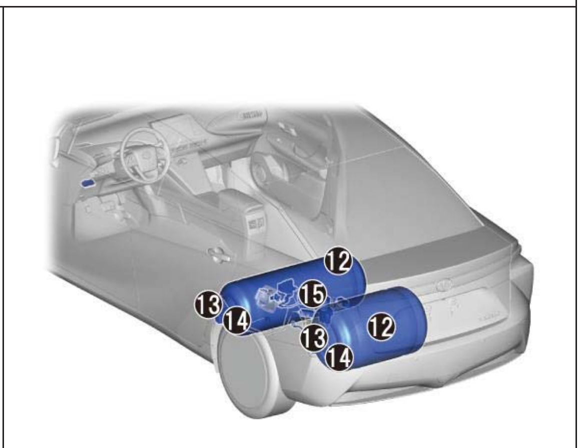
Fuel Cell Vehicle Component Locations & Descriptions (Continued)

Specifications

Electric Motors:	123 kW
EV Battery:	244.8 Volt Sealed NiMH Battery
Curb Weight:	1,850 kg / 4078 lb
Frame Material:	Steel Unibody
Body Material:	Steel Panels except for Aluminum Hood
Seating Capacity:	4 passenger







This illustration is for an LHD model

DISABLING THE VEHICLE

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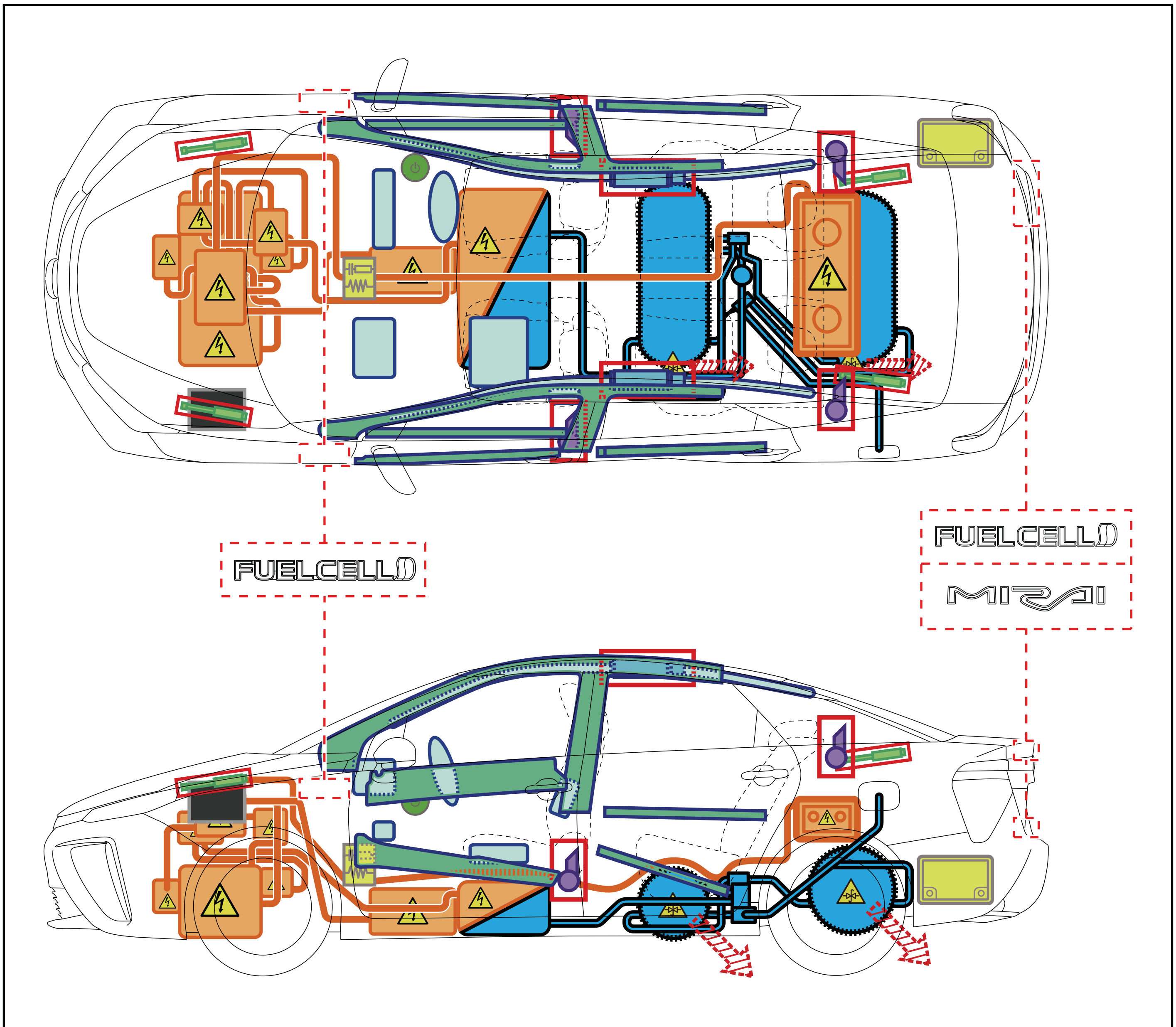
2015-6

TOYOTA

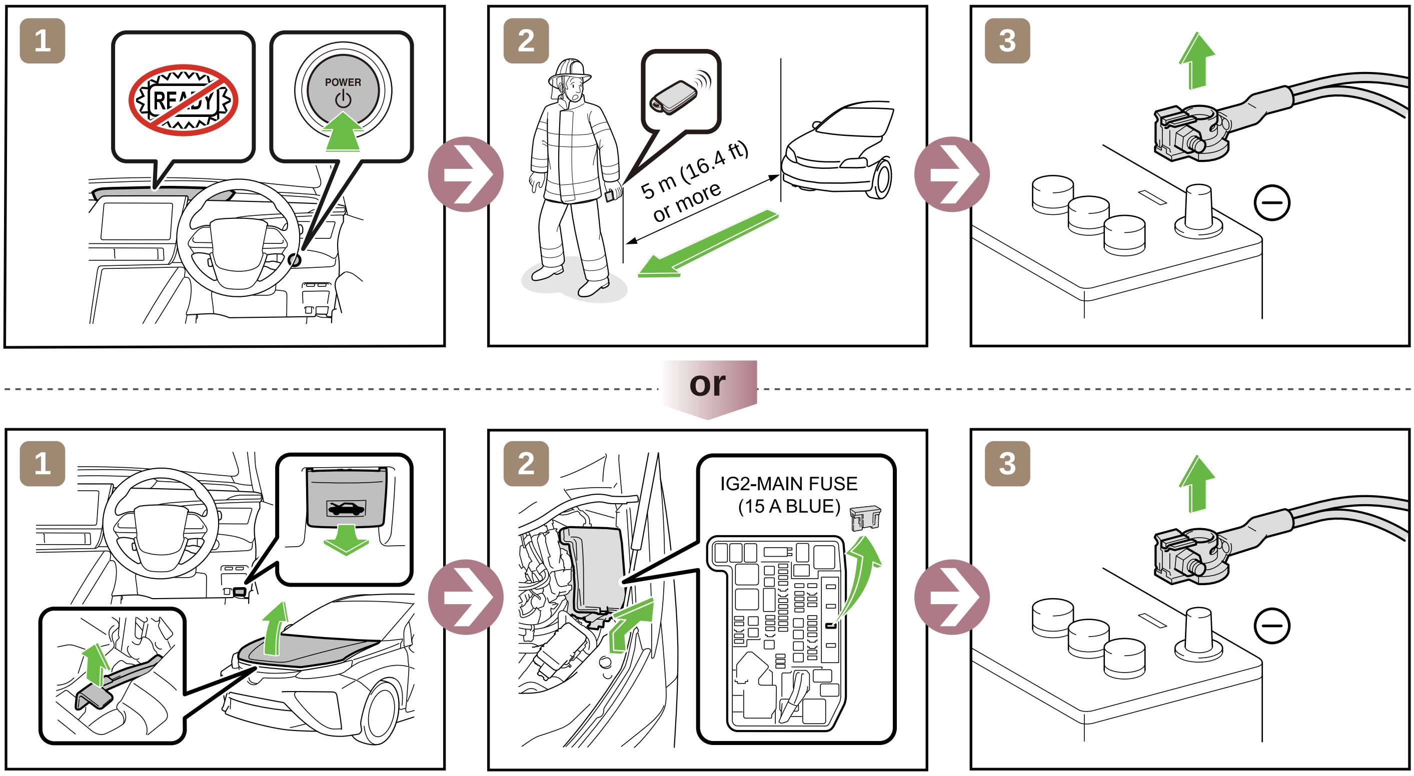
FUELCELL

HV BATTERY
Ni-MH

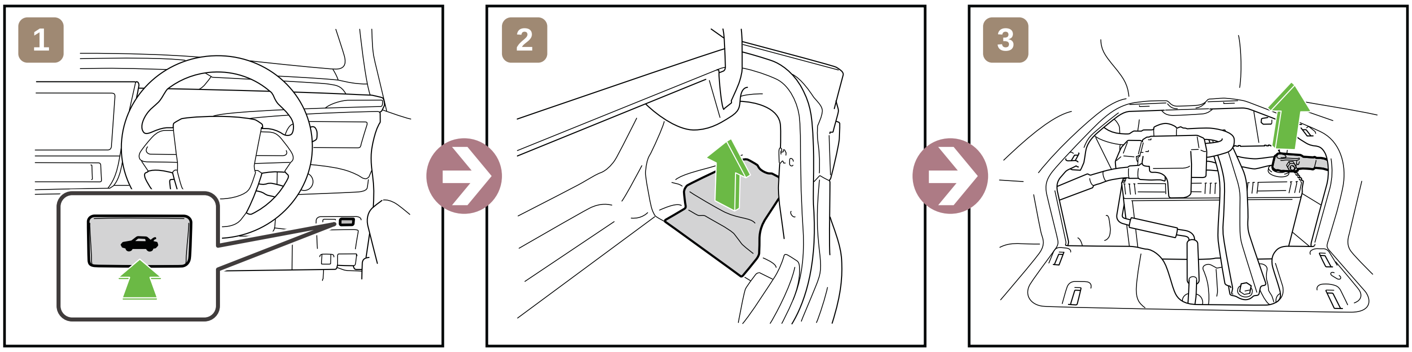


	POWER SW		Structural Reinforcements		Airbag Computer
	Airbag (incl. Inflator)		Fuse Box		12V Battery
	High Voltage Components		Inflator		High Voltage Battery
	Pressure relief device (PRD) (Hydrogen release direction)		Hydrogen Tank		Hydrogen Components
			Gas-filled Damper		Seat Belt Pretensioner (Gas Generator)

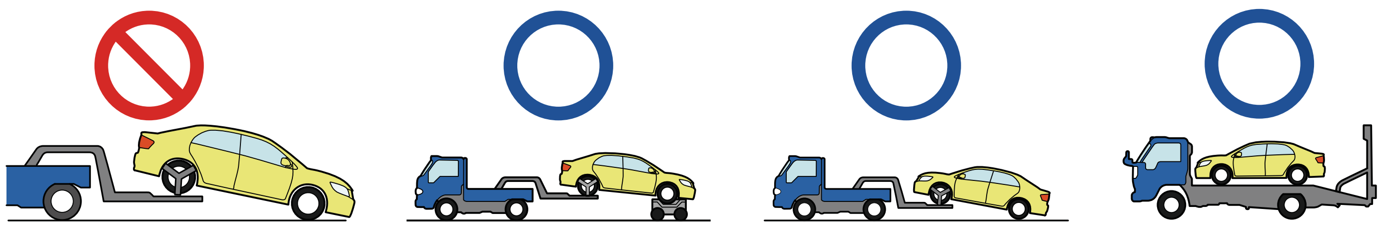
Disable Vehicle



Access to 12V Battery



Towing Information



DANGER OF ELECTROSTATIC DISCHARGE (ESD)

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The Danger of ESD

Electrostatic discharge (ESD) occurs when a non-conducting surface is rubbed against another and the contacted surfaces are then parted. ESD can **damage** or destroy **sensitive** electronic components, erase or alter magnetic media, or set off **explosions** (battery gasses) or **fires** in flammable environments.

ESD is a result of static electricity build up, and thus the transfer of charges- in this case the person to the equipment. Anyone familiar with the “ZAP” or shock received when touching a conductive object after walking or picking up an electronic component has experienced an electrooptic discharge. Handling everyday objects will eventually build up your own charge to the point where it will seek conductors for a non-inhibited path to ground. That small zap or zing carries enough current and voltage to render computing hardware or controlling devices useless. Semiconductors, like those found in CPU’s and node units, are particularly prone to failure from ESD.

ESD can carry charges upwards to several thousand volts- but it is important to note that it is the current that delivers the damage. Electrical circuits can be obliterated by very small charges (30V) with high current (0.50 Ma). Discharge of static electricity is not always felt by humans, due to body mass and resistance in the body, so it is important to remain grounded even if you do not think you are carrying a charge.

OHM’s LAW and ESD

According to OHM’s law, voltage = amperage x ohms, although our bodies do conduct electricity, they are very poor conductors. In fat, the resistance of dry skin is very high, somewhere in the area of 100,000 ohms, meaning the amperage that can pass through is very low. Plus ESD lasts only a fraction of time, literally billionths of a second or in some higher current ranges a nanosecond.

What does ESD create?

ESD does not show up immediately and most components will pass a normal operating test even after they have been *“ZAPPED”.* The actual damage rendered depends on the sensitivity of the component, the amount of voltage/current it has been exposed to and the number of times it has been “***hit”***. There are two types of ESD Damage, parametric (wounded) and catastrophic (dead). Once a component is “wounded” it may function normally for a period of time. But laboratory tests show it will fail eventually. This can put the vehicle in a “*Walk Home Mode”*.

Electrostatic Discharge (ESD) and High-Voltage Devices

Understanding and respect the miniature lightning bolts.

From the moment you get a sensitive electronic part to the moment you install and power it up it is extremally important to handle all parts with care. How do you know if it is a sensitive component? It will usually have some markings on the package and an additional inner wrapping with a sticker indicating the sensitivity of the part;

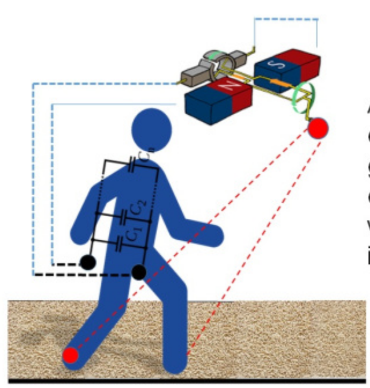
or


Always keep the part in the ESD wrapping until ready to install. NEVER drag an electronic part across your clothing. NEVER place the unprotected part on the seat of a live vehicle. The electrical waveform involved in ESD is a brief pulse, with arise time of about 1.0 nanosecond, and a duration of 100 to 300 microseconds. The peak voltage can be as large as 30 kV in dry weather, but is more commonly 0.5 to 5.0 kV.6 The fastest rise times occur from discharges originating at the tip of a hand-held tool, while discharges from the fingertip and the side of the hand are slightly slower. A typical human with a body capacitance of 150 picofarads, charged to 3 microcoulombs, will develop a voltage potential of 20 kV, according to the formula:

V = Q/C where V is voltage, Q is charge and C is capacitance.

The energy delivered upon discharge is: ω = ½ CV2 where ω is energy in joules, C is capacitance and V is voltage. It is interesting to note that most microcircuits can be destroyed by a 2500 volt pulse, but a **person cannot feel a static spark of less than 3500 volts!**

Just walking across a shop floor can create enough voltage/current to shut down a computer.



A simple process of walking on carpeted floor is like driving a DC generator and storing the generated charge on our clothing and body which act as capacitors connected in parallel.

Basic work habits for electronic components.

- Disconnect the accessory battery at the negative terminal and wait for capacitors to discharge. (most modern vehicles have SRS/air bag systems that require at least 5-10 minuets to discharge, check with the approximate information for the vehicle you are working on).
- Keep the new component in its protective packaging until you are directly in position to service/install it.
- Ground yourself before removing the component.
- ***NEVER*** touch the terminals of the component

How do you discharge this ESD safely?

There are several ways to do this depending on the manufactures instructions and the components manufacture. It some cases you will need a simple ground strap while handling the parts. Most commonly you will need to equalize your body to the vehicle. This can be accomplished by simply touching an unpainted metal surface in the vehicle while sitting in the vehicle.

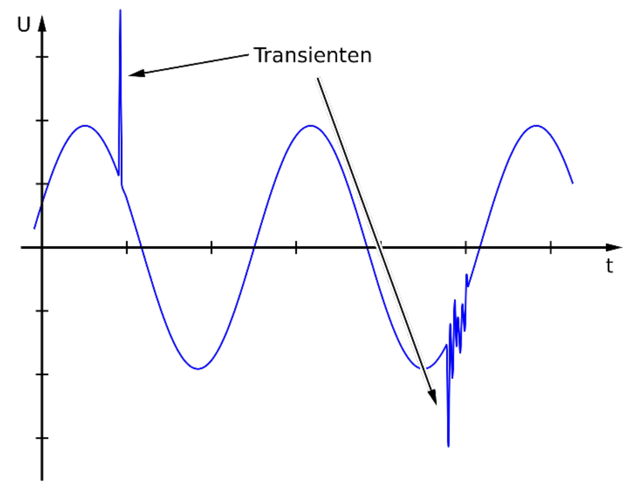
Basically, grounding lowers the charge in your body by providing a harmless path for the static electricity to escape thus equalizing the charges between your body and the component you are working with.

If you get out of the vehicle you will need to repeat this process until you are completed. If you are working with several components you may have to repeat this when switching the various parts.

The second part of High-Voltage Safety is the control of Transient Voltages

Damage to electrical systems is due to a combination of voltage and current. High voltage can open unintended current paths such as forward or reverse breakdown of diodes or oxides reaching their breakdown voltage within integrated circuits. Once the unintended path is initiated by over voltage the resulting currents cause damage. Excess current can also cause thermal damage directly. Protection is done with either voltage activated circuit elements that open low resistance paths to prevent excess voltage, current limiting devices or a combination of the two. Protection strategy will be illustrated by considering the concept of Primary and Secondary Protection.

After the discussion of Primary and Secondary protection the types of protection elements available will be reviewed, and then the use of protection devices in representative
situations will be discussed. Something as simple as using the wrong meter or incorrectly rated test leads can cause serious voltage spikes. It is important to note that the automotive industry has developed their own set of standards for preventing Transient Voltage spikes. What is transient voltage? **Voltage Transients** are defined as short duration surges of electrical energy and are the result of the sudden release of energy previously stored or induced by other means, such as heavy inductive loads or lightning. ... Random **transients**, on the other hand, are often **caused** by Electrostatic Discharge (ESD).



In the automotive voltage testing terms, the term Devise Under Testing (DUT) is more and more common. When you are asked to test a live voltage component, you must first insure that you are testing low, medium, or high voltage. Each of these require testing equipment that meets and or exceeds the National Fire Protection Association (NFPA 70e) standards. In some instances, you be required to have special rated gloves, CLASS "0" 1000 Vdc are what is required for most hybrid and electric vehicles. Check with the manufacture of the vehicle you are working on for specific High-Voltage instructions.

HYDROGEN & HIGH-VOLTAGE SAFETY

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Hydrogen Safety

About Hydrogen

Hydrogen can be produced using a number of primary energy sources other than petroleum, such as natural gas or ethanol. Also, solar power or wind power can be used to produce hydrogen from water.

Characteristics of Hydrogen

Compared to gasoline, hydrogen has disadvantages such as "easy leakage due to small molecular size", "odorless and colorless and thus difficult to detect", and "highly flammable at a wide range of concentrations". However, it also has advantages such as "easily dispersed due to low specific gravity", "does not easily auto ignite due to high ignition temperature", and due to the wide detonation concentration range, "does not easily explode" unless confined in an enclosed space together with oxygen.

Item	Hydrogen	Natural Gas	Gasoline	Hydrogen Characteristics
Molecular Weight	2	16	106	Leaks easily
Coloring / Odor	None	Colorless / Odorant can be added	Yes	Difficult to detect leaks
Flammability Concentration Range	4.0 - 74.5%	5.3 - 15.0%	1.0 - 7.6%	Burns readily
Detonation Concentration Range	18.3 - 59%	6.3 - 13.5%	1.1 - 3.3%	Does not readily explode
Specific Gravity (air= 1)	0.07	0.55	3.4 - 4.0	Easily dispersed
Ignition Temperature	527(°C)	540(°C)	228(°C)	Difficult to ignite

Hydrogen Safety (Continued)

Basic Safety Concepts for Hydrogen System Components

Prevent Leaks	Difficult-to-leak Design	The connection portions of hydrogen fuel piping have been designed with a strong focus on leak prevention.
	Selection of Materials	Appropriate materials have been selected with regard to hydrogen embrittlement
Detect and Stop	Equip with Hydrogen Detector	In the unlikely event that a hydrogen leak occurs, the hydrogen detector detects the leaked hydrogen and the hydrogen tank valve operates to prevent a large leak of hydrogen fuel.
	Equip with Collision Sensor	If the vehicle receives an impact that is judged to be a collision, the hydrogen tank valve operates to prevent a large leak of hydrogen fuel.
Prevent Accumulation of Leaked Hydrogen		In the unlikely event that hydrogen fuel leaks out, the vehicle is designed to prevent the leaked hydrogen from remaining inside.
Keep Ignition Sources Away		The vehicle is designed so that potential ignition sources are not located near the hydrogen system.

Caution

Fuel cell vehicles use high pressure hydrogen fuel at 70 MPa, and improper handling can cause hydrogen leakage possibly resulting in vehicle fires or explosions.

High Voltage Safety

The EV battery powers the high voltage electrical system with DC electricity. The power cable is a high voltage, high current electrical line. It is primarily used between the EV battery and FC inverter input junction block assembly, between the inverter with converter assembly and FC air compressor with motor assembly, and between the inverter with converter assembly and FC control ECU. To enable technicians to visually distinguish between the high voltage power cable and the normal low voltage electrical lines, the power cable and its corrugated tube have been standardized with an orange color.

The inverter with converter contains a circuit that boosts the EV battery voltage from 244.8 to 650 Volts DC. The inverter with converter creates 3-phase AC to power the motors.

The following systems are intended to help keep occupants in the vehicle and emergency responders safe from high voltage electricity:

High Voltage Safety System

- A high voltage fuse ❶* provides short circuit protection in the EV battery.

- Positive and negative high voltage power cables ❷* connected to the EV battery and FC stack assembly are controlled by 12 Volt normally open relays ❸*. When the vehicle is shut off, the relays stop electricity flow from leaving the EV battery.

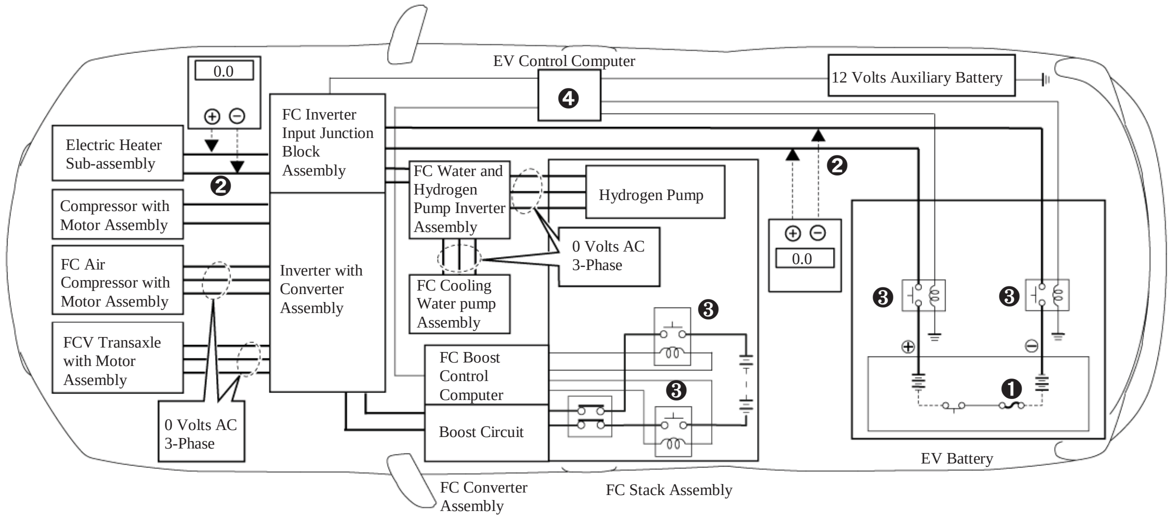
> ⚠ ***WARNING:***
>
> - ***The high voltage system may remain powered for up to 10 minutes after the vehicle is shut off or disabled. To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or opening any orange high voltage power cable or high voltage component.***

- Both positive and negative power cables ❷* are insulated from the metal body. High voltage electricity flows through these cables and not through the metal vehicle body.
  The metal vehicle body is safe to touch because it is insulated from the high voltage components.
- A ground fault monitor ❹* continuously monitors for high voltage leakage to the metal chassis while the vehicle is running. If a malfunction is detected, the EV control computer ❹* will illuminate the master warning light ⚠ in the instrument cluster and indicate "FC System Malfunction" on the multi-information display.
- The EV battery relays will automatically open to stop electricity flow in a collision sufficient to activate the SRS.

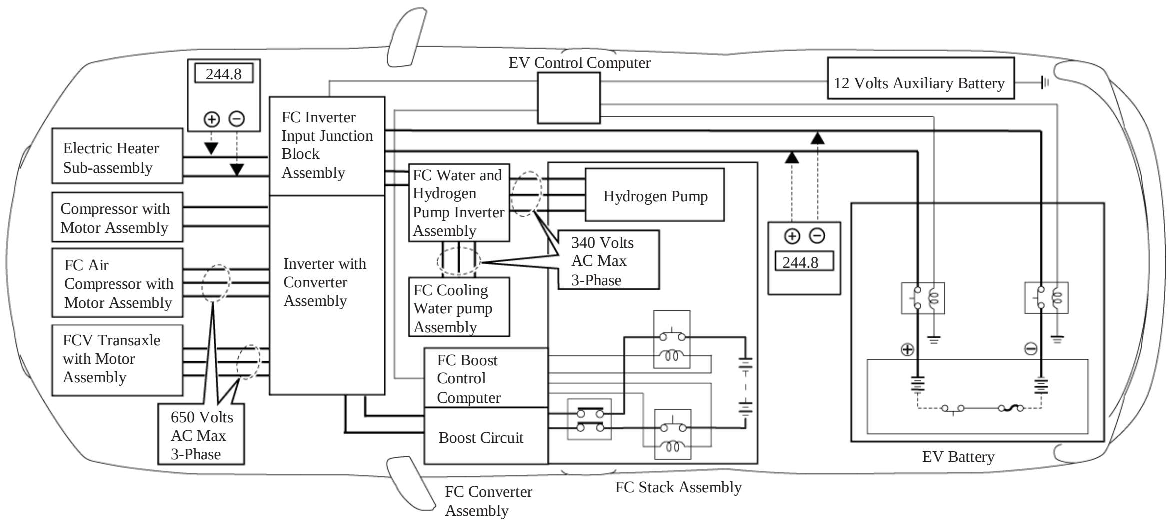
High Voltage Safety (Continued)

Service Plug Grip

- The high voltage circuit is cut by removing the service plug grip (see page 78).



High Voltage Safety System – Vehicle Shut Off (READY-OFF)



High Voltage Safety System – Vehicle On and Operational (READY-ON)

Precaution to be observed when dismantling the vehicle

⚠ ***WARNING:***

- ***The high voltage system may remain powered for up to 10 minutes after the vehicle is shut off or disabled. To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or opening any orange high voltage power cable or high voltage component.***
- ***When discharging pressurized hydrogen gas from the from the hydrogen tank assembly, do not perform the procedure in an indoor area with poor ventilation.***
- ***Do not install or remove any hydrogen system components without first performing depressurization procedures.***

Necessary Items

- Protective clothing such as insulated gloves (electrically insulated), rubber gloves, safety goggles, and safety shoes.
- Insulating tape such as electrical tape that has a suitable electrical insulation rating.
- Before wearing insulated gloves, make sure that they are not cracked, ruptured, torn, or damaged in any way. Do not wear wet insulated gloves.
- An electrical tester that is capable of measuring DC 750 Volts or more.

FUEL CELL STACK HYDROGEN SYSTEMS

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Fuel Cell (FC) System

- Fuel cell vehicles (FCV) use a motor for driving force in the same way as hybrid vehicles. In order to drive the motor, a high voltage (over 200 V, up to 650 V) is used. Not having an engine, the vehicle uses a motor driven by the power generated by a chemical reaction between the hydrogen fuel and oxygen in the air.
- Fuel cell vehicles (FCV) are equipped with dedicated high voltage components such as an FC stack, hydrogen pump, FC water pump, FC water pump and hydrogen pump inverter, FC boost converter and FC air compressor.
- To use hydrogen for power generation, fuel cell vehicles (FCV) are equipped with hydrogen pipes and hydrogen-related parts such as an FC stack, hydrogen tanks, etc.
- The hydrogen tanks are filled with high pressure hydrogen gas (a maximum of 70 MPa (714 kgf/ cm^2, 10,153 psi) at 15°C (59°F)).
- The hydrogen-related parts are inside cases/covers. Also, some of the insulation on high-pressure hydrogen pipes is in red.
- Hydrogen gas is colorless, odorless, and harmless.
- Hydrogen gas is flammable, and can ignite in a wide range of concentrations (4 to 74.5%). However, it diffuses easily and tends not to accumulate, so a small amount of leak would quickly dissipate to a concentration that cannot ignite.
- In the case of hydrogen leakage, the hydrogen detector equipped on the vehicle detects the hydrogen leak and shuts off the supply of hydrogen to prevent a mass leak. Also, hydrogen-related parts are located outside the cabin to allow leaked hydrogen to be easily diffused.
- If a collision is detected, the supply of hydrogen is shut off to prevent a mass leak due to vehicle damage.
- For details about the installation locations of hydrogen-related parts, refer to the QRS (Quick Reference Sheet) for the vehicle.

WARNING

- If the sound of hydrogen leaking (a loud hissing sound) can be heard when working on the vehicle, or if the hydrogen concentration around the vehicle exceeds 4% when measured with a hydrogen concentration detector, immediately step away from the vehicle as there is a chance that the hydrogen gas may ignite.
- Even after the vehicle is stopped (refer to P69), hydrogen remains inside the FC stack, hydrogen tanks and other hydrogen-related parts, as well as inside the hydrogen pipe. In order to avoid fires and explosions, never cut or damage these hydrogen-related parts or the hydrogen pipe.
- When the person(s) in charge of handling the damaged vehicle are away from the vehicle and someone else accidentally approaches or touches the vehicle, death or serious injury may occur due to electrocution, a rupture, an explosion or fire. To avoid this danger, display “HIGH VOLTAGE DO NOT TOUCH” and ”HIGH-PRESSURE GAS DO NOT TOUCH” signs to warn others (print and use page 25 and 36 of this guide).

CAUTION:

HIGH-PRESSURE GAS

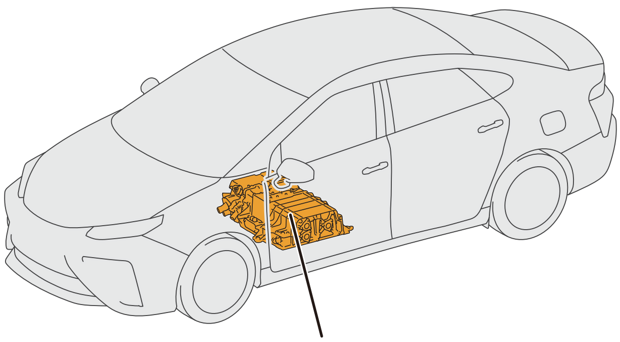
DO NOT TOUCH.

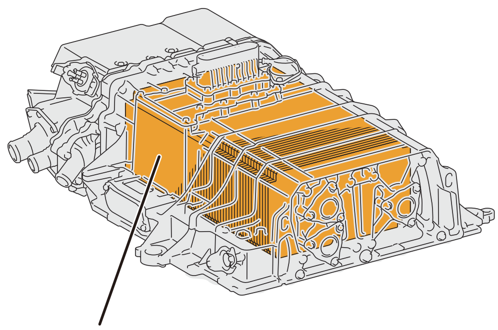
Person in charge:

CAUTION:
HIGH-PRESSURE GAS
DO NOT TOUCH.
Person in charge:

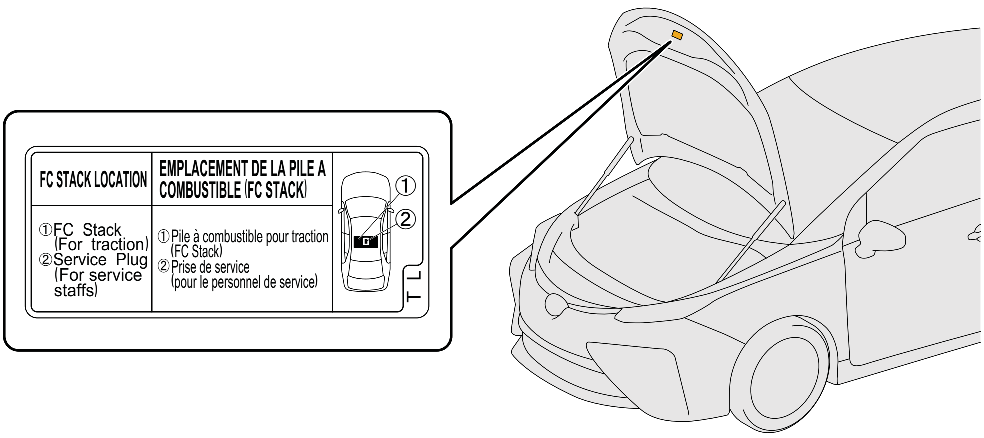
FC Stack

- The FC stack is a device to generate electricity through the chemical reaction between hydrogen and oxygen. Using the hydrogen supplied by the hydrogen tank and oxygen in the air drawn in from outside the vehicle, a high voltage of 200 V or higher is generated.
- The FC stack is installed underneath the floor.
- The FC stack generates power using so called “cells”, which are comprised of an electrolyte membrane sandwiched by separators. A few hundred cells are connected in a row to generate a high voltage.
- The cells are contained inside a metal case so that they are not easily touched.
- Water is generated through the chemical reaction between hydrogen and oxygen during power generation, and discharged via the discharge outlet.



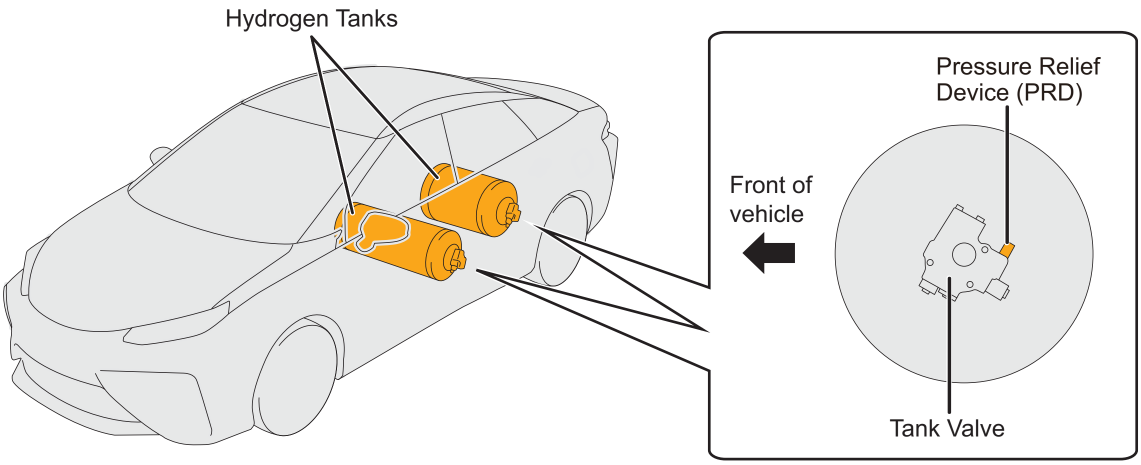


- An under-hood label shows the location of the FC stack.



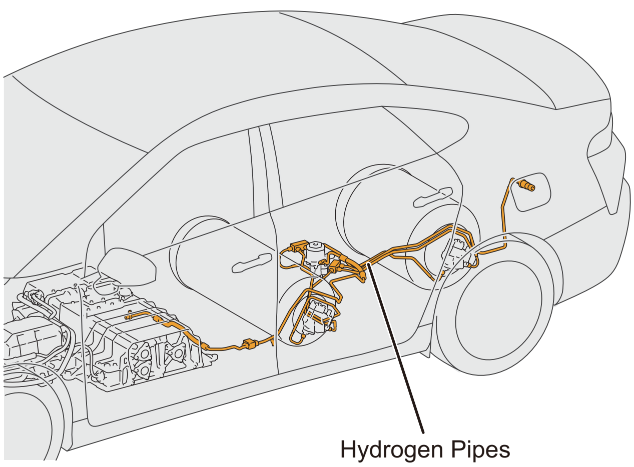
Hydrogen Tank

- The hydrogen tanks are filled with high pressure hydrogen gas (a maximum of 70 MPa (714 kgf/cm^2, 10,153 psi) at 15°C (59°F)) that is supplied to the FC stack.
- The hydrogen tanks are made of carbon fiber-reinforced plastic and located underneath the floor.
- The hydrogen detector used to detect hydrogen leaks is located near the tanks. If a specified concentration of hydrogen leakage is detected, the FC system cuts off the supply of hydrogen.
- Each tank is equipped with a pressure relief device (PRD) in order to prevent an explosion when the temperature of the hydrogen reaches abnormal levels due to a vehicle fire. The pressure relief device will open at approximately 110°C (230°F) to release the hydrogen gas in the tank outside of the vehicle.



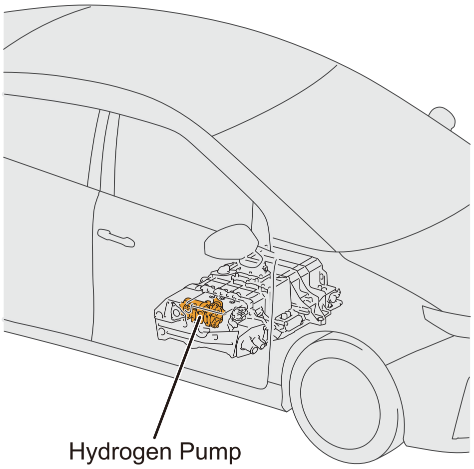
Hydrogen Pipes

- The hydrogen pipes connect the hydrogen-related parts such as the FC stack and hydrogen tanks.
- The hydrogen pipes are located underneath the floor.
- Some of the high-pressure hydrogen pipes are identified in red.



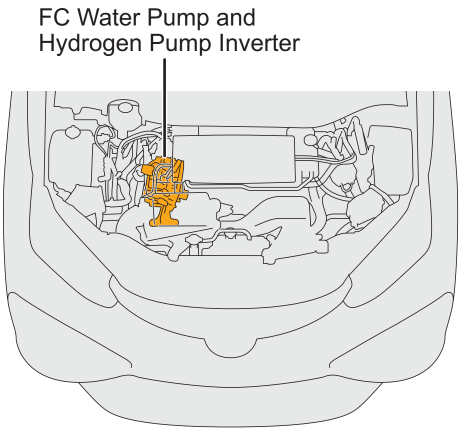
Hydrogen Pump

- The hydrogen pump circulates the hydrogen supplied from the hydrogen tanks into the FC stack.
- The hydrogen pump has a built-in motor that is operated using the high voltage from the FC water pump and hydrogen pump inverter. The hydrogen pump is installed underneath a cover at the side of the FC stack.



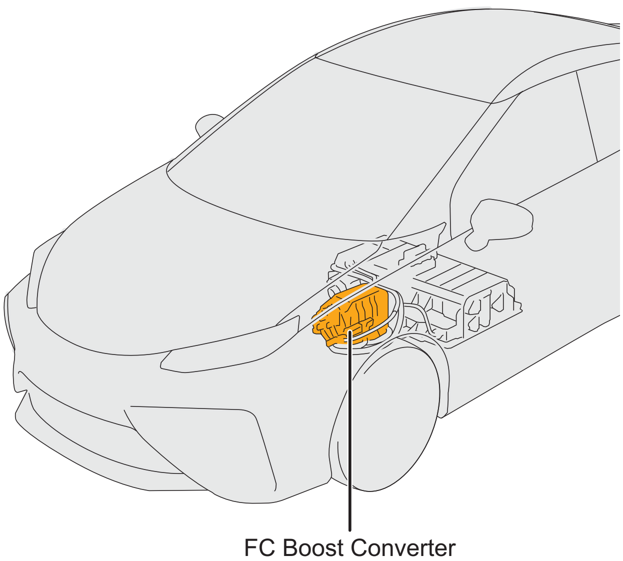
FC Water Pump and Hydrogen Pump Inverter

- The FC water pump and hydrogen pump inverter converts DC from the high voltage battery to AC, and supplies this current to the hydrogen pump and FC water pump.
- The FC water pump and hydrogen pump inverter is installed in the motor compartment.



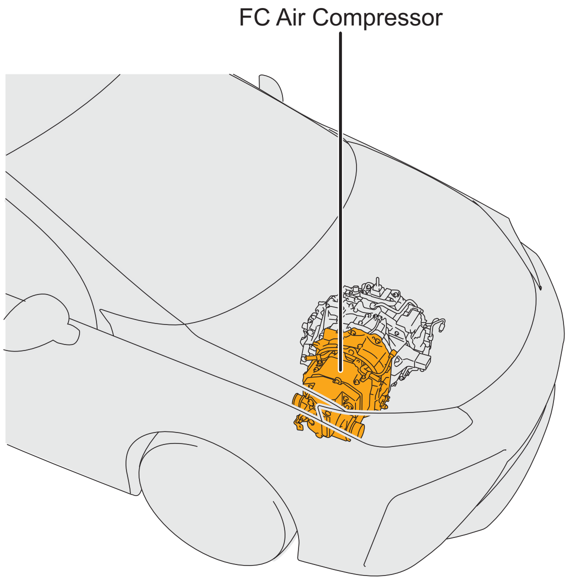
FC Boost Converter

- The FC boost converter increases the voltage of DC generated by the FC stack to a maximum of 650 V for motor operation, and then supplies this current to the inverter/converter.
- The FC boost converter is installed in the center tunnel (outside the cabin).



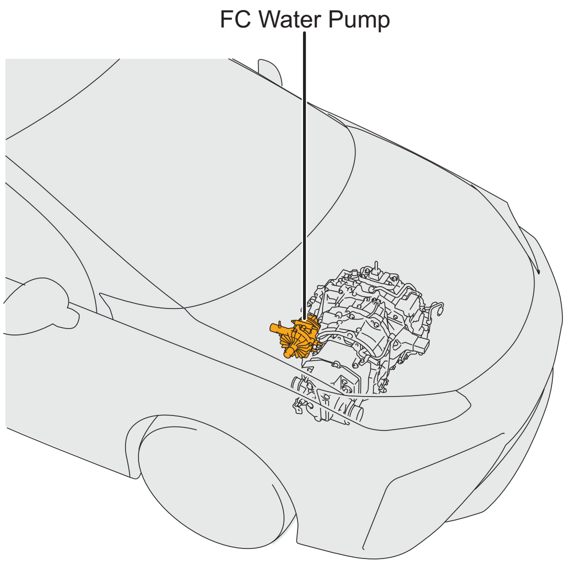
FC Air Compressor

- The FC air compressor supplies air (oxygen) to the FC stack.
- The FC air compressor has a built-in motor which is driven using the output voltage from the inverter/converter (up to 650 V), and is installed in the motor compartment.



FC Water Pump

- The FC water pump circulates the coolant to cool the FC stack.
- The FC water pump has a built-in motor which is driven using the high voltage from the FC water pump and hydrogen pump inverter, and is installed in the motor compartment.



2016 HYDROGEN & FUEL CELL COMMITTEE ANNUAL REPORT

Reference Document
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

Reference Document

The Hydrogen and Fuel Cell Technical Advisory Committee
Washington, D.C.

June 29, 2017

The Honorable Rick Perry
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave. SW
Washington, D.C. 20585

Dear Mr. Secretary:

On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), I hereby submit the Committee's 2016 Annual Report. The HTAC duties, under Title VIII of the Energy Policy Act of 2005, SEC. 807, are to review and make recommendations to you, the Secretary, on: (1) the implementation of programs and activities under Title VIII; (2) the safety, economical, and environmental consequences of technologies for the production, distribution, delivery, storage, or use of hydrogen energy and fuel cells; and (3) the Department of Energy (DOE) plan under section 804. The enclosed report summarizes the Committee's observations and recommendations in this regard.

The success of our Committee has been enabled by our very cooperative working relationship with your Department's Fuel Cell Technologies Office (FCTO). The progress made this year in the areas of fuel cell and hydrogen technologies clearly demonstrates their commitment, and that progress is even more evident when comparing the state of these technologies to that during the early days of President Bush's Hydrogen Fuel Initiative. The Office effectively orchestrates the Department's ongoing efforts on fuel cell durability, costs, advanced research and manufacturing, codes and standards and infrastructure. It also provides important leadership for other programs, including H2USA, the public-private partnership focusing on fueling infrastructure for fuel cell electric vehicles (FCEVs). The HTAC has received sustained support and strong engagement from key members of your leadership team over the past several years, particularly the Office of Energy Efficiency and Renewable Energy (EERE) Deputy Assistant Secretary for Sustainable Transportation, Reuben Sarkar, and FCTO Director, Sunita Satyapal. We also valued the opportunity to meet and speak with your then newly appointed Acting Assistant Secretary for EERE, Daniel Simmons during our May 5 meeting in Washington, DC. The Committee very much appreciates the advice they provide on how our Committee can best advise both you and the Department to help it complete its mission to support commercial hydrogen and fuel cell deployment within the United States.

Observations/Recommendations from 2016 HTAC Annual Report and Supporting Efforts

Be assured that as we share our observations and recommendations with you, the Committee stands ready to support you and the Department in addressing the challenges during this critical period. We respectfully request that you consider the following points, as you balance the many priorities facing you.

- ***The hydrogen and fuel cell industries made steady progress in 2016, in advancing hydrogen and fuel cell system utilization.*** *Noteworthy were ongoing R&D developments and growing sales in the stationary, transportation, backup, off-grid, military and material handling sectors.*
- ***The U.S. has led the world in developing fuel cell and hydrogen technologies, but our leadership position is now potentially at risk.*** *Most commercial advances in the areas of FCEVs, stationary power, and hydrogen technologies are now from outside the U.S., creating a growing gap in leadership and competitiveness. The importance of federal support in these areas cannot be understated.*
- ***Securing industry commitments to high volume manufacturing requires clear and stable policy.*** *FCEVs and associated refueling infrastructure investments are capital intensive and require a predictable environment, with a pathway to positive long-term economic returns. Commitments in line with those for Battery Electric Vehicles would send a clear signal of that promise and encourage the sharing of R&D between these complementary technologies.*
- ***The Committee reasserts that the U.S. is still not on track to meet the 2020 EPACT Title VIII goals for FCEVs.*** *Evidence shows that even the 2015 Title VIII goals have still only partially been met, and only in California where state zero emission vehicle (ZEV) mandates (with favorable "travel provisions" that are well aligned with the Title VIII goals) exist.*
  - *DOE support is critical to continue efforts in material and process integration and technology acceleration in order to meet the 2020 goals. Rapid learning cycles and manufacturing scale economies are essential prerequisites to overcome challenges in reducing costs to competitive levels.*
  - *DOE support is also critical to ensuring positive retail hydrogen fueling experiences, especially during early stage vehicle and fueling infrastructure deployments.*
  - *Extending federal FCEV tax credits and power generation investment tax credits is an essential enabler to promoting fuel cell commercialization and achieving Title VIII goals.*
  - *The Department should provide an explicit plan in 2017-2018, including measureable milestones, stating how the 2015 and 2020 Title VIII goals will be achieved and how the plan will be funded.*
  - *The Clean Cities Program should continue its emphasis on actively promoting and educating consumers on FCEV and hydrogen technologies along with promoting compressed natural gas, biofuel, renewable diesel, and electricity solutions.*
- ***The Committee finds the Department's updated draft Hydrogen and Fuel Cells Program Plan to be comprehensive and should be effective in meeting its objectives with appropriate resource commitments.***

In addition to the 2016 HTAC Annual Report, I have enclosed a report of the HTAC's Safety and Event Response Subcommittee, which provides an assessment of the current status of resources and practices that support a comprehensive, consistent, and coordinated response to hydrogen safety-related events. This assessment was deemed necessary by the Committee because of the potential for even a single safety related fueling event to negatively influence public perception about hydrogen fuel cell vehicles. Ms. Catherine Dunwoody (Assistant Chief, Monitoring and Laboratory Division, for the California Air Resources Board) led this Subcommittee. She and her cross-cutting team of experts worked with the goal of enabling the community of hydrogen stakeholders to understand event causes, address issues, share learnings, communicate status effectively with multiple stakeholders, including media, and maintain focus on advancing commercialization of hydrogen fuel. The recommendations from the report are summarized below.

- ***Recommendation #1: Maximize the Role of the Hydrogen Safety Panel (HSP)***

  DOE should develop a strategic plan that ensures continuation of safety and event response R&D activities that are fundamental to overall Program success. This includes a key element to position the HSP as a trusted resource on hydrogen safety and invest in marketing to make the HSP more visible. The plan should also provide resources to enable the HSP to develop relationships with safety officials at the local, state, and national levels. At the same time, state and privately funded projects should also budget for HSP involvement,

- ***Recommendation #2: Leverage the Capabilities of Public–Private Partnerships, Including Clean Cities Coalitions and Other Regional Partnerships***

  The broader stakeholder community can play an important role in supporting those who are new to the industry and communicating information to the media regarding hydrogen properties and safety.

- ***Recommendation #3: Take Steps to Support Reopening Hydrogen Stations in a Timely Fashion After a Safety-Related Incident***

  Hydrogen stations should be able to recover and reopen from safety-related incidents on a timeline similar to incidents at gasoline stations. Helping to establish clear event response decision tree procedures and response timelines is important in this regard.

- ***Recommendation #4: Identify and Support Other Federal and State Agencies that Need to Incorporate Hydrogen into Their Programs***

  Hydrogen fuel is on a trajectory to be as familiar as gasoline fuel as we move toward low-carbon, zero-emission fuels. Federal and State agency coordination is critical to achieving that end, and enhanced efforts should be made to connect Federal and State level programs for shared learning and knowledge transfer.

Hydrogen and fuel cells have an integral role in your portfolio approach to ensuring our nation's energy security. As such, The HTAC respectfully asks that that appropriate resources continue to be dedicated to this program to meet its congressional intent and to help the country achieve its energy security goals. We look forward to continuing our service to you, your Department of Energy team, the Fuel Cell Technologies Office, and the nation in advancing this important subset of the 21st Century U.S. energy system. We welcome your feedback and any ideas about how we can best support you.

Sincerely yours,

Frank J. Novachek

Chairman, HTAC
On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee

2016 HTAC ANNUAL REPORT SUMMARY

This Annual Report of the United States (U.S.) Department of Energy (DOE) Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) highlights worldwide advances and challenges in 2016 regarding hydrogen and fuel cell commercialization, policy, regulations, standardization, financial climate, and research and development (R&D).

Progress in 2016 has moved hydrogen and fuel cells toward greater realization of their potential to provide reliable and efficient power, serve as an energy storage medium, and create U.S. manufacturing jobs. There were growing shipments in commercial markets, including motive, stationary and portable applications, and new technical milestones and cost reductions were reached through ongoing research, development & demonstrations (RD&D) conducted by national laboratories, industry and academia. Continued investment in R&D and vehicle fueling infrastructure will enable these technologies to fully contribute to the nation's energy security and domestic economic resilience. Highlights from 2016 include:

- **Progress on the DOE "Hydrogen at Scale" (H2@Scale) concept** introduced in 2015. H2@Scale addresses the potential of hydrogen production to enable resiliency of the power generation and transmission sectors, while simultaneously serving multiple domestic industries and reducing U.S. emissions. Preliminary analysis performed by the national laboratories on the H2@Scale concept indicated that wide-scale use of electrolytic hydrogen can reduce U.S. petroleum consumption by about 1.2 billion barrels per year. An in-depth analysis is now underway to project future price points of electrolytic hydrogen, and thereby more accurately estimate future demand and value proposition.
- **Introduction of a third commercial fuel cell electric vehicle (FCEV), the Honda Clarity Fuel Cell**, to California customers in December 2016. Toyota and Hyundai have sold or leased more than 1,000 FCEVs in the U.S. and nearly 3,000 worldwide through late 2016.[1]
- **The addition of 18 retail hydrogen stations in California**, with a total of 25 hydrogen stations operating in the state at the end of the year.[2]
- **An announcement by Toyota and Air Liquide of the locations of the first four northeast public hydrogen stations, to be sited in Connecticut, New York, and Massachusetts.** These are the first in an initial 12-station refueling network that will span 300 miles across five states to support the introduction of FCEVs.[3]
- **Development of the Hydrogen Station Equipment Performance (HyStEP) testing device to validate operation of new hydrogen stations**. The open-source designs, developed by Sandia National Laboratories and the National Renewable Energy Laboratory, can be used to accelerate hydrogen fueling station deployment.[4]
- **The sale of approximately 50,000 Ene-farm residential fuel cell systems in Japan**, with a total of 190,000 Ene-farm fuel cells installed since 2009.[5]
- **Ten percent growth in natural gas fuel cell power generation installations, dominated by U.S. companies and technology.**[6]

Despite ongoing progress, challenges remain for the hydrogen and fuel cell industry. These challenges include:

- Reducing hydrogen cost from renewable resources below $2/kilogram, a key to the success of H2@Scale.
- Additional reductions in catalyst material costs for membrane electrode assemblies (MEAs) for low temperature fuel cell and electrolyzer systems.
- Better system integration and reduced component costs for lower balance-of-plant costs.
- Improvements in manufacturing processes and yield rates for electrolyzer and fuel cell system manufacturing.
- Reduction in components costs, improved compressors and metering/metrology for hydrogen refueling stations.
- Lower cost and simpler systems for continuous monitoring of impurities and contaminants in hydrogen gas streams.

In addition, two federal tax credits expired at the end of 2016: the 30 percent Investment Tax Credit (ITC) for stationary fuel cell systems and forklifts; and the Fuel Cell Motor Vehicle Tax Credit of up to $8,000. Expiration of these incentives is expected to significantly slow adoption.

Evidence suggests the U.S. is still not on track to meet the 2020 goals for hydrogen FCEVs and refueling infrastructure set by the U.S. Energy Policy Act of 2005 (EPACT) Title VIII. In response to the Committee's recommendation on this issue in 2015, DOE committed to provide the Committee a strategy paper outlining a pathway toward those goals. The Committee stands ready to provide feedback on that paper once it is developed.

The hydrogen and fuel cell industries made steady progress in 2016, with ongoing R&D developments and growing sales in the stationary, transportation, backup, off-grid, military and material handling sectors. Significant developments include:

- Three automakers now sell commercial FCEVs in the U.S. (California), Asia, and Europe. In California, 1,074 FCEVs were sold or leased in 2016, up from 112 FCEVs sold or leased in 2015.[7] Worldwide sales approached 3,000 units.
- Twenty-five retail hydrogen stations were open in California at the end of 2016, up from six in 2015, and more stations are in development.[8] Ninety-two new stations were opened worldwide.[9]
- Twenty-four fuel cell buses carry transit riders in the U.S. (California, Delaware, Massachusetts, Michigan, Ohio) and more deployments are planned. Fuel cell bus durability reached 23,000 hours, surpassing the DOE and FTA 2016 target of 18,000 hours, and range has reached up to 340 miles, more than 13 percent above the 2016 target.[10] Average fuel economy is 1.4 to 1.9 times higher than conventional diesel buses.[11]
- The number of fuel cell residential combined heat and power (CHP) units in Japan is approaching 200,000 with about 50,000 Ene-farm systems deployed in 2016.
- The H2@Scale concept moved beyond the National Lab team and DOE offices to include industrial/other stakeholders. The concept describes the potential for multi-sector energy benefits of wide-scale renewable hydrogen production.
- The California Fuel Cell Partnership (CaFCP) released a Medium & Heavy-Duty Fuel Cell Electric Truck Action Plan. Categories selected as the most feasible near-term vehicle platforms are the Class 4-6 urban "last mile delivery" trucks and Class 7-8 short haul/drayage trucks.

Unfortunately, 2016 also saw the expiration of the federal Investment Tax Credit (ITC) for most non-solar renewable energy technologies, including fuel cells and hydrogen. A federal FCEV tax credit of up to $8,000 also expired at the end of 2016. The expiration of these incentives is expected to significantly slow adoption rates.

Industry Metrics

Key industry metrics, reported in an annual assessment by E4Tech, *The Fuel Cell Industry Review 2016*, show worldwide fuel cell shipments increased by two-thirds on a megawatt basis, growing from 298 megawatts (MW) to 478 MW. On a unit basis, global fuel cell shipments grew from almost 61,000 units in 2015 to more than 65,000 in 2016. The increase in unit shipments, combined with a large increase in megawatts shipped, indicates many shipments were larger units.[12]

North American unit shipments grew slightly, from 6,900 fuel cells in 2015 to 7,300 in 2016, but on a megawatt basis, North America almost doubled the previous year's shipments, growing from 108 MW in 2015, to 209 MW in 2016.[13]

Asia supplied almost 54,000 of the total global shipments of more than 65,000 fuel cell units. Asia also shipped almost 246 MW, more than half of the 2016 global total of 478 MW.[14]

In 2016, FCTO reported other milestones, including:[15]

- More than 4 million passengers on fuel cell buses;
- More than 11,000 fuel cell forklifts in operation;
- More than 1,100 FCEVs sold or leased in the U.S.;
- More than 1.5 million hydrogen refuelings;
- The finding that 10-kW solid oxide fuel cell (SOFC) systems in volume production (50,000 units annually) would meet the DOE 2020 equipment cost target.[16]

Fuel cell technology was originally developed in the U.S. Despite aggressive, well-funded competition from Europe and Asia, U.S. products and technology still hold a strong position. Fully commercializing fuel cell technologies will mean significant high-wage job growth and economic gains for American companies. Figure 1 highlights the impact of DOE's fuel cell and hydrogen RD&D activities and U.S. job potential.

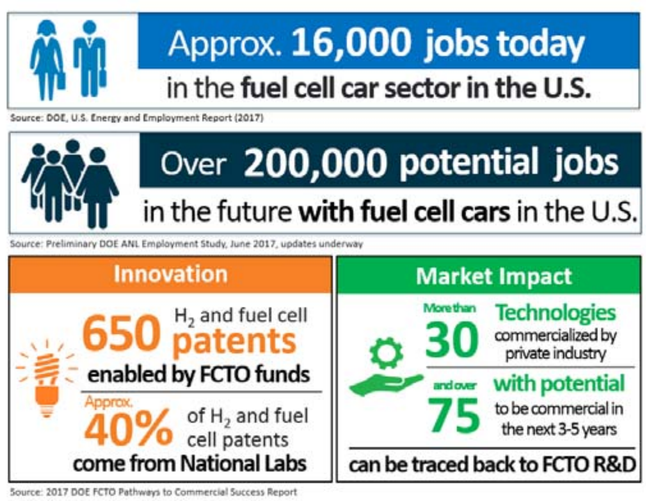


Figure 1: Fuel Cell Technologies Office (FCTO) Program Impact: H2 and Fuel Cells. *Source: DOE FCTO*

EPACT 2020 Goals

2016 accomplishments are important as the year 2020 approaches – a milestone year highlighted in Title VIII of the U.S. Energy Policy Act of 2005 (EPACT), which set forth the following goals for FCEV commercialization:

1) "To enable a commitment by automakers no later than year 2015 to offer safe, affordable, and

technically viable hydrogen fuel cell vehicles in the mass consumer market and to enable production, delivery, and acceptance by consumers of model year 2020 hydrogen fuel cell and other hydrogen-powered vehicles that will have, when compared to light duty vehicles in model year 2005: 1) fuel economy that is substantially higher; 2) substantially lower emissions of air pollutants; and 3) equivalent or improved vehicle fuel system crash integrity and occupant protection;" and

2) "To enable a commitment not later than 2015 that will lead to infrastructure by 2020 that will provide: 1) safe and convenient refueling; 2) improved overall efficiency; 3) widespread availability of hydrogen from domestic energy sources; and 4) hydrogen for fuel cells, internal combustion engines, and other energy conversion devices for portable, stationary, micro, critical needs facilities, and transportation applications."

Considerable progress has been made toward these goals since 2005, and the 2015 commitments have been partially met. Efforts such as H_2USA have brought industry and government together working in important ways toward these goals. FCEVs by three manufacturers have now been fully safety certified and offered for sale or lease; more are expected in the 2018–2020 timeframe. In the U.S. this progress has been mostly driven by state-level zero emission vehicle (ZEV) programs. Support does not appear to be adequate to spur the momentum needed to achieve the 2020 EPACT goals.

In response to the Committee's recommendation on this issue in 2015, Acting Assistant Secretary David Friedman committed to developing a strategy paper outlining steps toward the 2020 goals. The Committee stands ready to provide feedback on that strategy once it is developed.

Significant Challenges Remain

The efficiency and environmental advantages of hydrogen and fuel cells are well demonstrated and the economic and manufacturing potential is well understood. Significant strides have been made over the last decade to improve electrolyzer and fuel cell performance and durability, and to lower costs. Fuel cells are now making inroads in early commercial markets (material handling, backup power, military, specialty products) and as an alternative option to conventional power generation.

Despite these successes, challenges remain. DOE has set technical goals and objectives to advance hydrogen production and fuel cell technologies for transportation, power generation and other market applications. The 2020 objectives include:[17]

- A 65 percent peak-efficient, direct hydrogen fuel cell power system for transportation that can achieve 5,000-hour durability (ultimately 8,000 hours) and be mass produced at a cost of $40/kW (ultimately $30/kW).
- Distributed generation and micro-CHP (combined heat and power) fuel cell systems (5 kW) operating on natural gas that achieve 45 percent electrical efficiency and 60,000-hour durability at an equipment cost of $1,500/kW.
- Medium-scale CHP systems (100 kW–3 MW) that achieve 50 percent electrical efficiency, 90 percent CHP efficiency and 80,000-hour durability at a cost of $1,500/kW for operation on natural gas and $2,100/kW when configured for operation on biogas.

The current status of technology development has been reported by DOE in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (updated September 2016).[18]

For light-duty vehicles, current cost modeling (2015) places the cost of an 80-kW net automotive fuel cell system based on next-generation technology and operating on direct hydrogen at $53/kW when manufactured at a volume of 500,000 units/year and $60/kW at a volume of 100,000 units/year.

For CHP systems, the plan finds that common challenges across all fuel cell types include decreasing cost and increasing durability and cell component stability. For PEM systems, challenges also include decreasing fuel processor costs and raising operating temperatures.

- While durability of residential micro CHP systems has been improved to 70,000 hours for PEM systems, the price of deployed systems (Germany, Japan) is approximately $22,000/kW for a 0.7-kW system, substantially higher than DOE cost targets.
- For medium-scale CHP/distributed generation (100 kW–3 MW), phosphoric acid fuel cells (PAFCs) and molten carbonate fuel cells (MCFCs) have demonstrated durability of >80,000 hours and >40,000 hours respectively. Increasing MCFC durability requires, among other things, a more robust cathode. Reducing PAFC costs requires increasing performance, durability and stability for catalysts and supports.
- Common technical challenges for MCFCs and PAFCs include reducing system conditioning time, developing low-cost manufacturing methods, and decreasing the cost of the fuel processor and cleanup system.
- SOFCs have demonstrated durability of >25,000 hours. High operating temperature can lead to compatibility and reactivity issues among cell and stack components, especially over extended operating times. The ability of the stack to survive repeated thermal cycling and the relatively long start-up times are additional challenges.
- DOE cost estimates for a 100-kW low temperature - PEM CHP system show that balance of plant, catalyst and fuel processor costs are the main contributors to system costs. Increasing the temperature of operation could help simplify the fuel processor, reduce costs, and provide higher quality waste heat.

Hydrogen R&D

DOE's hydrogen program has made significant R&D progress in hydrogen production, storage and delivery over the past several years. DOE continued to advance the Hydrogen at Scale Big Idea concept initiated in 2015. This project shows great potential for hydrogen and fuel cell technologies to enable resiliency of the power generation and transmission sectors, while simultaneously serving multiple domestic industries and reducing U.S. emissions.

- A workshop on the cross-cutting value proposition of H2@Scale was held November 16-17, 2016, at the National Renewable Energy Laboratory, with representation from 10 DOE offices and a total of about 170 attendees. The workshop was meant to guide the development of an H2@Scale roadmap, which is currently being drafted. The workshop report is now online: http://www.nrel.gov/docs/fy17osti/68244.pdf.
- Analysis has been completed on the technical potential of hydrogen demand and hydrogen supply from domestic resources (including renewable, nuclear, and fossil fuel feedstock). The technical potential of demand for refining, direct reduction of iron, ammonia production, use of hydrogen as a combustion fuel (via blending into the natural gas infrastructure), biofuels production, and transportation (i.e. FCEVs) has been determined to be 60 million metric tonnes per year.

The cost and durability of electrolyzers and other hydrogen production technologies need improvement to enable greater customer acceptance which will drive manufacturing volume and, in turn, enable further cost reductions. Growing markets can also stimulate infrastructure development and resolve other key challenges.

Reducing electrolytic hydrogen production costs below $2/kilogram would enable success of the H2@Scale concept and improve U.S. competitiveness within this market.

Natural gas can provide a cost effective hydrogen source for initial fueling infrastructure, but continued R&D is needed to bring renewable hydrogen to equal or lower generation costs (Figure 2). Factors such as the cost of feedstock electricity and technology utilization, or capacity factor, have a significant impact on electrolytic hydrogen production costs.

The initial costs for capital equipment, manufacturing processes, installation, and warranty associated with fuel cell and electrolyzer systems need to be reduced.

In spite of these challenges, fuel cell and hydrogen R&D conducted over the past decade has spurred significant and ongoing cost, performance and durability improvements. Today, hydrogen and fuel cell technologies are making inroads into several early market areas where reliability and efficient power generation are valued.

HTAC Activities In 2016

HTAC activities in 2016 included formation of three new HTAC subcommittees.

EXTERNAL COMMUNICATIONS: This subcommittee will develop a standard communications package that consolidates a vision, objective and supporting messages for implementing hydrogen & fuel cell technology.

Key Deliverables: The primary focus is to provide communications resources online, accessible by industry, government stakeholders and the public. The subcommittee has identified messaging gaps and subcommittee members have gathered content, organizing it into packages in the areas

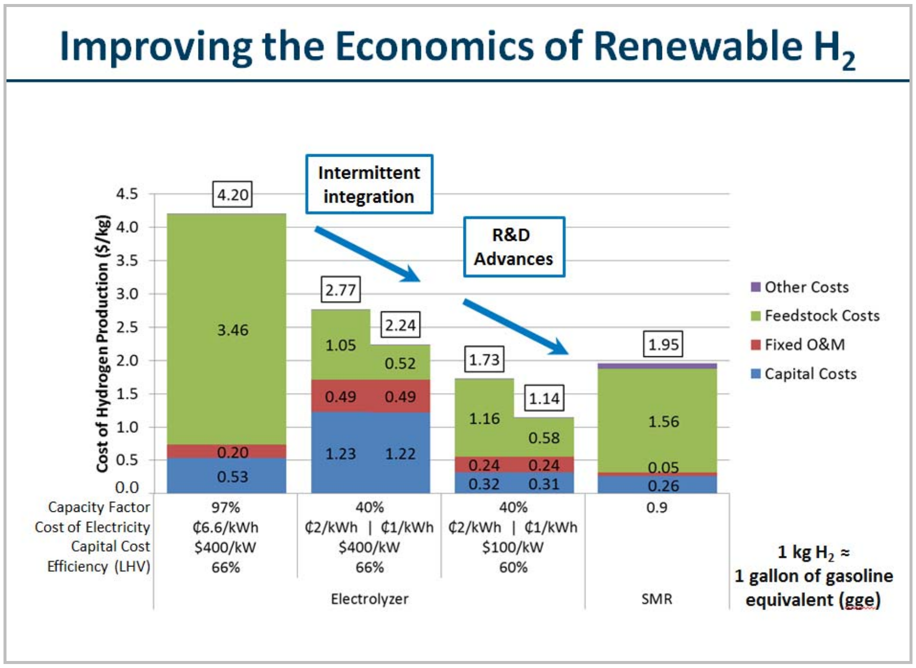


Figure 2. Improving the Economics of Renewable Hydrogen. *Source: U.S. Department of Energy*

of hydrogen, fuel cells, and electrolysis. A question-answer section will provide a streamlined location for users to review expert responses to frequently asked questions. The subcommittee plans to launch the site in 2017.

SAFETY/EVENT RESPONSE: The subcommittee has prepared a report identifying existing resources and resource gaps for responding to safety related events at retail hydrogen stations and recommended actions to address current and projected needs. The subcommittee's goal is to enable a comprehensive, consistent (to the extent practical) and coordinated response to hydrogen safety-related events to understand causes, address issues, share learnings, communicate status and maintain focus on advancing commercialization of hydrogen fuel.

Key Deliverables: The subcommittee has completed a final report that addresses technical, procedural and communications topics, identifies gaps, and offers the subcommittee's recommendations.

HYDROGEN AT SCALE CONCEPT REVIEW: The Committee actively monitored development of the H2@Scale concept. Project leads updated HTAC at both 2016 meetings. Individual members also participated in H2@Scale workshops held to solicit and incorporate feedback.

Hydrogen presents a unique potential to positively impact a number of areas. The H2@Scale value summary includes:

- Reducing greenhouse gas emissions and criteria pollutants across industrial, electrical, and transportation sectors. Analyses show that a 50 percent reduction in greenhouse gas emissions is possible by 2050.
- Supporting the needs of dynamic, variable power systems, including dispatchable, scalable storage. Additional benefits include energy security via energy diversity, resiliency and domestic energy production, manufacturing competitiveness and job creation, and decreased water requirements.

Figures 3 and 4 (next page) show the potential for sustainable hydrogen to support future energy needs across multiple sectors.

Commercialization Initiatives

Fuel cells are making significant inroads into an array of commercial sectors, including stationary power markets (primary and backup power), transportation markets (passenger vehicles, buses, trucks, rail, and forklifts), electricity grid-support applications, specialty (unmanned vehicles, aviation) and portable/off-grid applications (military, small electronics). Hydrogen, as an industrial chemical, also has broad impact for ammonia production, metal and semiconductor processing and refining of petrochemicals.

To help U.S. suppliers connect to original equipment manufacturers (OEMs) to improve the fuel cell industry supply chain, DOE supported the launch of Hydrogen Fuel Cell Nexus website in July. Managed by Virginia Clean Cities, the website serves as a business-to-business portal.[19]

Fuel Cells for Stationary Applications

Demand for stationary fuel cells continues to grow in both commercial and municipal applications. Systems finding markets range from micro-CHP systems to multi-MW power plants. More than 200 MW of stationary fuel cells were shipped globally in 2016, compared to 183 MW in 2015.[20]

- Bloom Energy has new or planned natural gas-powered fuel cell projects at more than 200 locations, including 40 MW at 170 customer sites for Exelon, 60 Home Depot stores integrated into Southern Company/ PowerSecure smart storage solutions, and 1.5 MW at five IKEA retail stores (Figure 5).
- Doosan Fuel Cell America partnered with Samsung C&T Corp. and Korea Hydro & Nuclear Power on a project that will supply power to 71,500 Korean homes. Seventy fuel cells will produce 30.8 MW of energy and heat.[21] Doosan also will deliver an 8-MW CHP system to Implats' South African platinum refinery.[22]
- FuelCell Energy installed a 5.6-MW CHP fuel cell power plant at Pfizer's Connecticut R&D facility.[23] FuelCell Energy has new or planned MW-scale fuel cell projects at wastewater treatment plants in Tulare and Riverside, California, and at two locations in Germany.[24]
- The European Commission's Fuel Cell and Hydrogen Joint Undertaking (FCH JU) announced it will provide almost 34 million € (US $36 million) to fund the PACE initiative, which will deploy 2,650 micro-CHP fuel cells in European to foster commercialization.[25]
- About 50,000 Ene-farm micro-CHP fuel cells were installed in Japanese homes in 2016, bringing the total installed since 2009 to more than 190,000 (Figure 5).[26]

Source: BloomEnergy.com   Source: OsakaGas.jp.co

Figure 5: Bloom Energy fuel cells at IKEA store, Ene-farm system.

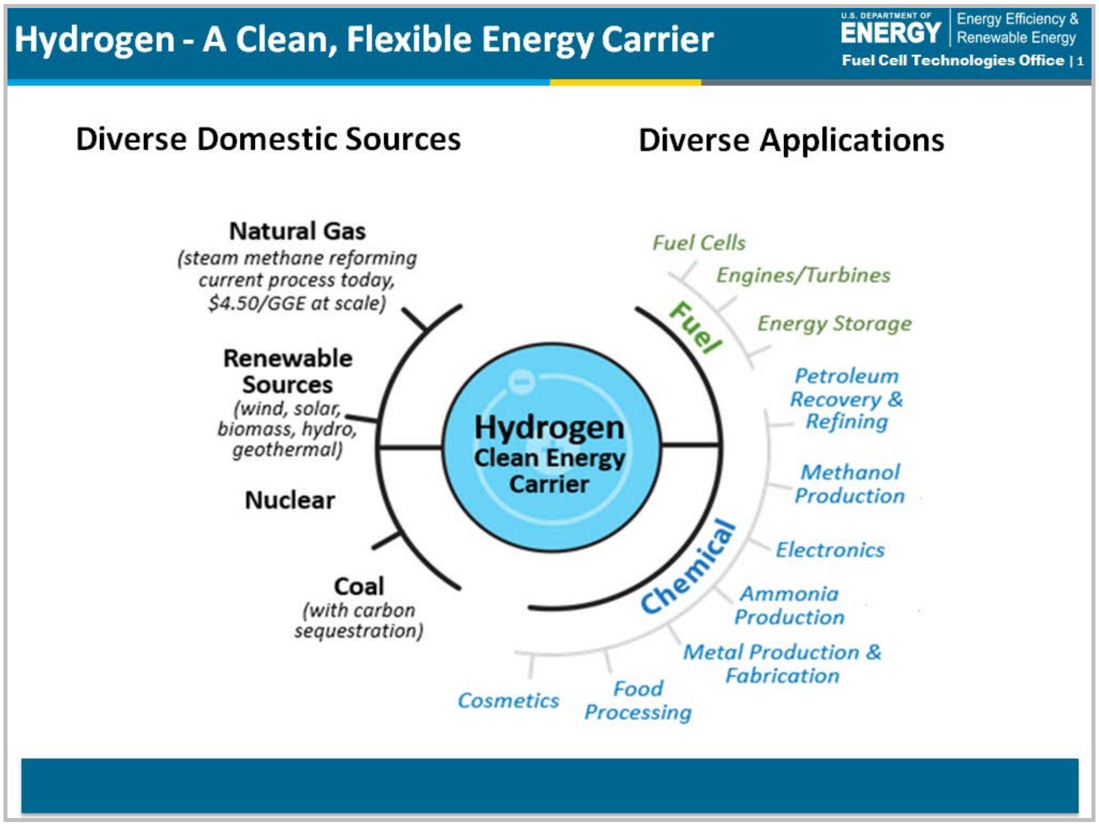
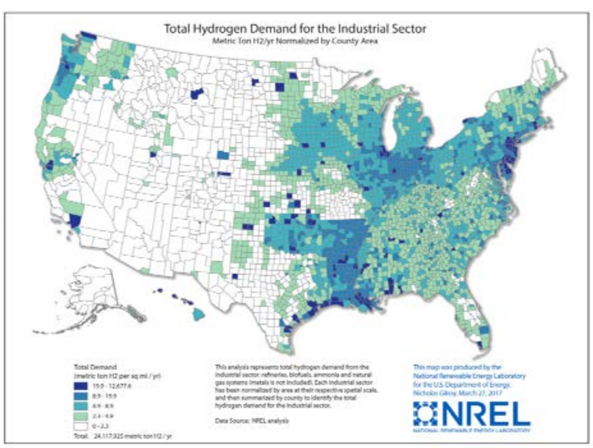


Figure 3. H2@Scale – hydrogen enables diverse feedstocks and applications. *Source: U.S. Department of Energy*

Initial Analysis: U.S. Hydrogen Demand Potential



Use	Market potential (million metric tonne H_2 / year)
Industrial Use	
Refineries & CPI§	8*
Metals	5
Ammonia	5
Natural Gas	7
Biofuels	4
Light Duty Vehicles	28
Other Transport	3
Total	**60**

Total market potential: 60 MMT/yr

Current U.S. market: ≈ 10 MMT/yr

Global H_2 production revenue: 6% CAGR, 2009-2016[1]

§ CPI: Chemical Processing Industry not including metals, biofuels, or ammonia
* Current potential used due to lack of consistent future projections
Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels
1. Global hydrogen Generation Market by Merchant & Captive Type, Distributed & Centralized Generation, Application & Technology- Trends & Forecasts (2011-2016)

NATIONAL RENEWABLE ENERGY LABORATORY 6

Figure 4. U.S. Hydrogen Demand Potential. *Source: U.S. Department of Energy*

Fuel Cells for Back-up Power Applications

More than 900 back-up power fuel cell systems have been deployed with DOE support, stimulating an more than 6,900 back-up power fuel cell shipments and orders with no DOE funding. These total more than 39 MW.[27]

In addition:

- Ballard Power Systems signed an agreement for a Chinese company to exclusively manufacture and sell Ballard's fuel cell backup power systems in China.[28]
- Proton Power signed a seven-year agreement with a German company for fuel cell emergency power units to be deployed in the Bavaria region of Germany.[29]

Fuel Cells for Passenger Cars

Automakers are selling and leasing increasing numbers of FCEVs around the globe.

- Three automakers now lease or sell FCEVs in California (Figure 6). Honda began deliveries of its 2017 Clarity in December. Toyota reduced the down payment and monthly lease payment on its 2017 Mirai FCEV, which was introduced in late 2015. Hyundai began leasing its Tucson FCEV in 2014 and has announced an update for 2018.[30]
- Several car companies committed to initial or next-generation commercial fuel cell vehicle rollouts, including Mercedes-Benz and Lexus.[31]
- Honda and GM announced a Fuel Cell System Manufacturing Joint Venture, based in Brownstown, Michigan. Production will begin sometime after 2020. This partnership's primary goal is system cost reduction.
- Nissan is researching and developing a SOFC-powered vehicle system that runs on bio-ethanol.[32]

Fuel Cells for Buses

Fuel cell buses are operating in revenue service in the U.S., Asia and Europe. Fuel cell buses are a particular interest in China, which has quickly become a world leader. Hyundai, New Flyer, Toyota, and Wrightbus announced plans to produce fuel cell buses. Other key developments include:

- The AC Transit fleet of 13 fuel cell buses is approaching 2 million miles and has carried more than 15 million passengers. The initial bus, built in 2003 and never expected to survive beyond 5,000 hours, has now exceeded 23,450 hours and remains in daily service. Four others are near or beyond the 20,000-hour mark.[33]
- The Federal Transit Administration (FTA) awarded Ohio's Stark Area Regional Transit Authority (SARTA) funds to buy three more buses, bringing its fuel cell bus fleet to 10 – the largest in the U.S. outside California.[34]
- The Fuel Cell Electric Bus Commercialization Consortium (FCEBCC) will deploy 20 fuel cell buses at two California transit agencies by December 2018. Ballard Power Systems will supply fuel cells for FCEBCC's 20 buses, for SARTA's 10 buses, and for California's Orange County Transportation Authority's (OCTA) American Fuel Cell Bus (Figure 7).[35] Ballard also is supplying modules for Solaris in Europe[36] and for 22 fuel cell buses operating in China.[37]
- The U.K. government awarded £2.8 million (US$3.6 million) to Birmingham City Council and Transport for London for 42 fuel cell buses.[38]
- Toyota and Wrightbus each announced they will make fuel cell-powered buses available in 2017. Toyota's bus features a high-capacity external power supply that can be used as a power source in an emergency.
- New Flyer of America's 60-foot electric heavy-duty transit bus, which incorporates a small Ballard Power Systems fuel cell operating as an on-board battery charger, will be tested at the FTA's proving grounds.[39]

Fuel cells are being utilized in a number of vehicles, including material handling vehicles, aircraft, ships, trucks, and unmanned vehicles. Among the 2016 announcements were:

- Plug Power announced new orders and deployments, including 96 additional fuel cells for forklifts in New Jersey's Newark Farmers Market, which already operates 240 units, and several orders from French companies.[40]
- A new class of ships, in 2022, from Royal Caribbean Cruises, will use fuel cell power generation. They will test fuel cells on an Oasis-class ship in 2017.[41]
- General Motors and the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) developed the off-road capable Chevrolet

Source: Toyota.com

Source: HyundaiUSA.com

Source: Honda.com

Figure 6: Toyota Mirai, Hyundai Tucson, and Honda Clarity FCEVs.

Colorado ZH_2 FCEV; it features an Exportable Power Take-Off unit to power activity away from the vehicle (Figure 7).[42] GM and the U.S. Navy have also partnered on fuel cells for unmanned undersea vehicles.[43]

- Kenworth is building a fuel cell truck for drayage operations at a Southern California port.[44]
- EasyJet disclosed plans to use fuel cells on aircraft for taxiing, saving up to 50,000 metric tons of fuel a year.[45]
- Alstom presented its Coradia iLint fuel cell-powered train, with a range of up to 500 miles per fueling (Figure 7). The train will be tested in 2017.[46] The German state of Schleswig-Holstein plans to electrify its entire railway network using fuel cell equipment by 2025.[47]
- H3 Dynamics unveiled a fuel cell-powered unmanned aerial vehicle (UAV) capable of 10 hour/300 mile flight.[48]

Hydrogen Production and Distribution

Milestones in hydrogen production and distribution include the opening of 13 retail hydrogen stations in California, for a total of 25 public stations at the end of 2016. True Zero announced its California stations had powered 2 million miles of FCEV driving, attaining this milestone just 60 days after reaching the first million. It took nine months to reach the first million.[49]

- Hydrogenics and StratosFuel will build a 2.5 MW renewable hydrogen plant, North America's largest, in Palm Springs, California, using wind and solar power.[50]
- Proton OnSite announced a 13 MW electrolyzer order for bus fueling in China and supplied an electrolyzer to produce renewable hydrogen for Switzerland's first public hydrogen station.[51]
- A demonstration hydrogen station was opened in Washington, D.C., through a partnership of Proton OnSite, SunHydro, Air Products, DOE and the National Park Service.[52]
- Toyota and Air Liquide will open four retail hydrogen refueling stations in 2017 in Connecticut, New York, and Massachusetts. The stations are part of a network of 12 retail hydrogen stations spanning 300 miles across five northeastern states that will support FCEVs.[53]
- Japan's Ministry of Economy, Trade and Industry outlined a plan for 160 hydrogen stations in 2021, growing to 320 in 2026. Toshiba, Tohoku Electric Power and Iwatani plan to produce enough hydrogen for 10,000 FCEVs annually using solar and wind power.
- Royal Dutch Shell, Kawasaki Heavy Industries, Iwatani and J-Power are partnering to produce hydrogen from low-quality brown coal in Australia and ship it to Japan markets.[54]
- H_2 MOBILITY, a joint venture of Air Liquide, Daimler, Linde, OMV, Shell, and Total, plan to develop up to 400 hydrogen stations in Germany by 2023.[55]

Hydrogen for Grid Support Applications

- FuelCell Energy announced a solid oxide electrolysis cells (SOEC) system that converts water into hydrogen during periods of excess electricity and low demand.[56]
- University of California, Irvine, engineers implemented the first U.S. power-to-gas (P2G) hydrogen pipeline injection, demonstrating how electricity from solar or wind can be used to make hydrogen and integrated into existing natural gas pipelines.[57]
- Japan's Obayashi and Kawasaki Heavy Industries, working with Kansai Electric Power, plan to use hydrogen to generate power in Kobe in 2018 via turbines using 80 percent natural gas and 20 percent hydrogen, with 100 percent hydrogen operation considered in the future.[58]

Policy, Regulations, Codes, and Standards

Policy and Regulations

Two federal tax credits expired at the end of 2016: 1) the 30 percent Investment Tax Credit (ITC) for stationary fuel cell systems and forklifts, and 2) the Fuel Cell Motor Vehicle Tax Credit of up to $8,000 on light-duty FCEVs. Expiration of the incentives is expected to slow adoption rates.

State policy developments include:

- Ongoing and new state-level FCEV purchase incentives, including in California ($5,000, and a new $7,000 incentive for low income drivers), Connecticut

Source: GM.com

Source: Alstom.com

Source: Ballard.com

Figure 7: GM/TARDEC's ZH2 vehicle, Alstom's fuel cell train, and Orange County's American Fuel Cell Bus.

(increased to $5,000 from $3,000), Massachusetts ($2,500), Pennsylvania ($1,000), and New York (up to $2,000, starting in 2017).

- Continuation of capital cost support for stationary fuel cell systems under California's Self-Generation Incentive Program, New York's Fuel Cell Program, and Pennsylvania's Alternative and Clean Energy Program.
- New policies that support stationary fuel cells, such as tax incentives, feed-in tariffs and sustainable energy goals, were implemented in five states (Connecticut, Delaware, Massachusetts, New York, and Rhode Island).

Noteworthy policy events in 2016 in the United States included a June 23 Congressional Fuel Cell and Hydrogen Policy Briefing on Capitol Hill, celebration of the second National Hydrogen and Fuel Cell Day on October 8, and a November 17 Hydrogen and Fuel Cell Forum in Hartford, Connecticut.

Codes and Standards

Codes and standards activities during the year include:

- Publication of the International Organization for Standardization (ISO) TS 19880-1 for hydrogen fueling stations, a first step towards standardizing hydrogen filling stations, superseding guidance developed as the earlier ISO TS 20100, published in 2008. The scope covers the processes from hydrogen production and delivery to compression, storage and fueling.[59]
- Publication of CSA Group's standard HGV 4.9, *Hydrogen fueling stations,* the first standard published for an entire hydrogen fueling station.[60]
- Passage of legislation in Connecticut allowing hydrogen-fueled vehicles to be parked under grade level.[61]

Financial Climate

Key finance and partnership agreements in 2016 include:

- FuelCell Energy and Exxon Mobil agreed to pursue a new application of carbonate fuel cells that captures carbon dioxide more efficiently than conventional technology, with the potential to substantially reduce capture costs for natural gas-fired power generation.[62]
- Cenovus Energy contracted with FuelCell Energy for front-end design and engineering for a fuel cell system to capture CO_2 from flue gas of boilers used to make steam in oil sands production at a 14-MW natural gas-fired co-generation facility in Alberta, Canada.[63]
- A strategic alliance was formed between Bloom Energy, Southern Company and its subsidiary PowerSecure, for project investment and joint-technology development.
- Hydrogenics and SinoHytec established a strategic partnership for the delivery of fuel cells designed for the Chinese market. The power systems will be integrated into buses and trucks in China.[64]
- Plug Power and two Chinese companies signed a Memorandum of Understanding to develop fuel cell and hydrogen fueling solutions for China's industrial electric vehicle market. The project's long-term goal is to deliver 13,500 industrial fuel cell vehicles over three years with a widespread hydrogen fueling network.[65]
- FuelCell Energy entered into a long-term loan facility with Hercules Capital for up to $25 million.[66]

Research and Development

Research and development activities focusing on hydrogen and fuel cell technologies continues at a steady pace in industrial, government lab, and university settings.

The U.S. DOE continued to advance the H2@Scale Big Idea concept initiated in 2015. This project shows great potential for hydrogen and fuel cell technologies to support multiple demands in transportation and industry (Figure 8), enabling dramatic emission reductions across many sectors/industries.

DOE's Advanced Research Projects Agency-Energy (ARPA-E) announced two new projects:

- The Integration and Optimization of Novel Ion-Conducting Solids (IONICS) projects will work to create high performance solid ion conductors that allow ions to be mobile and store energy, serving as a lower cost, high-performance alternative to parts used today.[67]
- The Renewable Energy to Fuels through Utilization of Energy-dense Liquids (REFUEL) program supports research on technologies that use renewable energy to convert air and water into cost-competitive liquid fuels.[68]

In addition:

- Researchers at UCLA and Caltech demonstrated how altering nanoscale wires from a smooth surface to a jagged one could dramatically reduce the amount of precious metal used as fuel cell catalysts.[69]
- Researchers at Sandia National Laboratories patented a polyphenyline membrane for PEM fuel cells that operates over a wide temperature range and lasts three times longer than comparable commercial products.
- Researchers at Stanford University developed solar cells that, after electrolysis, capture and store 30 percent of the energy from sunlight into stored hydrogen.[70]

Important areas for additional R&D include:

- Additional reductions in catalyst material costs for MEAs for low temperature fuel cell and electrolyzer systems, while maintaining durability over time.
- Optimized porous transport layers for electrolyzers to enable high current density and high catalyst utilization.
- Improved membranes for high efficiency and durability over a range of operating conditions.

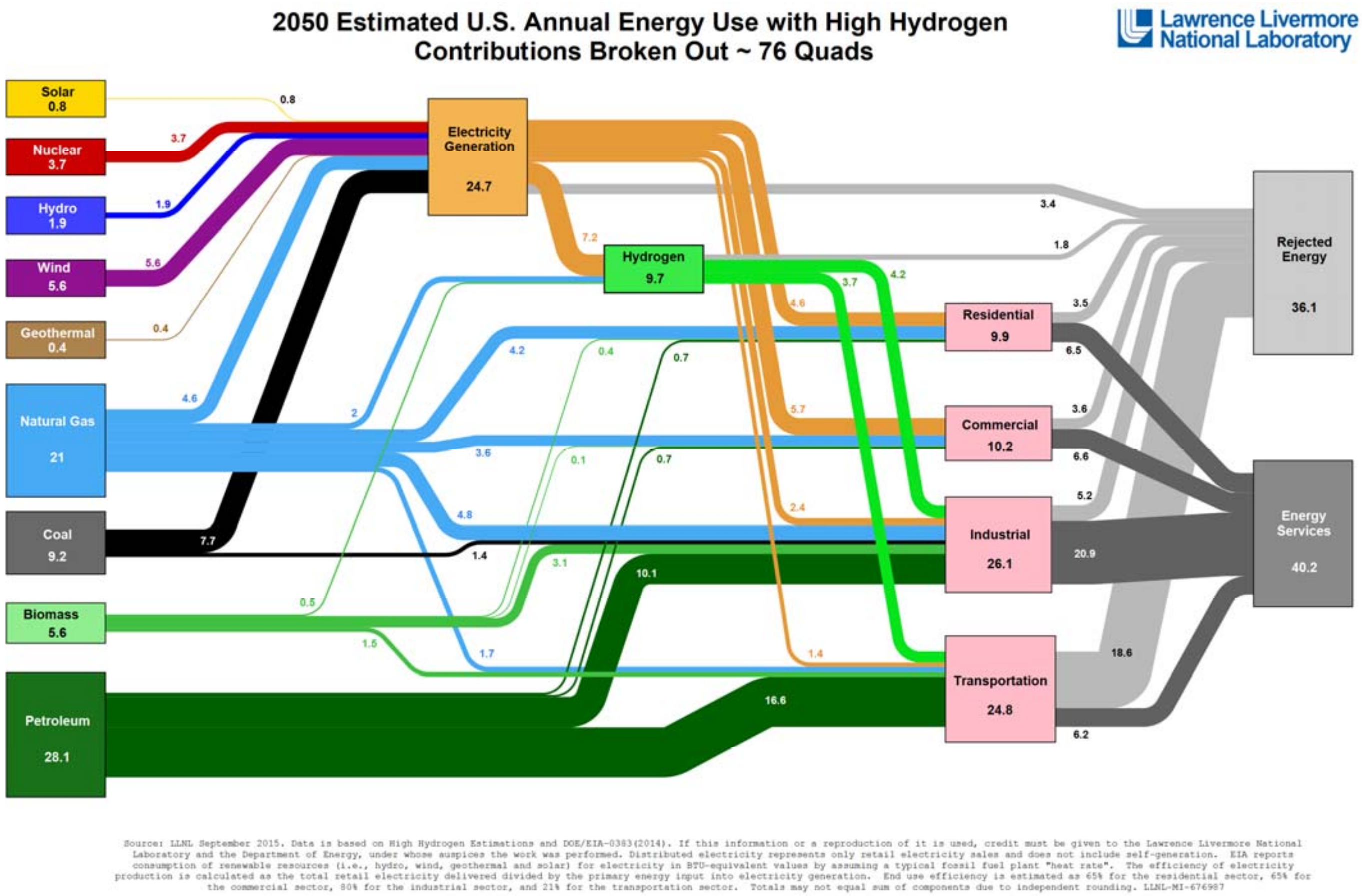


Figure 8: H2@Scale – Hydrogen Enables Diverse Feedstocks and Applications. *Source: U.S. Department of Energy*

- Better system integration and reduced component costs for lowered balance-of-plant costs.
- Improvements in manufacturing processes and yield rates for electrolyzer and fuel cell stacks and systems.
- Reduced component costs, improved compressors, and improved metering/metrology for hydrogen refueling.
- Improved and simpler systems for continuous monitoring of impurities and contaminants in hydrogen and reformate gas streams, with lowered costs.

Figure 9 presents the current cost and durability status and targets for various fuel cell market sectors.

Studies and Reports

Key reports were released in 2016 include:

- The DOE's *2015 Fuel Cell Technologies Market Report*[71]
- The DOE's *State of the States: Fuel Cells in America 2016*[72]
- The National Renewable Energy Laboratory (NREL)'s *Fuel Cell Buses In U.S. Transit Fleets: Current Status 2016*[73]
- California's *2016 ZEV Action Plan*[74]
- The California Air Resource Board's *2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*[75]
- The California Fuel Cell Partnership's *Medium & Heavy-Duty Fuel Cell Electric Truck Action Plan for California*[76]
- The Northeast Electrochemical Energy Storage Cluster (NEESC) analysis *Economic Impact of the Northeast Hydrogen and Fuel Cell Industry*[77]
- The Fuel Cell and Hydrogen Energy Association's *2015 State Policy Activity Wrap Up: Fuel Cells & Hydrogen*[78]

Federal R&D Budget

U.S. government support for hydrogen and fuel cell technology development efforts has remained relatively constant in recent years, with $101 million in funding allocated for FY 2017 for the Fuel Cell Technologies Office, about the same as in FY 2016. However, this is approximately $100 million lower than the historical peak funding level of over $200 million.

Budget details are shown in Figure 10.

Fuel Cell Type	Cost & Durability Status[a]	Cost and Durability Target[a]
Backup Power (direct hydrogen, 1-10 kW)	$6,100/kilowatt (kW) 8,000 hours (h)	$1,000/kW 10,000 h
Medium Scale CHP (natural gas, 100 kW – 3 MW)	$1,200 - 4,500/kW 40,000-80,000 h	$1,000/kW 80,000 h
APUs (diesel, 1-10 kW, system)	$2,100/kW 3,000 h	$1,000/kW 20,000 h
Buses	$800,000 +20,000 h	$600,000 25,000 h
Automotive (direct hydrogen, 80 kW, system)	~$53/kW 4,100 h (on road)[b]	$30/kW ($40/kW by 2020) 8,000 h
Portable Power (100 – 200 watts)	$15/watt 2,000 h	$5/kW 5,000 h

[a] Unless otherwise noted, all data is from the U.S. DOE, Fuel Cell technologies Office, Multi-Year Research, Development and Demonstration Plan, 2016 Fuel Cells section, https://energy.gov/sites/prod/files/2016/10/f33/fcto_myrdd_fuel_cells.pdf.

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Figure 9: Cost and Durability Status and Targets for Various Fuel Cell Market Sectors.

Hydrogen & Fuel Cells Budget

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
Fuel Cell Technologies Office | 1

Key Activity	FY 15	FY 16	FY17
	($ in thousands)		
	Approp.	Approp.	Enacted
Fuel Cell R&D	33,000	35,000	32,000
Hydrogen Fuel R&D[1]	35,200	41,050	41,000[1]
Manufacturing R&D	3,000	3,000	-
Systems Analysis	3,000	3,000	3,000
Technology Validation	11,000	7,000	-
Safety, Codes and Standards	7,000	7,000	7,000
Market Transformation	3,000	3,000	-
Technology Acceleration[2]	0	0	18,000[2]
NREL Site-wide Facilities Support	1,800	1,900	N/A
Total	97,000	100,950	101,000

Office	FY 2016
EERE	$101.0M
Basic Science	$24.7M
Fossil Energy, SOFC	$30.0M

FY 2016 DOE Total: ~$156M

New in FY17

1 Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

2 Combines Manufacturing R&D, Technology Validation, and Market Transformation

Figure 10: Recent DOE Funding for Hydrogen and Fuel Cells R&D. *Source: U.S. Department of Energy, Fuel Cell Technologies Office*

Conclusion

Fuel cell and hydrogen technologies continue to show progress and the overall outlook is promising. Fuel cells are making inroads in a variety of applications, including stationary, backup, off-grid and portable power, and in motive applications such as light- and heavy-duty vehicles, material handling, rail and unmanned systems. Hydrogen and fuel cell technologies are recognized as important solutions in providing grid support, in storing energy, and in delivering reliable and efficient, low emission power generation.

The expiration of the 30 percent ITC and FCEV tax credits, however, represent a significant risk to continued market development.

There is a worldwide race to foster fuel cell commercialization. Governments in Asia and Europe are supporting RD&D and early commercial deployment. China is fast becoming the leader in fuel cell buses. Japan's national energy strategy assigns hydrogen the central role, in partnership with renewable and advanced combustion systems.

Fuel cells are commercial today in some applications but like every game changing technology, early units are expensive. Where fuel cells may not yet be economical, for many individual applications, the technology offers more value streams than competitors. These include:

- Transportation applications: FCEVs offer the sustainable operation and rapid acceleration of other electric vehicles, but with faster refueling times and longer driving range.
- Electric grid support: Fuel cell systems offer clean, reliable distributed power, important in areas where local air quality is an issue, and can also provide various grades of waste heat and enhanced power reliability for host sites.
- Energy storage: Hydrogen can provide long-duration energy storage, which will be important in maximizing the benefits of high-penetration renewable energy systems.
- Natural gas system utilization and support: Fuel cell power generation overwhelmingly uses natural gas today but has the greatest fuel flexibility of any generating technology. Power-to-hydrogen and power-to-methane can utilize stranded intermittent renewable energy to supplement local natural gas-based fuel supplies.
- Industrial applications: Hydrogen is widely used today in industrial settings, but there are opportunities to expand the use of hydrogen for chemical manufacture, ammonia production, metals production and processing, enhancement of liquid fuels, and to take advantage of hydrogen produced as a co-product of industrial processes such as chlor-alkali production.

Commercializing fuel cells carries a big payoff in job growth, economic activity, competitiveness, and energy security. Fuel cell and hydrogen intellectual property originated in the United States and the U.S. has been the global leader in technology development. If the U.S. is to maintain its leadership, investment and innovation will be needed until the technologies and manufacturing capability have become more mature and established.

Evidence suggests that the U.S. is still not on track to meet the 2020 goals for hydrogen FCEVs and refueling infrastructure set by the U.S. Energy Policy Act of 2005 (EPACT) Title VIII. In response to the Committee's 2016 recommendation, DOE committed to developing a paper outlining efforts underway to work toward those goals.

The Committee re-asserts the need for an explicit plan to be provided in 2017 showing the pathway for achieving the 2020 EPACT Title VIII goals "endgame" for hydrogen and fuel cell technologies, with benchmarks and milestones required to reach this point. Achieving these goals will carry substantial benefits to American workers and industries and contribute to the Administration's jobs, infrastructure, and American manufacturing vision.

The Administration's 2018 budget blueprint stresses basic science and limited, early applied energy R&D activities. While the Committee supports early stage R&D, there is a critical need to continue efforts in material and process integration and technology acceleration in order to meet EPACT 2020 goals and to maintain U.S. competitiveness, and to meet competition from offshore companies and governments.

In conclusion, much progress is being made, but greater momentum is needed for these technologies to provide the benefits they are capable of in 2020 and beyond.

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POWER ELECTRONICS IN SMART GRID SYSTEMS

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Power electronics in smart grid distribution power systems: a review

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Abstract: Distributed generation (DG) in smart grid (SG) is being employed as a means of achieving increased reliability for electrical power systems as regarded by consumers. As the most of DG technologies utilise renewable sources, the power electronic interface plays a vital role to match the characteristics of a DG unit with the grid requirements. This paper presents the power electronics capabilities required for DG systems in SG to convert the generated power into useful power that can be directly interconnected with the utility grid and/or that can be used for consumer applications. Because of the enhancement and the different power ranges of power electronics devices, the development of advanced power electronic interface that is scalable to meet different power requirements, with modular design, lower cost, and improved reliability, will improve the overall performance and durability of smart grid distributed power systems.

Keywords: power electronics; smart grid; distribution generation; fuel cell systems; battery storage systems; flywheel storage systems; plug-in vehicles.

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Biographical notes: Ehab H.E. Bayoumi received his BS from the Helwan University and MS from the Ain Shams University, Egypt in 1988 and 1996, respectively. He received his PhD from the Cairo University, Egypt in collaboration with Lappeenranta University of Technology (LUT), Finland in 2001. He has been with Electronic Research Institute (ERI) Egypt since 1990. From 2000 to 2001, he joined LUT, Finland as a Visiting Researcher. He was appointed as an Assistant Professor at the Chalmers University of Technology (CTH), Sweden from 2003 to 2005. He is a Professor at the ERI, Egypt, and currently on leave to Abu Dhabi Men's College (ADMC), United Arab Emirates. His research interests include high performance ac machines, power quality, switching power converters, DSP-based control applications, and nonlinear control applications in power electronics and electric drive systems.

1 Introduction

Traditional power systems employ large power generation plants situated geographically and supply most of the power that is then transmitted to large consumption centres and then distributed between different customers. This composition has started to alter towards new scenarios at which distributed generation (DG) units are spread over distribution networks. These DGs utilise renewable resources such as wind turbines, photovoltaics, fuel cells, biomass, small hydro-plants…, etc. Beside their environmental benefits, DGs present a cheap way into market since they do not suffer vast transmission losses and the excess heat may be handled in useful purposes such as water heating (Al-Nasseri and Redfern, 2007; Anderson et al., 2011; Aquino-Lugo and Overbye, 2010; Atwa et al., 2010). Moreover, they present reliable and uninterruptible source for the customers (Anderson et al., 2011). The main disadvantage of applying renewable sources, beside the high capital cost, is the daily and seasonal pattern of the energy. However, due to the advances in power electronics (PEs), which plays a vital role to match the characteristics of the DG units and the requirements of the grid connection, a large number of DG is being established in the distribution level (Aquino-Lugo and Overbye, 2010). Furthermore, a common case where DG is efficient and economical occurs when it helps to supply load during contingencies until the utility can build additional delivery capacity (Atwa et al., 2010).

The distribution system consists of a network of feeders from the substation to the customers' metres. The first enhancement for the distribution system is installation of the smart metres. Smart metres have either one- or two-way communications with the electric control, metering, and billing network. These metres can also communicate with each other passing on metering data, billing data, and information for the implementation of automatic demand response and self-healing switching as needed (Borghetti et al., 2011; Bose, 2010; Ghosn et al., 2010; Bu et al., 2011; Calderaro et al., 2011).

The smart distribution system can be implemented in several ways. They can consist of micro grids, which are companies or communities that are connected to the main utility but are able to operate on their own with their own generation capabilities. Feeder networks could also be connected to several substations to automatically detect and isolate troubled areas and reroute power from alternate sources to minimise customer outages. This rerouting of power can also take place to maximise the efficiency of power flowing through specific paths increasing reliability. Or the feeders can stay as they are using data and automatic demand response to minimise the likelihood of equipment failures (Caron and Kesidis, 2010; Chen et al., 2009, 2010; Coll-Mayor et al., 2007; Colson and Nehrir, 2009; Deep et al., 2009; Efthymiou and Kalogridis, 2010; Forner et al., 2010; Godfrey et al., 2010).

Distributed automation and DG are two other aspects of the SG implementation in the distribution network. Distributed automation consists of monitoring, control and communications. This is the system used to control switches and other devices throughout the grid rerouting power and reconfiguring the grid to restore portions of the troubled areas, avoid additional failures, and minimise losses. DG is achieved by the interconnection of generators from various resources scattered throughout the distribution system injecting power back into the system. With the addition of solar panels, electric vehicles (EVs), fuel cells, stand-alone generators, private wind generators, bio-fuel generators and other ways of locally generating electrical energy, the customers will have multiple choices to produce electricity for local usage as well as for export to the grid. The smart grid (SG) has to allow for safe and reliable interconnection of DG from various renewable resources. However, to ensure safety and reliability, protection and schemes for various configurations at various DG penetration levels must be considered and analysed. This includes load forecasting and control to utilise storage equipment in addition to DG, which randomly fluctuates based on conditions, for optimal power flow through the distribution network (Hajimiragha et al., 2010; Moslehi and Kumar, 2010; Parvania and Fotuhi-Firuzabad, 2010; Sauter and Lobashov, 2011; Vandoorn et al., 2011; Wang et al., 2010; Steimer, 2010; Spagnuolo et al., 2010; Suntio et al., 2010; Brunton et al., 2010; Bayoumi, 20015a, 2015b, 2015b; Shen et al., 2009; Bragard et al., 2010; Sterner, 2010; Sannino, 2009; Hamed et al., 2015).

Furthermore, DG systems in SG are receiving increased attention today because of their ability to provide combined heat and power, peak power, demand reduction, backup power, improved power quality, and ancillary services to the power grid. PEs are the integral part of most of the DG technologies, in order to convert the power generated into useful power that can be directly used on the grid, they can cost up to 40% of the costs of a distributed energy (DE) system (Bayoumi, 2015b). Therefore, the improvement of the DG economics strongly requires decreased costs for the PEs. Another important aspect to the life-cycle cost of the DG systems is reliability. Many of the PEs used for DG applications have a low reliability rate, typically operating less than five years before a failure occurs. This rate can be improved with modern reliability testing techniques and needs to be fully examined to improve the economics of DG systems. This objective is accomplished through:

- Developing an architecture for standardised, highly integrated, modularised PEs interconnection technologies that will come as close as possible to 'plug-and play' for DG in SG platforms.
- Reducing costs and improving the reliability for DE and interconnections by developing standardised, high production volume PE modules.
- Improving the flexibility and scalability for PE modules and systems to provide advanced functionality at a range of power levels.

There are many DG systems in the SG distribution systems, generally we can select six application-specific areas:

1 photovoltaic systems
2 wind systems
3 fuel cell systems
4 battery storage systems
5 flywheel storage systems
6 plug-in vehicles.

In Bayoumi (2015b), the first two areas have been discussed in details. The other four areas (fuel cell systems, battery storage systems, flywheel storage systems and plug-in vehicles) are introduced, discussed and demonstrated in this paper.

2 Fuel cells

2.1 General description

Fuel cells that are currently being developed can be used as possible substitutes for the internal combustion engine in vehicles as well as in stationary applications for power generation. A fuel cell is an electro-chemical device which produces electricity without any intermediate power conversion stage. The most significant advantages of fuel cells are low emission of greenhouse gases and high power density. The energy density of a typical fuel cell is 200 Wh/l, which is nearly ten times that of a battery (Xu et al., 2004; Kirubakaran et al., 2011). The efficiency of a fuel cell is also high, in the range of 40% to 60%. If the waste heat generated by the fuel cell is used for cogeneration, the overall efficiency of such a system could be as high as 80% (Kirubakaran et al., 2011).

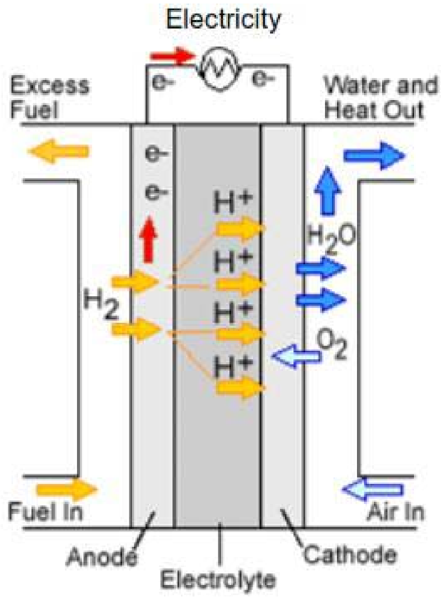
Fuel cells can be classified into five different categories based on the electrolyte chemistry: proton exchange membrane fuel cell (PEMFC); solid oxide fuel cell; molten carbonate fuel cell; phosphoric acid fuel cell; and aqueous alkaline fuel cell. In these kinds of fuel cells, PEMFCs are being rapidly developed as the primary power source in movable power supplies and DG, because of their high energy density, low working temperature, and firm and Fuel cells can be classified into five different categories based on the electrolyte chemistry: PEMFC; solid oxide fuel cell; molten carbonate fuel cell; phosphoric acid fuel cell; and aqueous alkaline fuel cell. In these kinds of fuel cells, PEMFCs are being rapidly developed as the primary power source in movable power supplies and DG, because of their high energy density, low working temperature, and firm and simple structure (Stanton and Lai, 2005; Bayoumi, 2012, 2014a, 2014b, 2014d; Bayoumi and Salmeen, 2014b). Table 1 provides a summary of various fuel cell types and corresponding characteristics.

Table 1 Summary of typical fuel characteristics for DE applications

Electrolyte material	*Operating temperature (warm up time)*	*Anticipated applications*	*Comments*
Proton exchange membrane (PEMFC)	80°C (relatively short)	Stationary and vehicle	Minimum contamination and material problem
Alkaline (AFC)	Approximately 100°C (relatively short)	Space program	Susceptible to contamination, very expensive
Phosphoric acid (PAFC)	Approximately 100°C (medium)	Stationary	High temperature and longer warm up time makes unsuitable for vehicles.
Solid oxide (SOFC)	1,000°C (long)	Stationary	High temperature create material problems, steam generation could increase efficiency by cogeneration
Molten carbonate (MCFC)	600°C (long)	Stationary	Same as SOFC

For the PEM type of fuel cell, hydrogen and oxygen gas are fed into the fuel cell. The fuel cell *anode* – a negative connection that conducts electrons those are freed from pressurised hydrogen molecules – typically has etched channels that uniformly distribute the pressurised hydrogen gas over the surface of a catalyst. The *cathode* is the positive connection of the fuel cell that carries electrons back from the external circuit to the catalyst, where it combines with hydrogen ions and oxygen, forming the water that is the by-product of the fuel cell. The electrolyte is the proton exchange membrane (PEM), a specially treated material that allows the conduction of positively charged ions while not allowing electrons to pass through it. There is a catalyst material that facilitates the reaction of oxygen and hydrogen. The catalyst is usually made of a platinum powder coated on a carbon paper or cloth. The catalyst is porous to maximise the surface area that can be exposed to the hydrogen and oxygen. The platinum coated side of the catalyst faces the electrolyte. Figure 1 shows a graphic of a PEMFC. The reaction described takes place in one cell, resulting in approximately 0.7 volts cell potential. Multiple cells can be placed in series, often called as a stack, to increase the DC voltage output.

Figure 1 Proton exchange membrane fuel cell (see online version for colours)



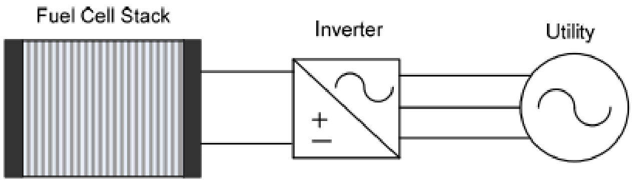
A number of engineering problems need to be overcome before PEMFCs can be widely adopted for stationary power purposes. Most of these systems use expensive materials and have a low mean time before failure (O'Garra et al., 2005; Haraldsson et al., 2006; Thesan and Langhelle, 2008). The use of impure hydrogen causes the deterioration of electrolyte and catalyst materials, which can lead to replacement of the entire fuel cell after limited operation. One of the biggest technical barriers to widespread adoption of PEMFCs is the development of safe hydrogen distribution and storage systems. Hydrogen has a low energy/volume ratio compared to other fuels. Innovative research is being conducted to obtain and store hydrogen such as wind-electrolysis, thermo-chemical production, chemical hydride storage, etc. (Thesan and Langhelle, 2008).

2.2 *Fuel cell system configurations*

Fuel cells are similar to PV systems in that they produce DC power. Power conditioning systems, including inverters and DC-DC converters, are often required in order to supply normal customer load demand or send electricity into the grid.

The simplest form of fuel system configuration, as shown in Figure 2, consists of a fuel system stack followed by the DC-AC converter. If the isolation or a high ratio of the voltage conversion is required, a transformer is usually integrated into the system. The main drawback for this configuration is that the low-frequency transformer placed at the output of the inverter makes the system very bulky and expensive (Palsson et al., 2000; Costamagna et al., 2001; Bayoumi et al., 2001, 2002; Selimovic and Palsson, 2002; Alcaide et al., 2006; Pillai et al., 2008; Maamoun et al., 2002).

Figure 2 Fuel cell system configuration with a single inverter



A DC-DC converter is usually put between the fuel cell and the inverter, as shown in Figure 3. The DC-DC converter performs two functions:

1 It acts as the DC isolation for the inverter.

2 It produces sufficient voltage for the inverter input so that the required magnitude of the AC voltage can be produced (Maamoun et al., 2002). The inverter can be single-phase or three-phase depending on the utility connection.

Figure 3 Fuel cell configuration with cascade DC-DC and DC-AC converter

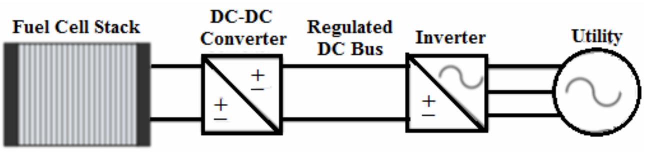
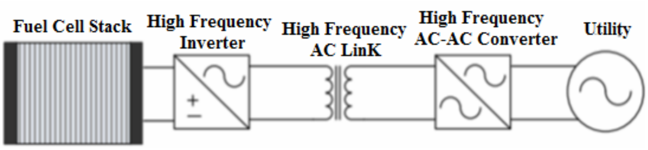


Figure 4 Fuel cell system configuration with cascaded DC-AC and AC-AC converter

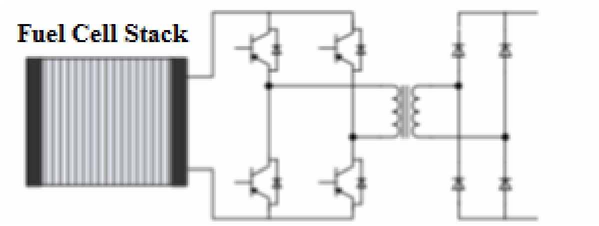


Another possible configuration of the system includes a high-frequency DC-AC inverter which converts the fuel cell DC voltage into a high-frequency AC voltage. A cycloconverter is then used to change the high-frequency voltage into a power-frequency AC voltage, as shown in Figure 4 (Maamoun et al., 2002). This way, the power conversion is more direct than with a conventional DC bus structure with an isolated DC-DC converter. Moreover, the topology supports bidirectional power flow and is suitable for power conditioning systems that double as active filters (Bayoumi et al., 2001). This topology is more relevant for the single-phase utility connection.

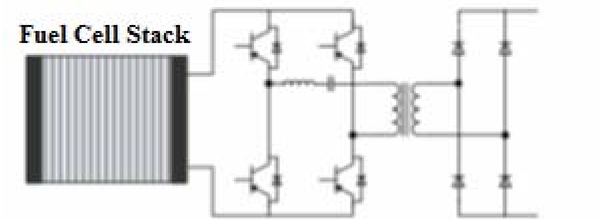
2.3 *PEs topologies*

The PEs topologies for fuel cell systems are varied and are based on the number and types of cascaded stages in the conversion systems. Two such topologies that can be used with fuel cells for supplying consumer loads and for utility connection include cascaded DC-DC and DC-AC converters (DC-link) and cascaded DC-AC and AC-AC converters (high-frequency link). There are also many recently developed and/or proposed circuit configurations for fuel cell applications, including a Z-source converter that combines functionality of DC-DC boost and voltage-source inverter (VSI) (Bayoumi et al., 2001).

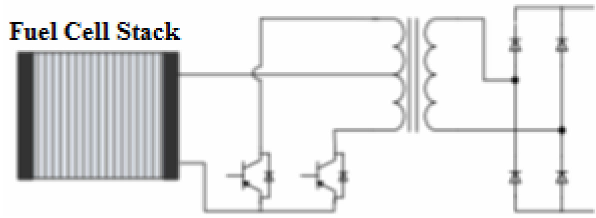
Figure 5 Isolated DC-DC converters, (a) H-bridge (b) series-resonant H-bridge (c) push-pull



(a)



(b)

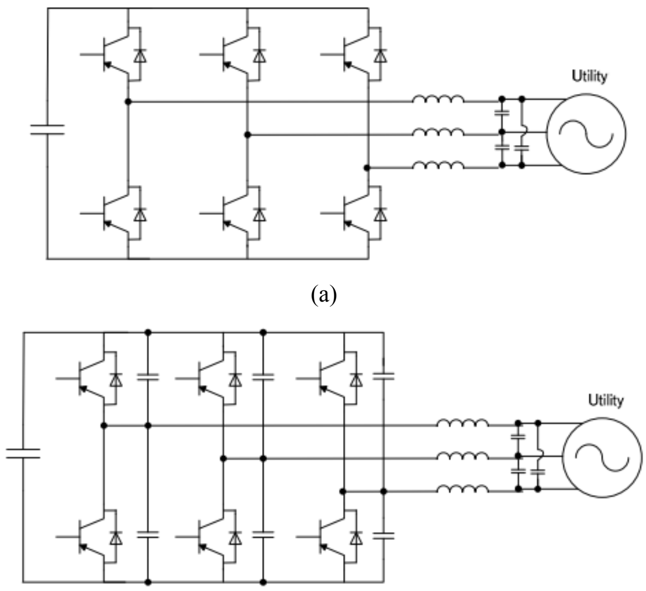


(c)

2.3.1 *Cascaded DC-DC and DC-AC converters (DC-link)*

Many topologies can be used for DC-DC converters and DC-AC inverters, including hard-switching and soft-switching circuits (Pillai et al., 2008; Maamoun et al. 2002; Bayoumi et al., 2001). The classical DC-DC converter, the H-bridge type forward converter shown in Figure 5(a), is a well-developed and proven technology. However, in order to reduce the switching loss, soft-switching PE such as the H-bridge series-resonant converter shown in Figure 5(b) can be used. Whereas the hard-switching forward converter requires a very accurate bi-polar waveform or current mode control to prevent the transformer from experiencing saturation and causing extra losses (Bayoumi, 2015b), the main advantages of the resonant converter are its inherited short-circuit protection and the fact that the transformer has no saturation problems. Figure 5(c) shows a push-pull type of a DC-DC converter, which requires the high DC voltage and current. The diode rectifier bridges shown in Figure 5 can also be replaced with half bridge diode rectifiers (Bayoumi et al., 2001).

Figure 6 Three-phase inverters, (a) hand-switching inverter (b) RPLI



Various three-phase inverters can be used for three-phase utility connections. Figure 6 shows two popular inverter topologies for fuel cell applications. The hard-switching three-phase VSI, as shown in Figure 6(a), is well proven design and the converter is widely used in industrial applications; however, it suffers from switching loss (Bayoumi et al., 2001). The resonant-phase leg inverter (RPLI) is shown in Figure 6(b) and is an improvement to the hard-switching inverter with zero-voltage switching (Bayoumi, 2015b). A modified variable-frequency modulation can further improve the soft-switching range. The active clamp resonant DC-link inverter (ACRDI) is an improvement to the classical resonant DC-link inverter where the DC-link voltage is twice as high as the original DC-link voltage. After using additional clamping devices, the DC-link voltage can be controlled to 1.3 times of the input voltage. However, only the delta modulation method can be used, causing some reliability issues (Bayoumi et al., 2001).

A power conditioning system for a fuel cell with a DC-DC converter and a DC-AC inverter can be constructed with a combination of the converters discussed above. An example of a fuel cell system with PEs interfacing into a three-phase utility system is shown in Figure 7, where an isolated DC-DC bridge converter and a three-phase hard switching VSI are used.

2.3.2 *Cascaded DC-AC and AC-AC converters (high frequency link)*

For residential power systems, a medium power fuel cell is used. This application can use a compact DC-AC converter with required galvanic isolation. The high-frequency link power conversion technique is attractive for this application because a high-frequency link direct DC-AC converter which consists of a high-frequency inverter, a cycloconverter, and a high-frequency transformer between them provides a possible way to build a compact direct DC-to-AC converter without the DC-link capacitor. The advantage of this approach provides a high power conversion efficiency due to the reduced number of conversion steps (Pelly, 1971). High-frequency-based PE topologies are mainly used in single-phase systems. Three-phase cycloconverters require a large number of devices, which results in higher costs, more switching losses, and increased system complexity.

Figure 7 Cascaded DC-DC and DC-AC converter topology with DC-link

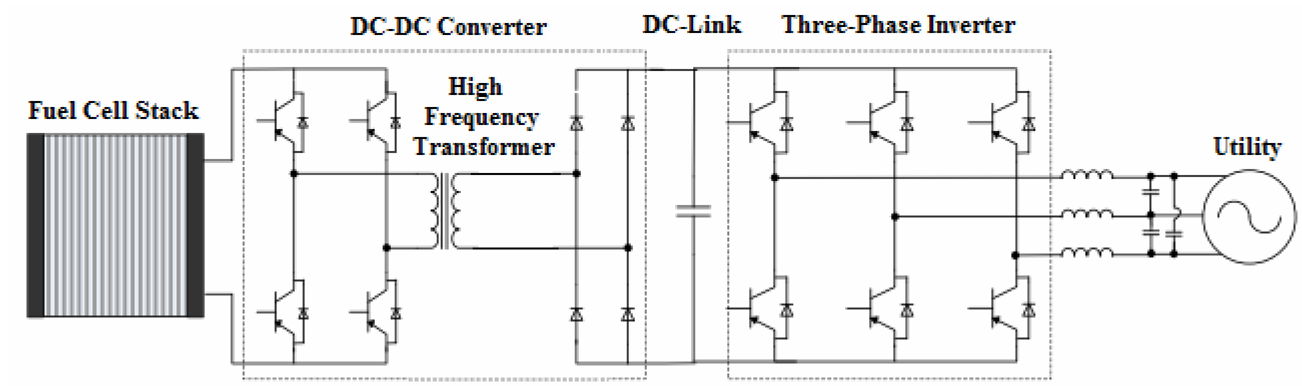
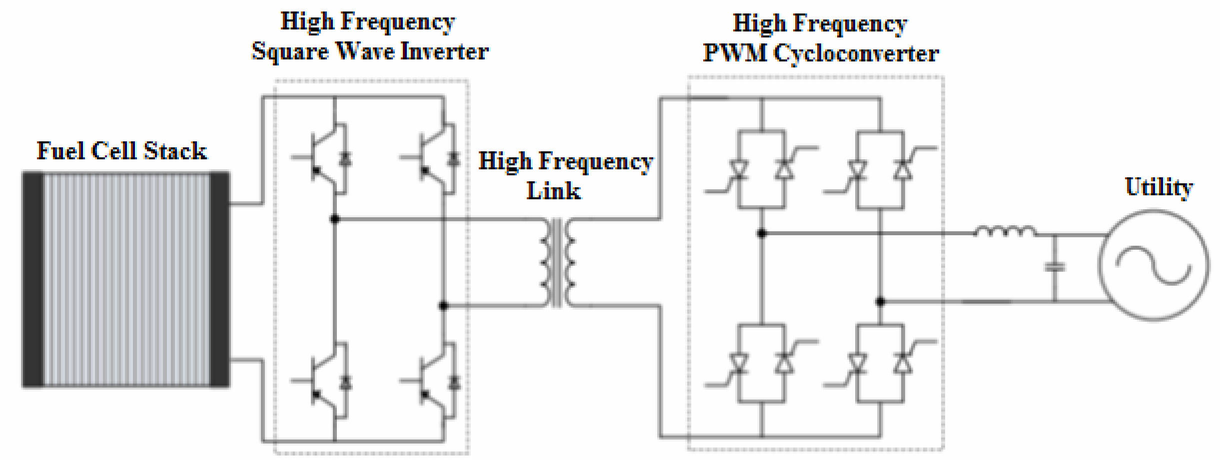


Figure 8 Cascaded DC-AC and AC-AC converter topology with high frequency link



The conventional cascade topology, as described in the previous subsection, is a DC-DC forward converter with a DC-AC inverter. This configuration actually has three stages of power conversion: DC-AC in the forward converter primary, DC in the rectification for the DC bus, and then DC-AC in the inverter. The cascaded conversion would appear to have redundancy, especially since the topology adds a DC bus that must be filtered. A few topologies exist for cascaded DC-AC and AC-AC cycloconverter for the fuel cell applications (Pelly, 1971; Li et al., 1998; Ozpineci and Bose, 1998; Bayoumi, 2003, 2004a). In the future, the possibility of using matrix converters as the AC frequency changer will probably introduce more high-frequency link topologies for the fuel cell systems.

One high-frequency topology for the fuel cell system is shown in Figure 8. In this circuit, the forward converter is replaced with a simple square-wave inverter that produces a high-frequency link at the transformer. The internal rectifiers and DC bus filtering have been eliminated; the output inverter is replaced with an AC-AC converter that processes the high-frequency link and delivers the AC at utility frequency. The PWM cycloconverter concept is used for the control of an AC-AC converter which reduces some of the complexities of cycloconverter control (Li et al., 1998; Ozpineci and Bose, 1998; Bayoumi, 2003, 2004a).

2.4 Generalised PEs circuit and control

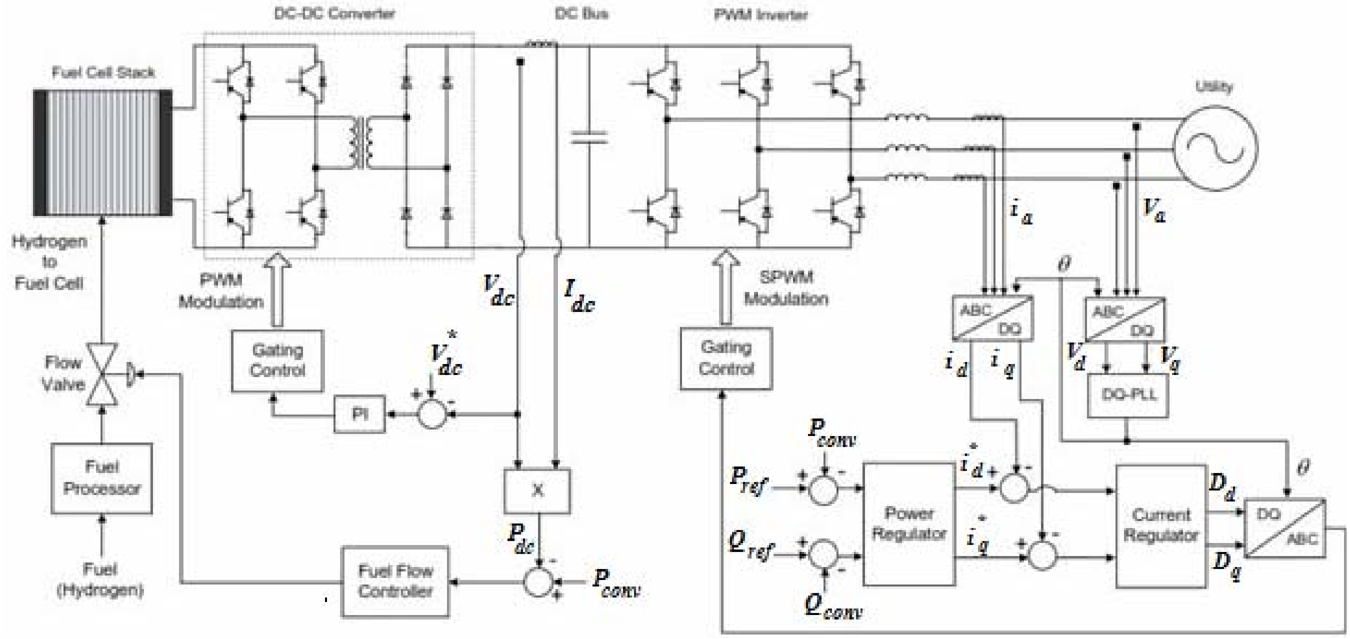
From the discussion in the previous subsections, it can be observed that the most generalised form of PEs topology for the fuel cell system is the DC-DC converter with an embedded high-frequency transformer and the DC-AC inverter as shown in Figure 8. In general, the voltage boost and isolation are done by the DC-DC converter. The power flow control to the utility, as well as the sinusoidal unity power factor current injection into the utility, is obtained by the DC-AC inverter controller. A simplified block diagram of the PEM fuel cell system with the PEs and control is given in Figure 9.

The PEM fuel cell uses hydrogen as input fuel and produces DC power at the output of the stack. The performance of the stack is expressed by the polarisation curve, giving the relation between stack terminal voltage and load current. The cell voltage decreases almost linearly as the load current increases. Therefore, the output voltage should be regulated at a desired value. To keep the polarisation characteristic at a constant level, additional parameters such as cell temperature, air pressure, oxygen partial pressure, and membrane humidity also need to be controlled (Selimovic and Palsson, 2002).

The control of a utility connected inverter, as shown in Figure 9, is developed with constant power control (Selimovic and Palsson, 2002). The controller works similarly as described in the photovoltaics section of this report. The power loops are on the outer level of the current loops, and in some cases, the reactive power reference Qref could be a power factor reference. By controlling this reference, the injected current to the utility can be maintained at unity power factor. The output of the control system is the high-frequency sine PWM signals for the VSI switches.

When the active power reference is increased, drawing more power from the fuel cell with constant hydrogen flow rate reduces the fuel cell output voltage, which in turn decreases the DC bus voltage (Bayoumi, 2004a). The DC-link voltage regulator tries to maintain the constant DC-voltage by changing the PWM switching pattern of the single-phase high-frequency inverter embedded in the DC-DC converter. For the steady state power adjustment, power changes must be followed by a proper hydrogen flow rate control as shown in Figure 9. It is important to remember that the response of the fuel cell is much slower than electric load response, especially when the load power changes abruptly. The chemical reaction of the PEMFC cannot keep up with the fast changes of the load demand. The use of PEs converters mitigates this problem to some extent. Employing high-power density ultra-capacitors (UC) and/or battery storage system is required in some cases, especially when the fuel cell is used for supplying power in the islanded mode to some local loads.

Figure 9 Generalised PEs and control of a PEM fuel cell system



3 Battery storage

3.1 General description

To optimise the SG's efficiency, the largest system generators need to be operated at rated capacity at all times. These generation systems are also referred to as base loaded plants and include large hydroelectric, nuclear, and coal fired plants. During a typical daily cycle, customer usage of the grid fluctuates. At times of heavy usage, or peak-loading, additional low-efficiency utility generators (oil or gas-fired generators) are added to the grid in order to support the increased load. These low-efficiency generators are expensive to operate due to high fuel costs. Several energy storage systems are under consideration to harness excess electricity produced by the most efficient utility generators during low loading. This harvested energy can be released onto the grid, when needed, to eliminate the need for high-cost generators. Inclusion of storage in the DG system actually provides the user dispatch capability of its distributed resources, which generally are renewable energy sources like PV and solar, having no dispatchability on their own. During periods of low demand, excess generation can be used to charge an energy storage device. The stored energy can then be used to provide electricity during periods of high demand (Zhang et al., 2010; Hopkins et al., 2012; Meliopoulos et al., 2011; Bracale et al., 2011).

There are a variety of technologies that can be used to store energy on the SG power system, including: lead-acid, nickel-electrode, and sodium-sulphur modular batteries; zinc-bromine, vanadium redox, and polysulfide-bromide flow batteries; superconducting magnetic energy storage (SMES); flywheels; electrochemical capacitors (ultracaps); compressed air energy storage (CAES); pumped hydro; and production and storage of gases such as hydrogen (to run fuel cells or hydrogen IC engines) (compressed air energy storage and Salem, 2012). Of these technologies, batteries and flywheels are commonly integrated at the distribution system level and are commercially available (Carrasco et al., 2006; Schainker, 2004; Sun et al., 2011; Barton and Infield, 2004; Hussein et al., 2010; Cimuca et al., 2006, 2010; Wadi et al., 2004; Bayoumi, 2004b; Soliman et al., 2008; Awadallah et al., 2009).

The emphasis of this section will be on energy storage in batteries and some prevalent grid-tied interconnections that can be used to maximise system efficiency. Battery banks connected to the grid are generally either lead-acid or flow batteries. Lead-acid batteries consist of electrodes of lead metal and lead oxide immersed in an electrolyte consisting of 35% (by weight) sulphuric acid in water. This electrolyte solution produces electrons, creating energy flow through the external circuit (Sun et al., 2011).

Lead-acid batteries are the prevalent form of electrical energy storage in use today. They have a commercial history of well over a century, and are being applied in every area of the industrial systems, including: telecommunication, emergency power, and auxiliary power in stationary power plants. Because of their low cost and ready availability, lead-acid batteries always become the default choice for energy storage in new applications. This popularity comes despite many perceived disadvantages, including low specific energy (W-h/kg) and specific power (W/kg), short cycle life, high maintenance requirements, and environmental hazards (Schainker, 2004).

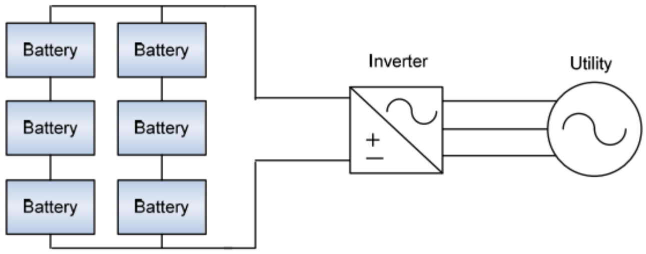
Deep-cycle batteries are designed to be discharged down as much as 80% time after time, with 85% to 95% efficiency. All lead-acid batteries supply about 2.14 V per cell (12.6 V to 12.8 V for a 12 volt battery) when fully charged. Flow batteries work in a similar fashion as lead-acid batteries, but the electrolyte is stored in external containers and circulated through the battery cell stack as required. This external reservoir of rechargeable electrolyte can be as large as needed and situated where convenient. Because of the high energy density and relatively low cost of zinc, rechargeable zinc battery technology has long been considered attractive for large-scale energy storage systems. Similarly, flow batteries are recognised as a favourable technology for large systems because they are eminently scalable and allow a great deal of flexibility in system design. The zinc-bromine flow battery is a combination of these two technologies, with significant potential for use in large scale utility applications (Sun et al., 2011). The vanadium redox battery (VRB) is also a flowing-electrolyte battery (or 'flow battery'). For flow batteries, aqueous liquid electrolyte is pumped from storage tanks through reaction stacks where chemical energy is converted to electrical energy (discharge), or electrical energy is converted to chemical energy (charge). There are a limited number of manufacturers of sodium sulphur (NaS) batteries for utility applications (Barton and Infield, 2004). There are also five common battery technologies that use the nickel-electrode: nickel-iron (NiFe), nickel-cadmium (NiCd), nickel-hydrogen (NiH_2), nickel-metal hydride (NiMH), and nickel-zinc (NiZn). Of these, NiCd, NiMH, and lithium ion are the most common and well-known for low voltage consumer electronics (Schainker, 2004; Sun et al., 2011; Barton and Infield, 2004; Hussein et al., 2010; Cimuca et al., 2006, 2010; Wadi et al., 2004; Bayoumi, 2004b; Soliman et al., 2008; Awadallah et al., 2009).

3.2 Battery storage system configurations

All of the battery technologies, discussed in the previous section, produce DC that must be converted to AC to connect to the utility. The individual battery cells are generally connected in different configurations in series and/or parallel to achieve the required voltage and current outputs. The power conditioning systems, including inverters and DC-DC converters, are often required for the battery energy storage systems (BESSs) in order to supply normal customer load demand or send electricity into the grid. The most unique aspect to PEs for energy storage is that they must be bidirectional, that is both taking power (during charging) and providing power (during discharge) from/to the SG. Unlike PV and fuel cell inverters, however, BESS inverters are not expected to consider the peak power operations. They only provide the power level demanded by the system that can be sustained by the battery (Sun et al., 2011).

The simplest form of BESS configuration, as shown in Figure 10, consists of a battery system followed by the DC-AC converter. If the isolation or a high ratio of the voltage conversion is required, a transformer is usually integrated into the system. The current at full operating power determines the rating of the inverter. The current, in turn, is dependent on the BESS voltage at full operating power, which varies substantially from no-load to full load, and is at its lowest level under full operating power. The main drawback for this configuration is that the low-frequency transformer placed at the output of the inverter makes the system very bulky and expensive (Schainker, 2004). The inverter can be of single-phase or three-phase depending on the SG connection.

Figure 10 BESS configuration with single inverter (see online version for colours)



A DC-DC converter is often used between the BESS and the inverter, as shown in Figure 11. The DC-DC converter must be bidirectional and is mainly utilised to produce sufficient voltage for the inverter input so that the required magnitude of the AC voltage can be generated (Schainker, 2004). Additionally, in some PE topologies, high-frequency transformers are used in DC-DC converters for galvanic isolation.

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Figure 11 BESS configuration with cascaded DC-DC and DC-AC converters (see online version for colours)

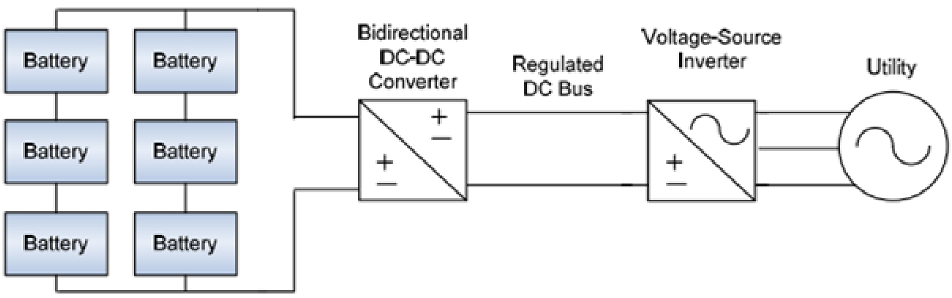


Figure 12 Hybrid system configuration with BESS and wind energy system (see online version for colours)

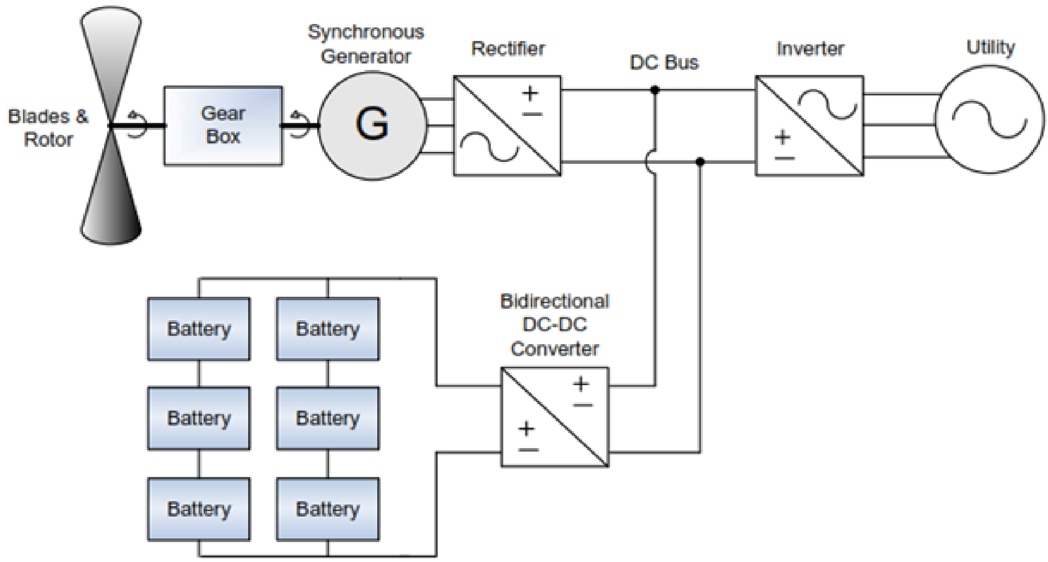
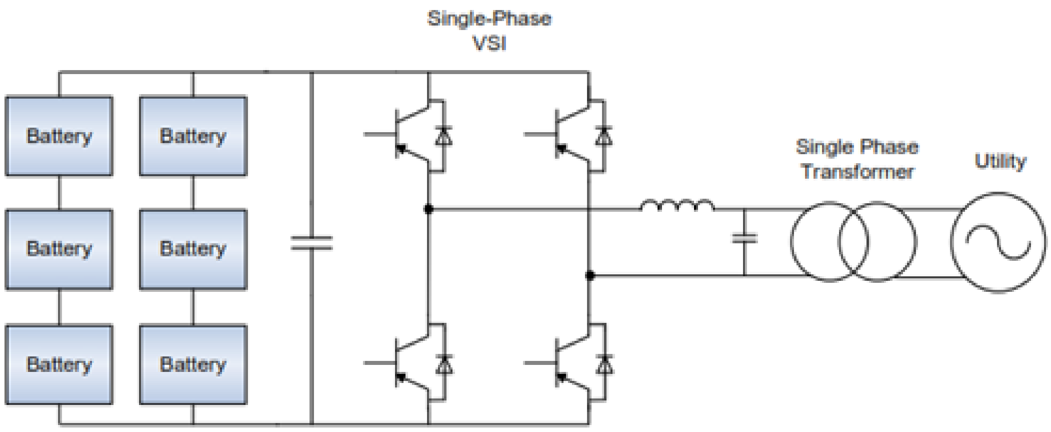
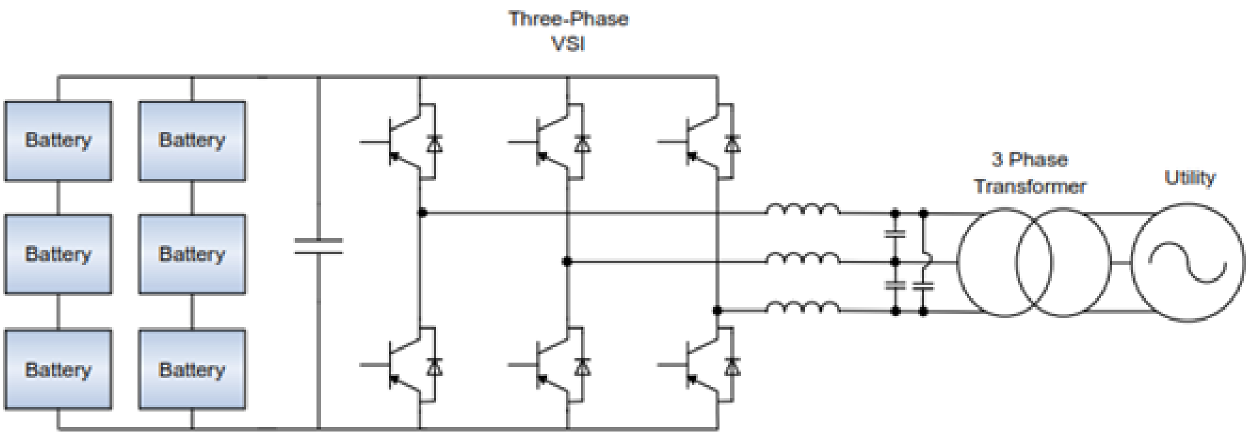


Figure 13 Single-stage PEs topologies, (a) single-phase inverter (b) three-phase inverter (see online version for colours)



(a)



(b)

Additionally, the battery storage system is very common to use with other types of energy sources in form of hybrid systems. When using with renewable sources, such as wind or PV, the BESS can offset the daily and seasonal intermittency of the primary energy, smooth-out load fluctuations, damp out utility transients, and facilitate islanding operation. In Figure 12, one such hybrid system is shown where the BESS is included in wind energy system. The battery is integrated into the DC bus of the wind system by using a bidirectional DC-DC converter. These hybrid systems can be of various types, depending on the primary source of energy and the type of BESS integration.

3.3 PEs topologies

The PEs topologies for the BESSs can be of different types based on the number of cascaded stages in the conversion systems, types of converters, presence of galvanic isolation, and utility connection.

The most fundamental topology for utility connection of the BESS is the single-stage, self-commutated VSI as shown in Figure 13. While the DC output of the battery system is connected across a filter capacitor, the capacitor itself is used to limit the harmonic currents in the battery.

The output of the capacitor connects to a VSI (Gabash and Pu, 2012; Jen-Hao et al., 2013; Seung et al., 2012; Manjunatha et al., 2013; Hill et al., 2013; Pellegrino et al., 2010). Depending on the utility connection, the inverter can be single-phase or three-phase. The output of the inverter is then connected to a low-pass filter to prevent high-frequency harmonics injected into the AC system. A synthesised AC-output voltage is produced by appropriately controlling the switches and consists of a controlled series of positive and negative pulses that correspond to the positive and negative half cycles of a sinusoid.

The most common two-stage topology for the BESS consists of a DC-AC grid-connected voltage source PWM inverter with a bidirectional DC-DC converter. The DC-AC full-bridge inverter controls the grid current by means of pulse width modulation (PWM), known as a ‘bang-bang’ operation. A simple design for a two-stage PEs topology, as shown in Figure 14, incorporates a full-bridge DC-DC converter that can operate with any voltage and current polarity. The voltage polarity and amplitude can be set irrespective of the current direction (Manjunatha et al., 2013).

All of the PEs topologies discussed before do not provide isolation. For utility connection, a line-frequency transformer is used for galvanic isolation. To avoid the bulky, low-frequency transformers (regarded as poor components mainly due to their relatively large size and low efficiency), several bidirectional isolated DC-DC converter topologies have been developed (Hill et al., 2013). Figure 15 provides galvanic isolation between the output terminals from the input terminals, and can step up and down its output voltage by using a high-frequency transformer.

Figure 14 Cascaded PEs topologies with DC-DC and DC-AC converters (see online version for colours)

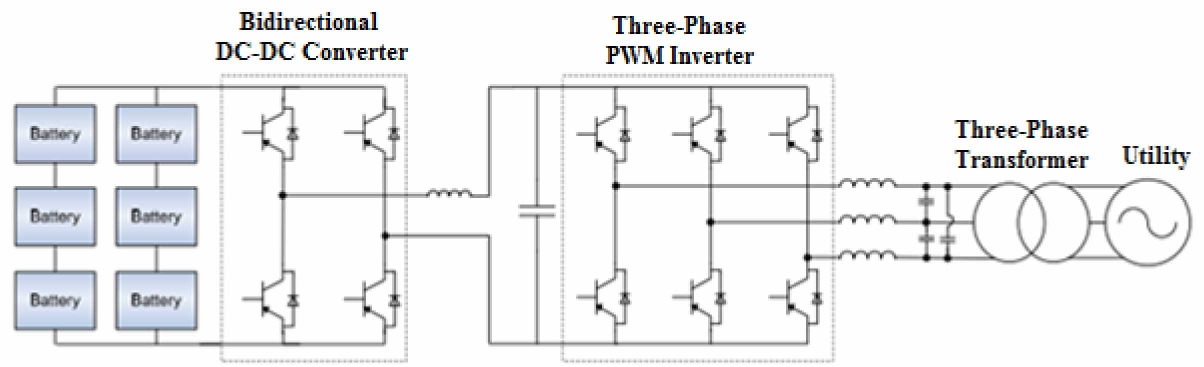


Figure 15 Bidirectional isolated DC-DC PEs topology (see online version for colours)

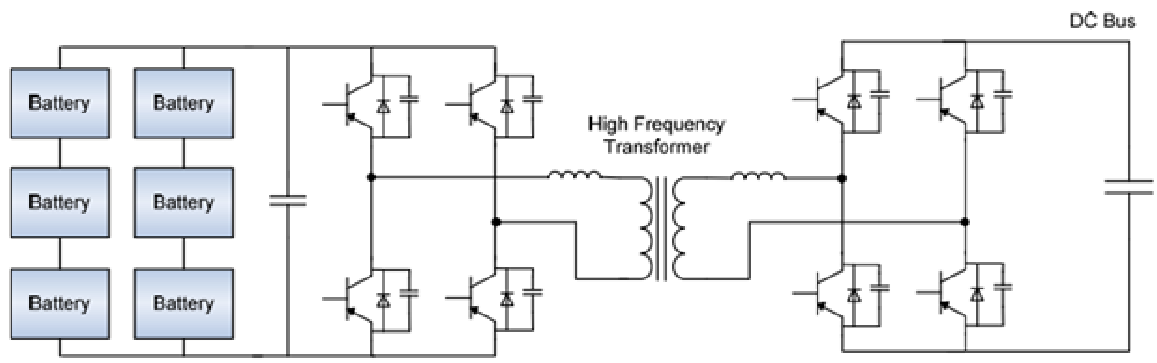
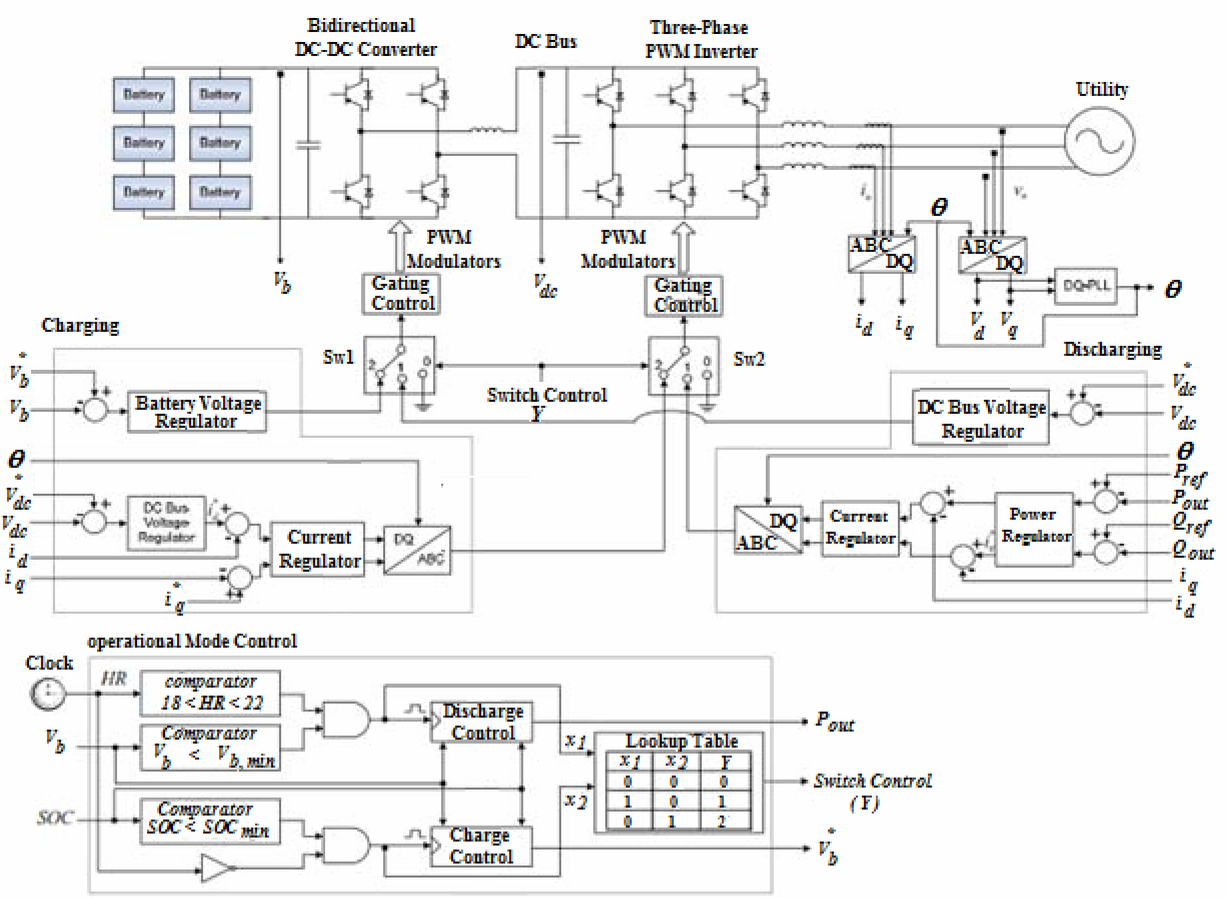


Figure 16 Generalised PEs and control of a BESS (see online version for colours)



3.4 Generalised PEs circuit and control

From the discussion in the previous subsections, it can be observed that the most generalised form of PEs topologies for the BESSs is the bidirectional DC-DC converter cascaded with the DC-AC three-phase inverter as shown in Figure 16.

There are different modes of operation for the BESS connected to the utility. The BESS can either send power to the utility by discharging or it can receive power from the utility to charge itself (Bayoumi, 2015b). The operation mode control block, as shown in Figure 16, decides the charging/discharging operation for the BESS. The control design for PE systems is different for charging and discharging modes. Based on the mode in which the battery is operating, the control signals from charging or discharging blocks are connected to the PEs system by the selector switches Sw1 and Sw2.

The operation mode control block is designed based on a simple charge-discharge schedule of the BESS. The BESS can send the power to the utility during the peak-load period (i.e., from 6 PM to 10 PM) only if the voltage of BESS is greater than the nominal value (V_b, nom). During the discharge mode – based on the present voltage (V_b) and the state-of-charge (SOC) of the BESS – the P_{ref} signal determines the amount and rate of discharge to be generated. The BESS can be charged any other time, provided the SOC of the battery is smaller than the maximum storage capacity (SOCmax). The switch control signal is generated based on a lookup table. According to the design, the signal '0' means no charge/discharge, '1' means discharging, and '2' indicates charging. This signal simultaneously controls switches Sw1 and Sw2. Based on the status of this signal, the PEs converters are either connected to the charging block or the discharging block. Other charge-discharge schedules can also be programmed in the operation mode control depending on the application.

When the mode of operation for the BESS is charging, the power flows from the utility to the battery system through PE converters. The DC-DC converter determines the voltage at the battery terminals (V_b) based on which the battery is charged. The battery voltage regulator generates the PWM pattern based on the reference battery voltage (V_b^*) (coming from operation mode control) such that the (V_b) follows this reference voltage. For the proper control, the DC-DC converter requires a constant DC input. The DC-AC converter works as the controlled rectifier and the controller maintains the DC bus voltage (V_{dc}) at a preset value. This control design is a variation of the constant power control (Pellegrino et al., 2010; Bayoumi, 2013a, 2014c; Soliman et al., 2011, 2012). Instead of using the active power reference, a DC bus voltage is regulated while the input to the inverter acts as a constant power source to represent the prime mover. In this case, the output of the DC bus regulator is proportional to the active power.

During discharge mode, the power flows from the BESS to the utility. In this mode, the DC-DC converter maintains the DC bus voltage for the inverter, and the grid connected inverter controls the active and reactive power flow. The control of the utility connected inverter, as shown in Figure 16, provides constant power control.

4 Flywheels

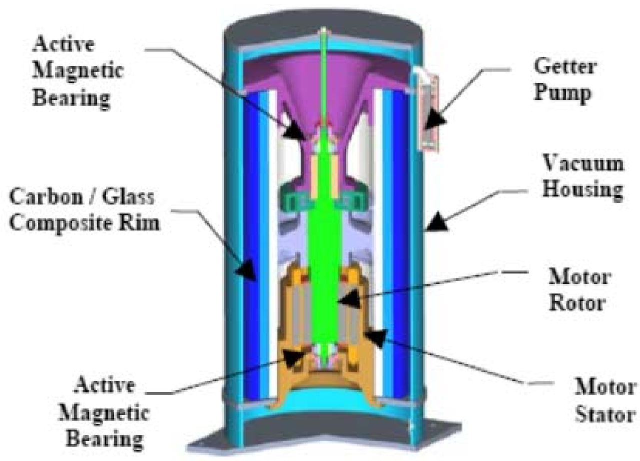
4.1 General description

Flywheels are very popular as energy storage due to the simplicity of storing kinetic energy in a spinning mass. For approximately 20 years, it has been a primary technology used to limit power interruptions in motor/generator sets where steel wheels increase the rotating inertia, providing short power interruptions protection and smoothing of delivered power (Subkhan and Komori, 2011; Lee et al., 2011). Flywheel energy storage system (FESS) works on the same principle: it stores energy in the form of the kinetic energy of a spinning mass. Conversion from kinetic to electric energy is accomplished by electromechanical machines. Many different types of generator machines are used in flywheel systems, such as permanent magnet (PM) machines, induction machines, and switched reluctance machines (Ichihara et al., 2005; Hamsic et al., 2006). The key design element is to match the decreasing speed of the flywheel during discharge and the increasing speed during charging with a fixed frequency electrical system. Along with electromechanical machines, two methods are used to match system frequencies, mechanical clutches, and PEs. The basic operation of a flywheel can be summarised as follows: When there is excess in the generated power with respect to load demand, the difference is stored in the flywheel that is driven by the electrical machine operating as a motor. On the other hand, when a fluctuation in delivered power is detected in the loads, the electrical machine is driven by the flywheel and operates as a generator supplying the extra energy needed (Abdel-Khalik et al., 2013; Ortjohann et al., 2007; Xiang-Dong et al., 2009).

FESS often utilises PEs that convert and regulate the power output from the flywheel. As the motor/generator draws mechanical energy from the rotor during discharge, the rotor slows down, changing the frequency of the AC electrical output. The output must be converted to DC or to constant-frequency AC power. When PEs is used, the variable frequency AC output of the flywheel alternator is rectified, providing a DC-voltage and current. The primary purpose of the PEs system is to couple the fixed-frequency AC-electrical grid with the variable-speed flywheel as well as to invert, regulate, and provide the proper wave form for providing power to the grid. By reversing the process, the PEs are also able to draw power from the AC utility connection and drive the flywheel motor to spin up and recharge the flywheel (Lazarewicz and Judson, 2011).

Typical flywheel systems are intended for standby power applications. The energy storage assembly is designed to operate at high speeds (typically > 10,000 rpm) to achieve its highest energy storage density (Wh/kg). The motor/generator rotor is mounted on a shaft which is integral to the flywheel. An active lift magnet system supports the shaft axially. Two active magnetic bearing systems provide support at the ends of the shaft for frictionless and maintenance-free operation. The flywheel rotor assembly rotates in a low-pressure environment to reduce drag loss. The flywheel is typically connected to at three-phase motor/generator. A sectional view of a commercially available FESS is shown in Figure 17.

Figure 17 Flywheel energy storage module (see online version for colours)



4.2 Flywheel storage system configurations

The FESSs can be classified into two categories. The first technology is based on low-speed flywheels (up to 6,000 rpm) with steel rotors and conventional bearings. The second involves more recent high-speed flywheel systems (up to 60,000 rpm) that are available commercially and make use of advanced composite wheels that have a much higher energy and power density than steel wheels. This technology requires ultra-low friction bearing assemblies, such as magnetic bearings (Suvire and Mercado, 2012; Sutanto and Cheng, 2009; Molina and Mercado, 2003; Karasik et al., 1999; Rojas, 2007).

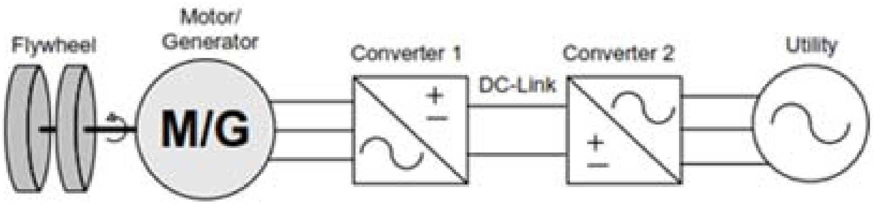
Flywheels can be used together with batteries to reduce the number of discharge cycles of the batteries to extend useful life of the batteries. Flywheels can also be used together with emergency generators to provide temporary power during the changeover to emergency power. The primary use of flywheels for DE applications is to provide voltage and frequency regulation for utilities. The major electrical components of a FESS include a bidirectional inverter, variable-speed motor drive, and controller. An electronic control module controls the PEs to operate in charge, discharge, or standby modes (Sutanto and Cheng, 2009).

The most common configuration for supplying flywheel energy to the grid is the back-to-back converter as shown in Figure 18(a). The variable frequency AC output of the flywheel generator is first converted to DC power. The DC bus is then connected to a DC-AC converter for connection to the grid. During charging, the grid-connected converter works as a rectifier while the generator-connected converter works as the inverter. During discharge, the two converters exchange their roles to supply power from FESS to the utility. In this configuration, multiple flywheel systems, as shown in Figure 18(b), can be connected to the grid via the DC bus to provide frequency, voltage regulation, and backup power for customer loads. Multiple flywheels tied together can provide higher energy storage capacity which will provide higher power levels (Lazarewicz and Judson, 2011).

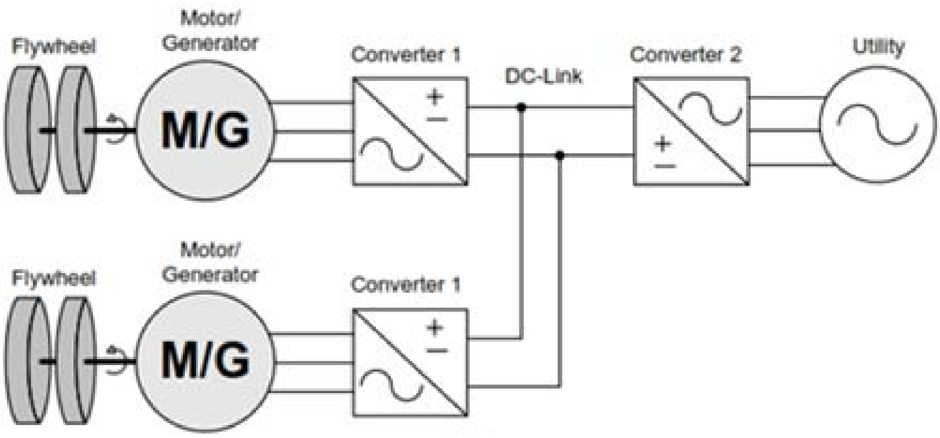
In Song et al. (2004), Ye et al. (2006), Ponnaluri et al. (2005), Inoue and Akagi (2006), Salem et al. (2015) and Bayoumi (2013b), a field-oriented controlled (FOC) induction machine-based FESS consists of a 20 kHz high-frequency AC link (HFAC-link) and back-to-back pulse density modulated (PDM) converters. The 20 kHz HFAC-link and PDM technology, as shown in Figure 19, provides a convenient means for power management in a multi-terminal converter distribution system, offers flexibility in voltage level changes, and allows single stage power conversion.

Similar to the BESS, flywheel systems can be used in-tandem with the other renewable DE sources to smooth out load fluctuations; damp-out voltage sags and frequency variations. As flywheel systems are capable of tens of thousands of cycles, they are the optimum solution for highly cyclic applications where electrochemical batteries are not beneficial. FESS can be used together with batteries to reduce the number of discharge cycles on the batteries to extend useful life of the batteries. In Figure 20, one such hybrid system is shown where the FESS is included in a wind energy system (Cimuca et al., 2006). The flywheel is integrated into the DC bus of the wind system by using a bidirectional AC-DC converter. These hybrid systems can be of various types, depending on the primary source of energy and the type of FESS integration.

Figure 18 FESS with back-to-back DC-link converters, (a) single system (b) multiple systems



(a)



(b)

Figure 19 FESS with back-to-back HF AC-link PDM converters

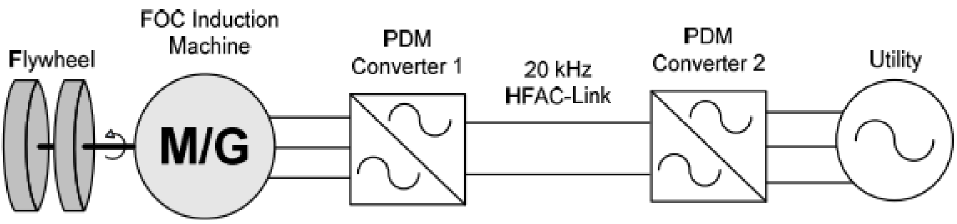


Figure 20 Hybrid system configuration with FESS and wind energy system (see online version for colours)

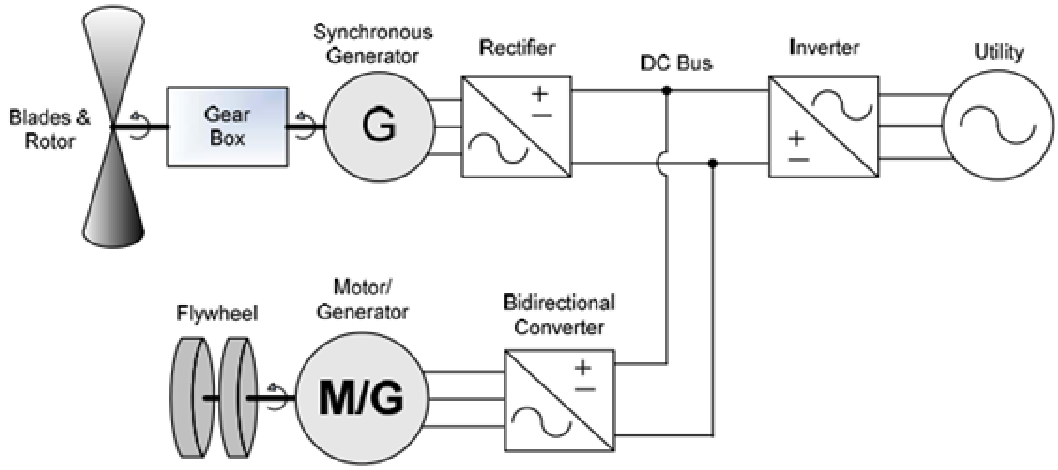


Figure 21 DC-link-based PE topology

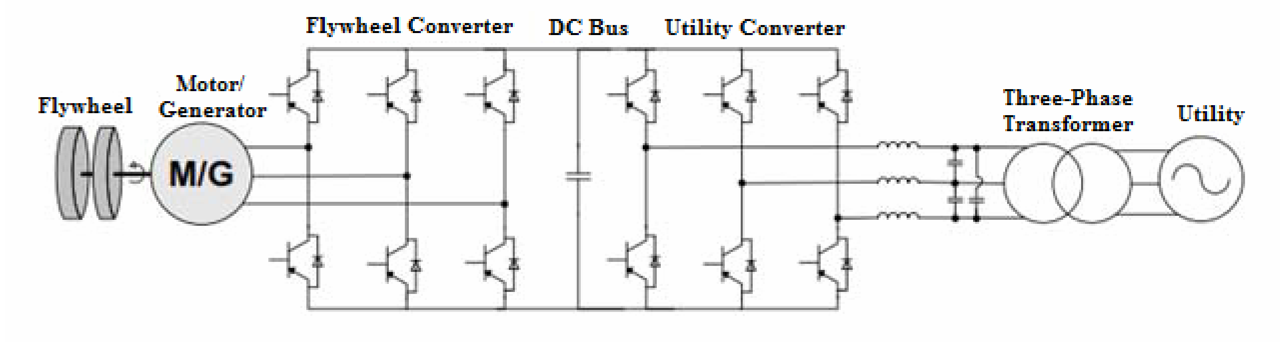


Figure 22 DC-link-based PE topology with additional boost converter

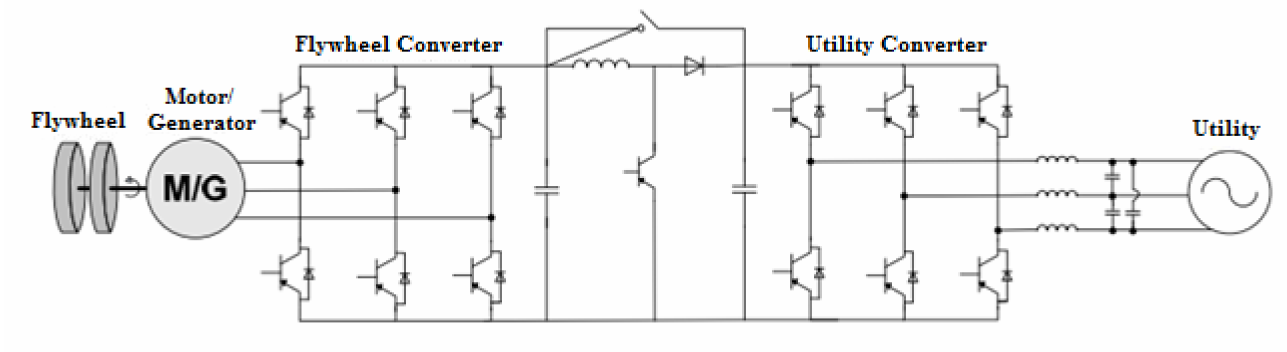
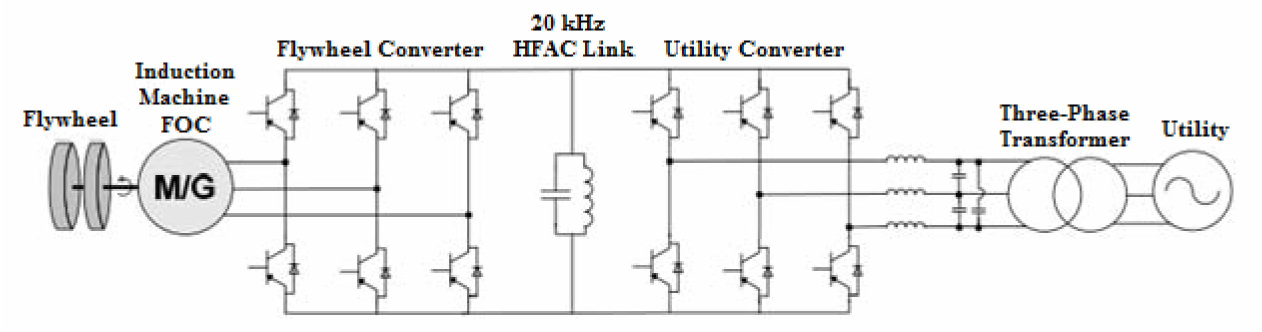


Figure 23 HF AC-link-based PE topology



4.3 PEs topologies

The most common PEs topology for the FESS consists of a DC-AC grid-connected converter and a bidirectional AC-DC flywheel converter, having a common DC bus. During discharge, the flywheel converter works as the rectifier and the grid converter works as the inverter to control the grid current by means of PWM. During charging, the rectification and inversion processes are reversed and the power flows from the utility to the flywheel. Depending on the utility connection, the utility converter can be of single-phase or three-phase. A simple design for a back-to-back converter topology is shown in Figure 21. Galvanic isolation is provided by the three-phase transformer connected to the utility converter.

One modification of the conventional DC-link-based topology (Stanton and Lai, 2005), an additional DC-DC boost converter that is included between the flywheel and the DC-link as shown in Figure 22. A switch is included in the topology that is closed during charging to bypass the boost converter. This topology can be useful in such cases where the transformer connection is not mandatory for galvanic isolation (Bayoumi and Salem, 2012; Bayoumi and Nashed, 2005; Nomura et al., 2010; Li, 2012; Brown et al., 2008; Lemofouet and Rufer, 2006; Ise et al., 2005).

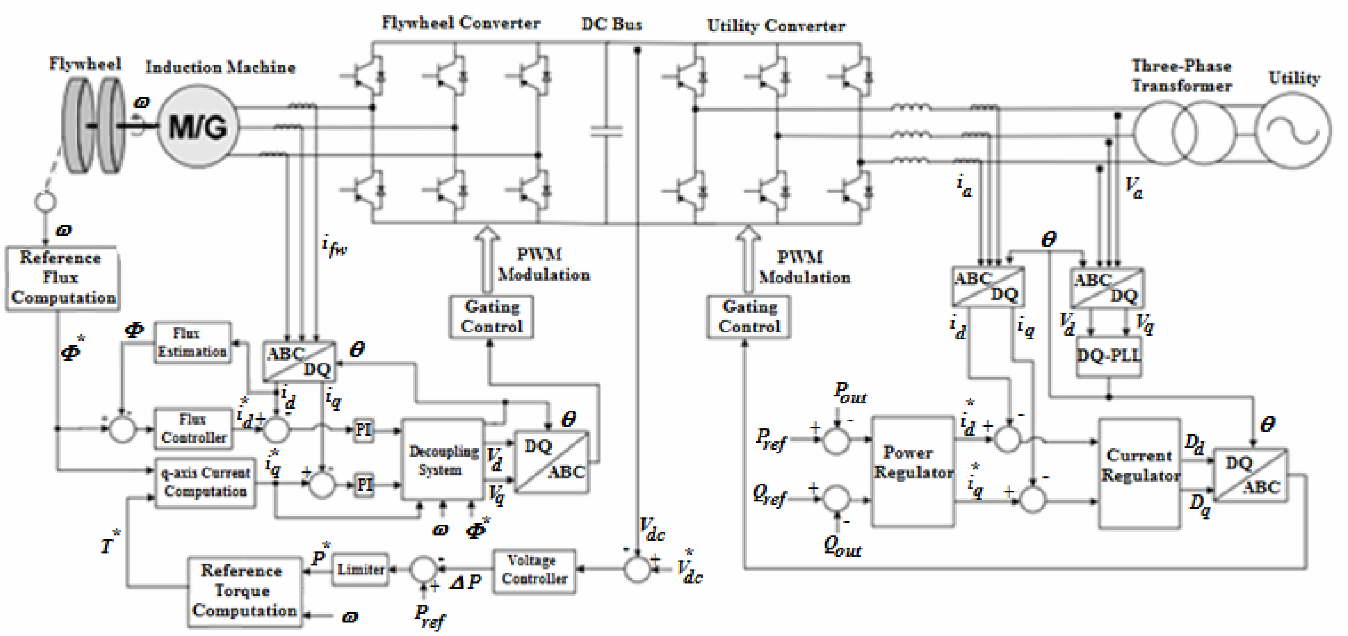
The topology developed in Bayoumi and Nashed (2005) is based on an FOC induction machine-based FESS fed from a 20 kHz HFAC-link and back-to-back PDM converters. The technology provides reduced switching losses due to the utilisation of the zero voltage switching (ZVS) technique. The design for the HFAC-link-based back-to-back converter topology is shown in Figure 23.

4.4 Generalised PEs circuit and control

From the discussion in the previous subsections, it can be observed that the most generalised from of PEs topology for the flywheel application is the back-to-back rectifier/inverter connection which provides the improved power flow control as well as increased efficiency. The voltage-fed converter scheme used in such a system is shown in Figure 21; the PEs and controls for the FESS are shown in Figure 24. The control for the system is designed for two main functions: DC bus voltage regulation and power flow control.

The induction machine (IM) associated with the flywheel operates using a rotor flux-oriented control approach. The torque control is used for the FESS induction machine. Based on the d-axis current from the induction machine, stator flux is estimated, which is then compared with the reference flux command that is generated from the machine speed. Often, a flux weakening mode of operation is required for the IM to match the flywheel and IM speed. The error in the reference and estimated flux is then fed to the flux controller which generates the reference d-axis current. To regulate the DC-link voltage, a voltage controller is used to output the power signal (ΔP) required for maintaining this voltage at the reference value (Vdc*). If P_{ref} is the, power expected from the FESS, the reference value of the active power exchanged between the FESS and the DC-link is determined by $P^* = (P_{ref} - \Delta P)$. Based on this power signal, the reference torque is computed. The reference q-axis current is then computed based on the reference torque computation.

Figure 24 Generalised PEs and control of a flywheel storage system



The control of the utility connected inverter, as shown in Figure 24, is developed with constant power control (Lu and Ooi, 2003, 2005; Xiang et al., 2006; Ran et al., 2006). Many functions to deal with practical control issues are not shown in the diagram, such as the negative sequence regulation, DQ decoupling, etc. The power loops are on the outer level and generate the reference current signals for the current controller. Then the inner current control loops are implemented to generate the duty cycle for the PWM converter connected to the utility. In some cases, the reactive power reference Qref could be a power factor reference. By controlling this reference, the injected current to the utility can be maintained at unity power factor. The output of the control system is the high-frequency sine PWM signals for the VSI switches.

4.5 Plug-in vehicles

4.5.1 General description

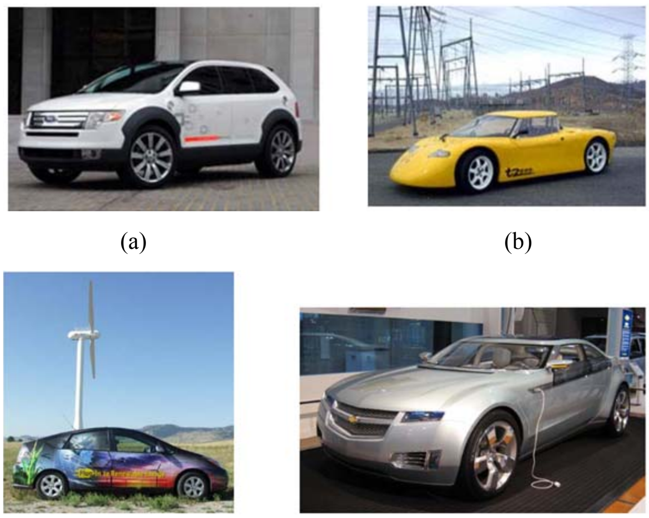
Plug-in hybrid vehicles (PHEV) can be classified into different categories such as electric vehicles (EV), hybrid electric vehicles (HEV), PHEV, and plug-in fuel cell vehicles (PFCV). A typical EV has a battery pack connected to an electric motor and provides traction power through the use of a transmission. The batteries are charged primarily by a battery charger that receives its power from an external source, such as the electrical utility. The primary advantage of an EV is that the design is simple and has a low part count. The primary disadvantage is that the driving range of the vehicle is limited to the size of the battery and the time to re-charge the battery can be 15 minutes to 8 hours, depending on how far the vehicle was last driven, the battery type, and charging method (Li et al., 2009; Clement et al., 2008, 2009; Acha et al., 2010; Maitra et al., 2009).

Typical PHEV batteries can be charged with a battery charger that receives its power from the utility; however, it can also be charged through the use of the on-board internal combustion engine and generator. The best PHEV designs are those that allow the vehicle to operate on electric power only, reducing the amount of time that the engine runs. When the vehicle is not operating, the battery can be charged through the use of a battery charger that is ‘plugged in’ to the SG or other energy source to charge the on-board battery. A PHEV normally has a larger battery pack than an HEV. The advantage of a PHEV over an HEV is that the battery is charged from an external source and can allow the vehicle to run longer on electric power instead of engine power, reducing engine fuel consumption (Galus and Andersson, 2009; Karnama, 2009; Axsen and Kurani, 2010; Judd and Overbye, 2008; Kempton and Tomic, 2005a, 2007; Markel et al., 2007).

In a PFCV, a battery pack and a fuel cell that are connected to an electric motor that provides traction power to the wheels through a transmission. The batteries can be charged with a battery charger that receives its power from the utility, or it can be charged with the fuel cell. Examples of plug-in vehicle prototypes are shown in Figure 25. The GM Chevrolet Volt shown in Figure 25(d) is a series HEV prototype that uses an electric driveline for traction. The design is reported to have a 40 mile battery-only range which can be extended using the on-board engine driven generator. The 2006 Toyota Prius PHEV shown in Figure 25(c) was converted to operate as a plug-in vehicle. The vehicle includes a standard Prius driveline, a lithium ion battery, and on-board battery charger (Clement et al., 2009).

Ford Edge PFCV, as seen in Figure 25(a), is prototype vehicle that includes a PEM fuel cell with a 5,000 psi hydrogen fuel tank, 336 volt lithium-ion battery pack, and electrically powered drive train. The vehicle, presented in Washington, DC in January of 2007, is a hybrid vehicle that uses the on-board fuel cell to charge the batteries when their state of charge drops below a pre-determined level. The prototype vehicle also has an on-board charger that can be plugged into a 110 or 220 VAC. The vehicle has a battery-only range of 25 miles and the on-board storage tank has enough capacity to allow the vehicle to travel 200 miles using the PEM fuel cell (Parks et al., 2007; Putrus et al., 2009; Alvarez-Herault et al., 2011; Kempton and Tomic, 2005b; Short and Denholm, 2006; Bayoumi and Salmeen, 2014a; Sutanto, 2004; Salem and Bayoumi, 2013; Brooks, 2002).

Figure 25 Plug-in-prototypes, (a) Ford Edge PFCV (b) AC Propulsion Tzero V2G EV (c) Toyota Prius PHEV (d) GM Chevrolet Volt (see online version for colours)



(a) (b) (c) (d)

4.5.2 Plug-in vehicle system configurations

According to the Electric Power Research Institute (EPRI), more than 40% of US generating capacity operates at a reduced load overnight, and it is during these off-peak hours that most PHEVs would be recharged. Recent studies show that if PHEVs replace half of all vehicles on the road by the year 2050, only an 8% increase in electricity generation (4% increase in capacity) will be required PHEVs that are vehicle-to-grid (V2G) capable allow these vehicles’ batteries to deliver power back to the SG. When the battery is being charged, the amount of DC power delivered to the battery is regulated according to a charge profile based on the type of battery technology. When the vehicle provides power back to the SG, the DC power is converted to a fixed frequency AC output, and the amount of current that is drawn from the battery is either fixed or variable depending on the complexity of the PEs and control strategies that are used. V2G technology is a promising future alternative to increase the amount of DG that can be used during peak hours (Clement et al., 2009).

Figure 26 Typical EV configuration (see online version for colours)

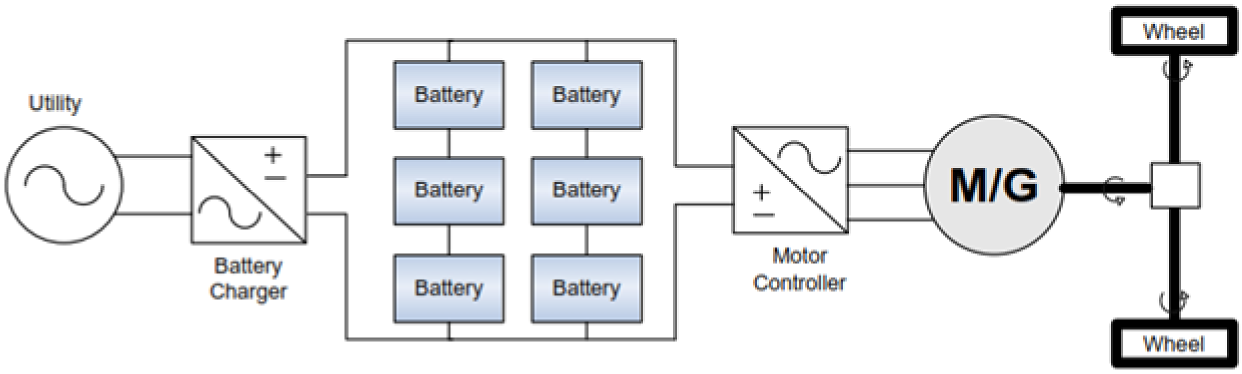


Figure 27 Typical parallel HEV configuration (see online version for colours)

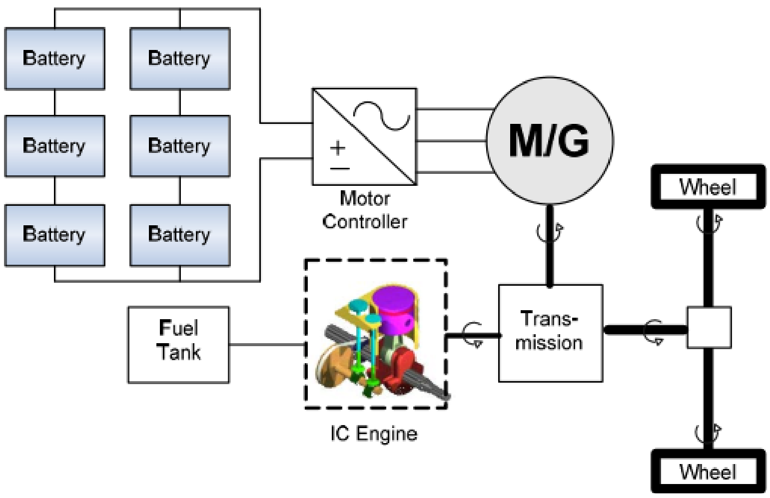


Figure 28 Prius HEV configuration (see online version for colours)

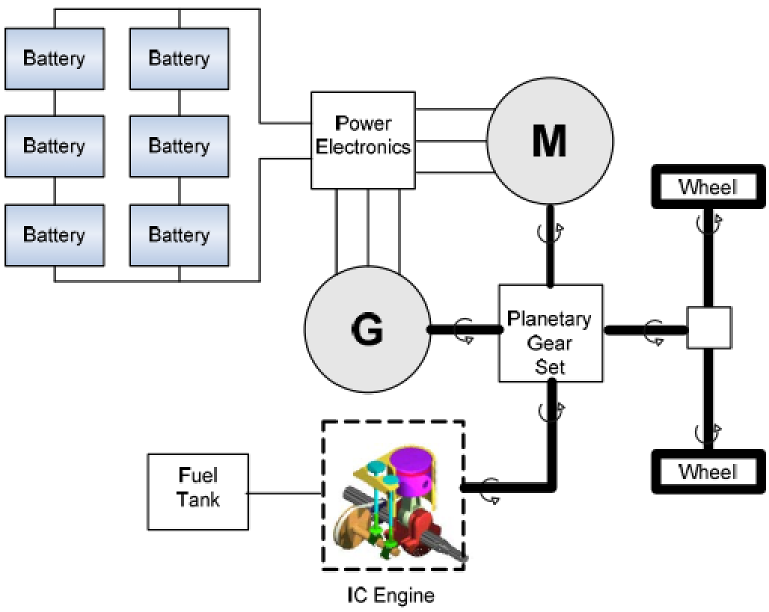
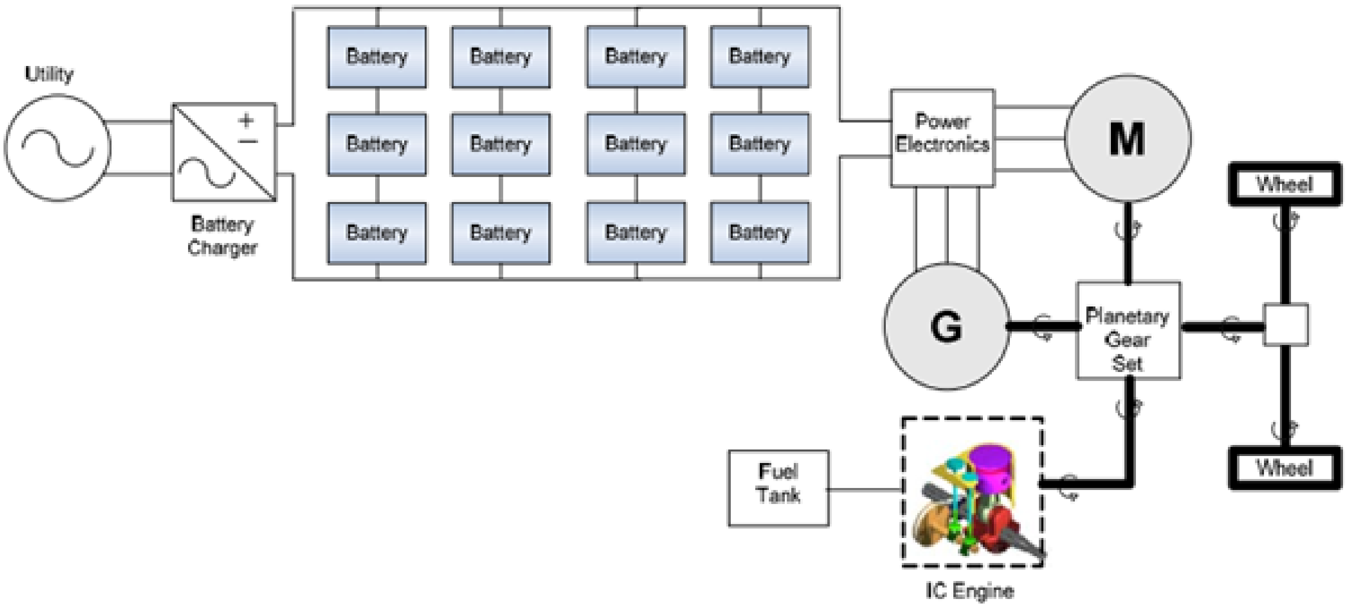


Figure 29 Prius PHEV configuration (see online version for colours)



The simplest, most typical form of an EV configuration is shown in Figure 26. This configuration consists of a battery system and a motor controller that supplies power to the motor, which in-turn supplies power to the wheels for traction. Many of today's EVs use a PM-electric motor that can also act as a generator to recharge the batteries when the brakes are applied, also known as 'regenerative braking'. During regenerative braking, the motor acts as a generator, providing power back to the batteries while slowing down the vehicle. When the vehicle must be stopped quickly, or if the batteries are at full charge, friction brakes are used. Most EV systems also utilise an on-board battery charger to recharge the batteries using utility power.

Figure 27 shows a typical parallel HEV configuration. A number of HEVs are in production and are available for purchase, include the Toyota Prius, Toyota Highlander Hybrid, Toyota Camry Hybrid, Lexus RX 400h, Lexus GS450h, Honda Insight, Honda Civic Hybrid, Honda Accord Hybrid, Silverado, Saturn Vue, and Ford Escape. The components that make up a typical HEV include a battery pack, motor controller, motor/generator, internal combustion engine, and transmission and driveline components. The primary PEs in an HEV include a DC-AC motor controller which provides three-phase power to a PM motor (Kharnashawy et al., 2011; Srivastava et al., 2010; Bayoumi, 2005; Bayoumi and Soliman, 2007; Soliman et al., 2009a; Saber and Venayagamoorthy, 2010; Zhang et al., 2011b; Dias et al., 2012; Bayoumi et al., 2011; Bayoumi, 2010a).

The Toyota Prius HEV configuration, as shown in Figure 28, uses a PM motor, PM generator, and gasoline engine feed into a planetary gear set. The system operates with a continuously variable transmission (CVT) where the gear ratio is determined by the power transfer between the generator and motor. The batteries on the standard Prius are charged using the on-board PE. There is no provision to charge the batteries externally (Michalek et al., 2011; Bayoumi, 2007; Kharnashawy et al., 2009; Quinn et al., 2010; Bayoumi and Soliman, 2008; Bayoumi et al., 2009; Soliman et al., 2009b; Berthold et al., 2011).

For plug-in vehicles, batteries are charged when they are not being driven. This is normally accomplished through a utility connected AC-DC converter to obtain DC power from the grid. The batteries can also be charged directly from a solar resource using a DC-DC converter, or from a wind source using an AC-DC or DC-DC converter depending on the type of power that is available from the wind resource.

In PHEVs or PFCVs, charging the batteries with an external source allows the electric motor to run more often on the batteries, thus reducing the amount of fuel used. A PHEV is basically an HEV with a larger battery pack that can be charged using a battery charger. Energy flow is unidirectional as power is taken from the utility to charge the battery pack. While a typical Prius HEV configuration is shown in Figure 28, there are a few companies who convert hybrid vehicles like the Toyota Prius to add plug-in capability as shown in Figure 29.

The battery voltage for most converted PHEVs are maintained at the same voltage level (typically 200–400 VDC) as the original design and battery modules are added in parallel to increase the energy capacity of the battery pack. This allows the motor to run more often than the original HEV design. Some of the PHEV conversion companies include: CalCars, Energy CS, Hymotion, Electrovaya, and Hybrids Plus – most of whom use lithium batteries (Clement et al., 2008).

Figure 30 FCV configuration (see online version for colours)

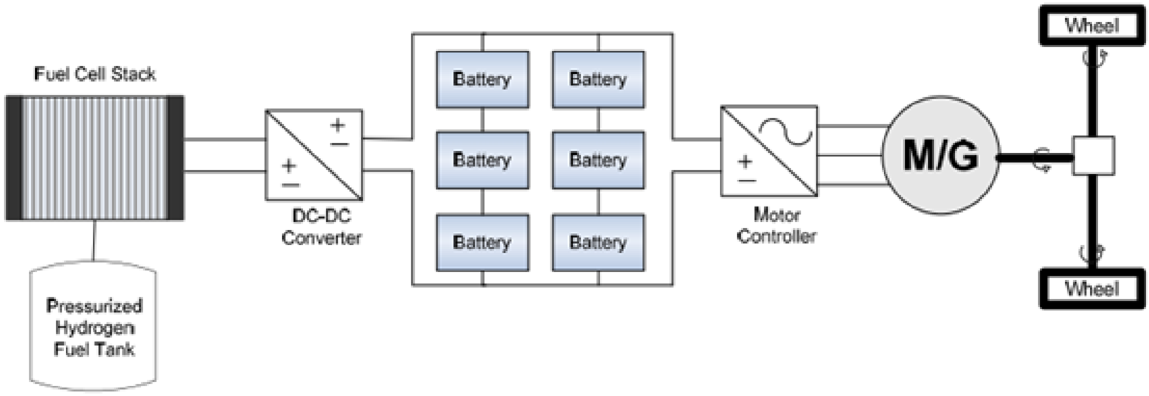
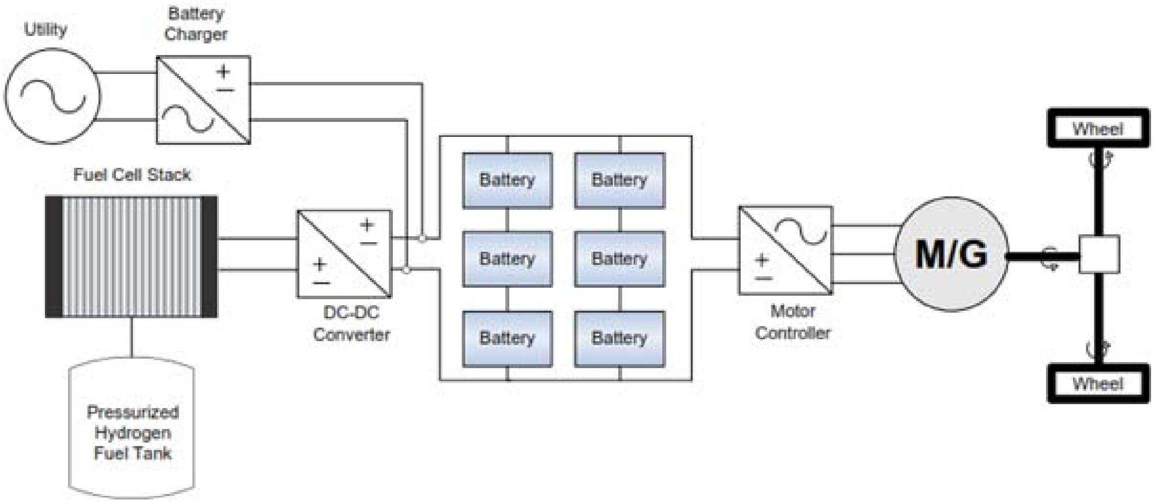


Figure 31 PFCV configuration (see online version for colours)



Prototype fuel cell vehicles (FCVs) are currently under development; a typical FCV configuration is shown in Figure 30. Most vehicles utilise a pressurised 5,000 to 10,000 psi tank on-board to store the hydrogen. The hydrogen and conditioned air are fed into a PEM stack, and fuel is provided by a pressurised hydrogen fuel tank. As the fuel flow increases, the DC output current increases. The DC output from the stack is fed into a DC-DC converter to a DC power bus. Connected to the DC bus is a battery pack and motor controller. The configuration is very similar to the EV configuration in which a motor/generator provides the mechanical power for traction. The on-board batteries allow the energy to be stored during regenerative braking and provide peak power to the motor controller during vehicle acceleration. In field-tests, over 800,000 miles have been placed on a fleet of various FCVs. The demonstration showed that the vehicles were performing between 52% to 58%, efficiency with distances ranged between 100 to 190 miles (Bayoumi, 2010b; Soliman et al., 2010; Kempton and Tomic, 2005a; Emadi et al., 2005; Gao et al., 2005; Chan et al., 2010).

In a typical PFCV configuration, as shown in Figure 31, the batteries are charged using an on-board utility connected battery charger. This configuration typically uses a larger battery pack than an FCV to give the vehicle a longer driving range under electric power. The fuel cell produces DC power which is boosted to a higher voltage using a DC-DC converter. Batteries connected to the bus are used to allow the fuel cell stack to operate at more constant operating conditions. The motor controller draws its power from the DC bus and provides three-phase power to the motor/generator. Regenerative braking is also used and the power is stored by the battery pack for later use. An on-board battery charger is connected to a single phase utility connection to allow the batteries to be recharged when the vehicle is parked.

A plug-in vehicle can also be designed to provide power for standby power applications such as back up power to a home. For EVs, the amount of energy (watt-hours) that can be provided is limited to the size of the on-board energy storage device. For PHEVs and PFCVs, the amount of energy is limited to not only the battery pack size but also the amount of fuel that is on board. Control systems can be designed that will cycle the engine or fuel cell on and off to keep the batteries within a specified state of charge range; however, the vehicle needs to either be located outside or have provisions to allow the exhaust to be vented outside from an enclosed space, providing sufficient ventilation for both exhaust and cooling requirements for the PHEV.

In a study conducted by Parks, as documented in the 'Costs and emissions associated with plug-in hybrid electric vehicles charging in the XCEL Energy Colorado service territory' technical report, the RESEARCHERS concluded that the actual electricity demands associated with PHEV charging are quite modest compared to normal electricity demands. Replacing 30% of the vehicles currently in the Xcel Energy service territory with PHEVs with a 20 mile all-electric range, 39% of their miles would be derived from electricity increasing their total load by less than 3%.

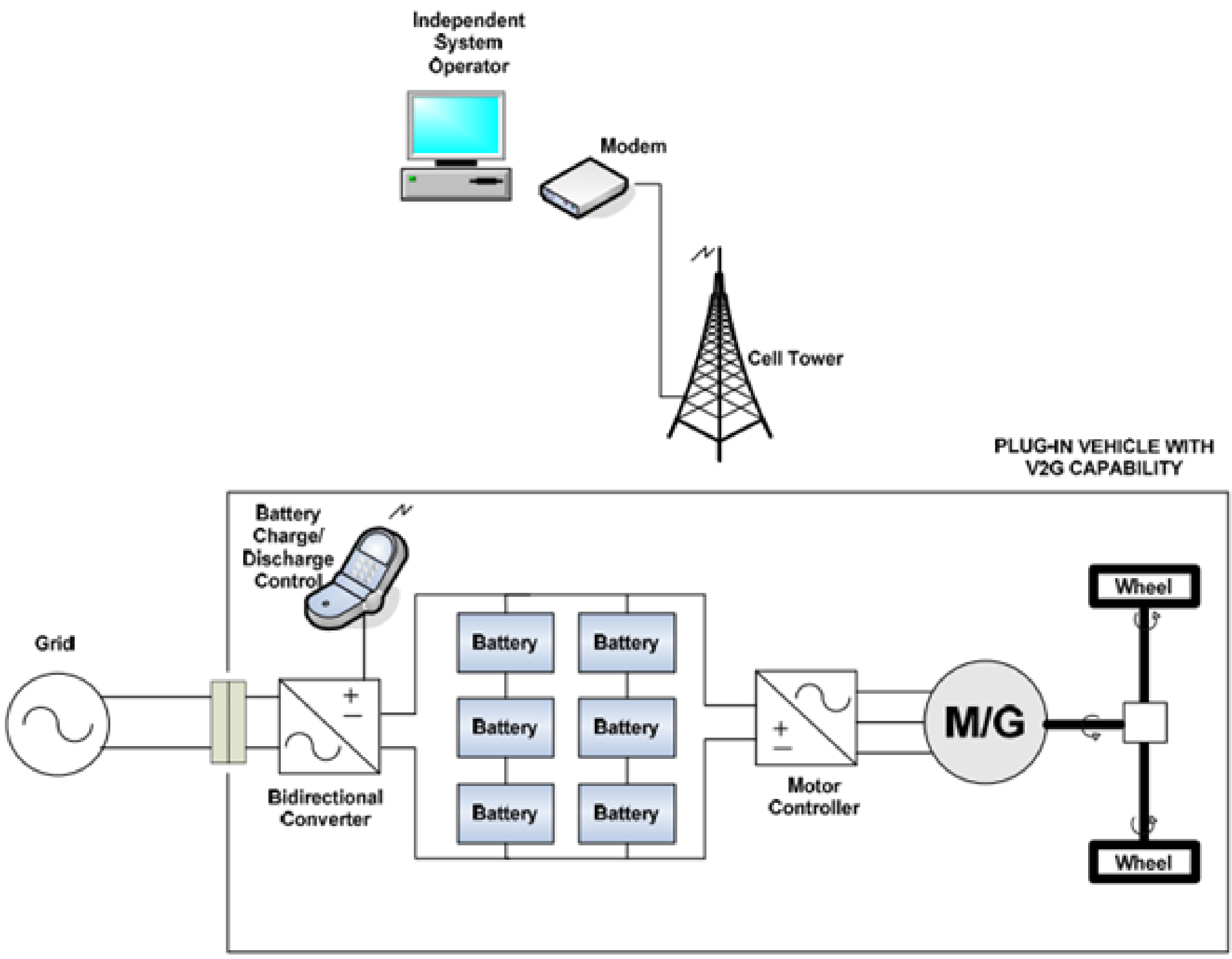
A very large penetration of PHEVs into society would place increased pressure on peaking units if charging is completely uncontrolled. There is a large natural coincidence between the normal system peaks and when significant charging would occur during both the summer and winter seasons. At today's electrical rates, the incremental cost of charging a PHEV fleet in overnight charging will range from \$90 to \$140 per vehicle per year. This translates to an equivalent production cost of gasoline of about 60 cents to 90 cents per gallon (Clement et al., 2009). Further study is needed to determine the effects of battery life, state of charge control, driving range, life, and any associated replacement costs.

4.5.3 V2G system configurations

A PHEV can only charge its batteries using AC power, typically provided by a SG; however, as discussed, EVs, HEVs, and PFCVs can also be designed to send power back to the SG. A vehicle with this type of technology is defined as being V2G capable.

All of the technologies, as discussed in the previous section, utilise a battery pack that produces DC power that must be converted to AC power in order to connect to the utility for V2G applications. The individual battery cells are generally connected in different series and/or parallel configurations to achieve the required voltage and current outputs. The power conditioning systems include inverters and motor controllers. The unique aspect to PEs for V2G vehicles is that they must be bidirectional, that is, both taking power from the grid during charging and providing power to the grid during discharge (Chan et al., 2010).

Figure 32 ISO controlled V2G (see online version for colours)



The proposed use of V2G vehicles for DE applications is to provide voltage and frequency regulation, spinning reserves, and electrical demand side management. If used in large numbers, V2G vehicles have the potential to absorb excess electricity produced by renewables (e.g., wind power) when the grid is operated at low load conditions – studies show that PHEVs could be a significant enabling factor for increased penetration of wind energy (Gao and Ehsani, 210; Bernard et al., 2009; Kempton and Tomic, 2005a; Tomi and Kempton, 2007; Robalino et al., 2009; Geng et al., 2012). Controls can be developed that would allow an operator to dispatch these renewable resources through the use of the vehicle's battery when they are needed by the utility. During periods of low demand, the driver can use excess generation to charge the on-board batteries which can then be used by to run an electric motor, offsetting fuel consumption. A set of fleet vehicles that are parked at a company's facility could potentially be used to provide electricity during periods of high demand to offset the facility's electrical demand charges. Such a system is referred to as an independent system operator (ISO). A proposed wireless configuration for ISO control is shown in Figure 32.

Each V2G capable vehicle must have three required elements:

1 a power connection to the grid for electrical energy flow

2 control or logical connection necessary for communication with SG operators

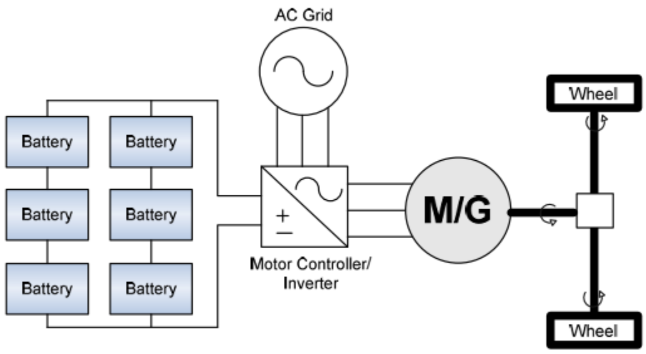
3 precision metering on-board the vehicle (Gao and Ehsani, 2010).

The configuration shown in Figure 32 shows the PEs being controlled using a wireless cell connection to communicate with the V2G capable vehicles. While V2G-capable cars could provide peak power or serve as a demand-response resource, their economic values do not generally justify the expense. These services are needed for just a few hours each year; therefore, the potential revenue from providing these services is limited. In current research suggests that the most promising markets for V2G power are for those services that the electric industry refers to as ancillary services (Bernard et al., 2009).

V2G vehicles typically use a high-power, high-energy battery pack and a bidirectional inverter and controller. An electronic control module controls the PEs to operate in charge, discharge, or standby modes. Typical V2G vehicles utilise either a nickel metal hydride or a lithium-ion battery pack. Similar to the battery and FESSs, a V2G system can be used in-tandem with the other renewable DG sources to smooth out load fluctuations and damp out voltage sags and frequency variations. A concern using batteries for this application is the state-of-charge of the batteries must be controlled within a given range to avoid premature life degradation of the electrochemical batteries. Limiting the state-of-charge range will limit the system's power duration, thus limiting its usefulness for this highly cyclic control requirement.

A promising V2G configuration for supplying battery energy to the grid is the integrated motor controller/inverter shown in Figure 33. This configuration shows a utility connection using the same PEs that are used for the motor controller, eliminating the need for a separate battery charger (Gao and Ehsani, 2010).

Figure 33 PE configuration with V2G (see online version for colours)



V2G PEs provide bidirectional power either from or back to the grid. With proper PEs, these vehicles can provide regulation services, a spinning reserve, or provide power back to the utility during high demand periods and charge their vehicle's backup during low demand times. A V2G vehicle can be designed that will provide regulation services by absorbing or providing power back to the utility to match generation with the load. A grid operator could provide commands to V2G-capable vehicles to allow the vehicles to absorb or produce power in order to keep the utilities area control error (ACE) low. ACE is a measure that indicates the deviation of the generation in a power system area from the load. The ACE is generally controlled by managing individual generators within that control area so that it complies with the National Electric Reliability Council and the area's governing electricity council's prescribed acceptable limits (Bernard et al., 2009; Kempton and Tomic, 2005a; Tomi and Kempton, 2007; Robalino et al., 2009; Geng et al., 2012).

At today's gas prices in the USA, a vehicle that can provide regulation services is expected to provide the highest return to the V2G owner (Gao and Ehsani, 2010). An annual revenue estimate for a 10 kW V2G capable vehicle could provide between $920 to $1,117 for spinning reserves and $2,497 to $3,285 for regulation for the PJM and Electric Reliability Council of Texas (ERCOT) territories (Bernard et al., 2009). State-of-charge regulation, battery life, power capacity, energy capacity, and available power connection will be critical factors in the design of these vehicles. The number of battery discharges, charges, and state-of-charge control directly effects battery life. It is expected that with today's battery technology, designing a vehicle that can provide spinning reserve capability will be easier than a vehicle that provides regulation. The number of charges, discharges, energy capacity, and range of state-of-charge control will be less for V2Gs that provide spinning reserve over V2Gs that are used for regulation services that will require deeper discharges and more frequent operations.

4.5.4 PEs topologies

The schematic for Semikron's Advanced Integrated Power Module (AIPM) motor controller PE topology, commercially available for sale, has been used some of the automaker's prototype vehicles as shown in Figure 34. The AIPM uses six insulated-gate bipolar transistors (IGBT), a DC-link capacitor, integrated current sensors, temperature sensors, and a driver board that are all mounted on a heat sink. The AIPM uses pressure contact technology for a compact design, improved thermal performance, and high reliability. Integrating the DC-link capacitors in the design reduces internal inductance and allows higher bus voltages to be used. Integrating the DC-link capacitor also allows less capacitance to be used for a smaller, more reliable design. The AIPM can be purchased with either 600 volt or 1,200 volt rated IGBTs. The packaging allows heat to be removed through the use of either water cooled or air cooled heat sinks. Together with a controller board, the AIPM can be controlled using a driver board with an integrated digital signal processing (DSP) controller. Customer supplied software can be downloaded the AIPM's DSP to allow the AIPM to act as a motor controller (Lianghong et al., 2011; Zhang et al., 2011a; Gummi and Ferdowsi, 2010; Benavides and Chapman, 2005).

Figure 34 General AIPM PE schematic (see online version for colours)

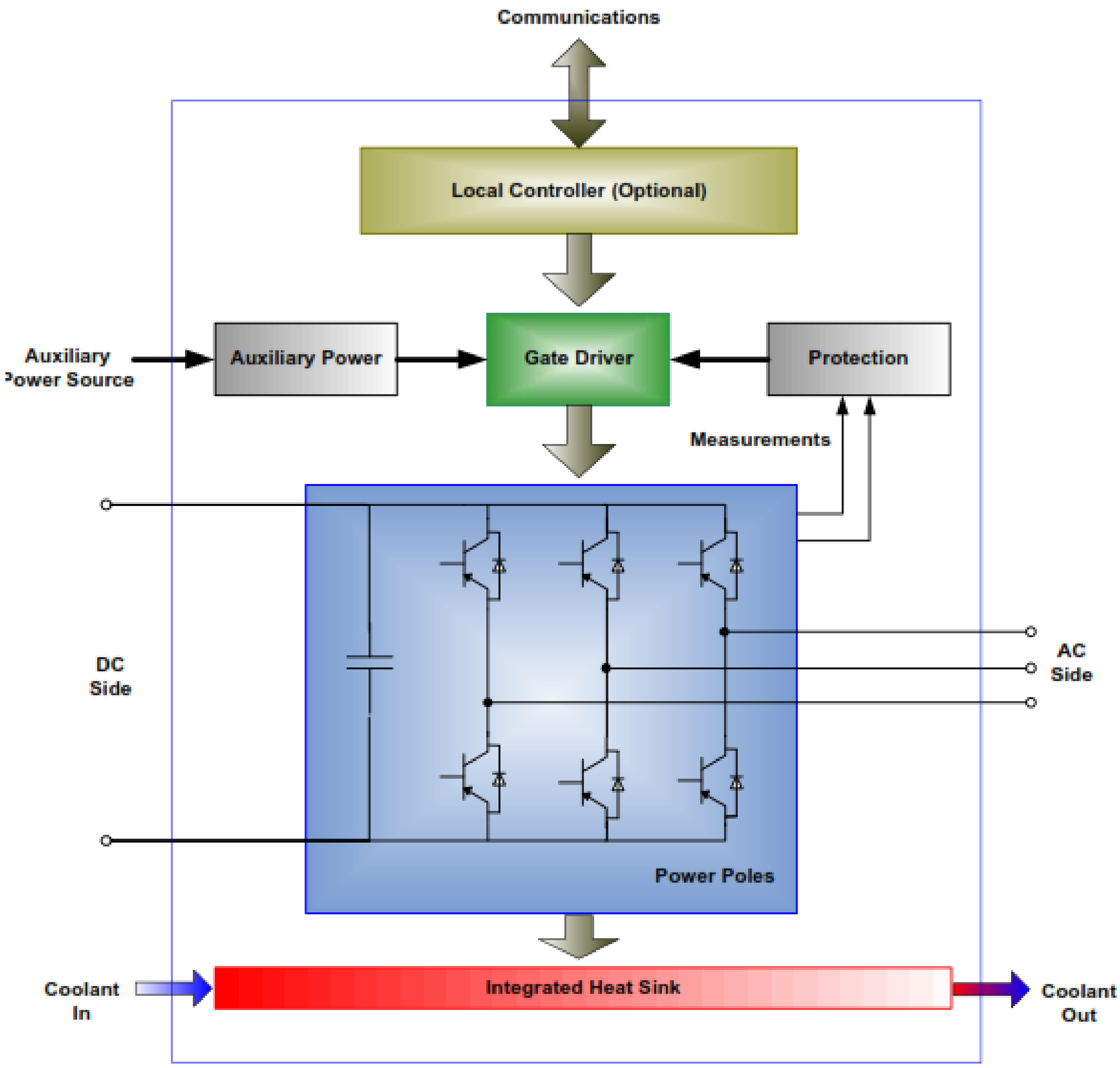
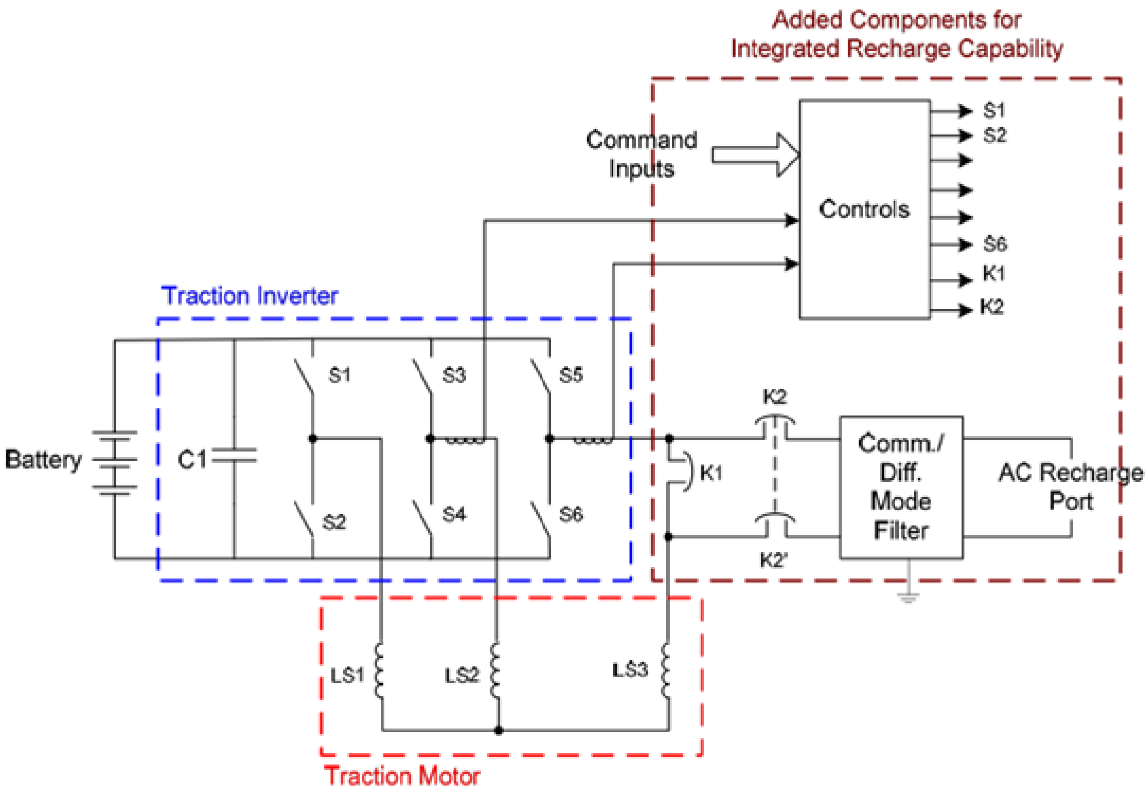


Figure 35 AC propulsion V2G model AC-150 electrical schematic (see online version for colours)



In Figure 35, the AC Propulsion Systems' AC-150 drive system is rated at 150 kW (200 HP). The system uses a 20 kW bidirectional grid power interface that allows the drive to be used for DG, selling grid ancillary services, and using vehicles to provide uninterruptible backup power to homes or businesses. The system includes a digital interface for instrumentation and recharge control, and an integrated DC bus power port for the connection of other DC power sources. The system is designed to operate as an induction motor controller with traction control and regeneration. The PE allow it to operate as a battery charger or V2G interface to the utility grid. The system reuses the power switches of the propulsion inverter (which drive the traction motor) as the power switches for a grid-tied inverter, using the motor windings as the inductors needed for the grid-tied inverter. This provides a bidirectional, high-power interface to the electric power grid with no extra power components beyond what is needed for propelling the vehicle. In addition to operating as a battery charger to convert AC grid power to DC for charging the battery, the system can operate in reverse to convert DC power from the vehicle's battery, generator, or fuel cell into AC power at the grid frequency. The AC power from the vehicle can then be used to power stand-alone loads or can be fed back into the grid. Safety systems similar to those used with small DG systems prevent the vehicle from feeding power into the grid when grid power is not available (Zhang et al., 2011a; Gummi and Ferdowsi, 2010; Benavides and Chapman, 2005; Mummadi and Sawant, 2008; Chen et al., 2003).

5 Conclusions

Distributed automation and distribution generation (DG) are two main aspects of the SG implementation in the distribution network with the aids of the state of the art PEs circuits and systems. Distributed automation consists of monitoring, control and communications. This is the system used to control switches and other devices throughout the grid rerouting power and reconfiguring the grid to restore portions of the troubled areas, avoid additional failures, and minimise losses. DG is achieved by the interconnection of generators from various resources scattered throughout the distribution system injecting power back into the system. With the addition of solar panels, electric vehicles, fuel cells, standalone generators, private wind generators, bio-fuel generators and other ways of locally generating electrical energy, the customers will have multiple choices to produce electricity for local usage as well as for export to the grid. The SG has to allow for safe and reliable interconnection of DG from various renewable resources. However, to ensure safety and reliability, protection and schemes for various configurations at various DG penetration levels must be considered and analysed. This includes load forecasting and control to utilise storage equipment in addition to DG, which randomly fluctuates based on conditions, for optimal power flow through the distribution network.

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TOYOTA EMERGENCY RESPONSE GUIDE

Reference Document
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

Reference Document

Emergency Response Guide

2017.01
ER27E0E

TOYOTA MOTOR CORPORATION

Foreword

- This guide provides precautions for emergency responders when handling TOYOTA/LEXUS vehicles during an incident.
- It is important to read this guide thoroughly and understand the structure and features of TOYOTA/LEXUS vehicles to ensure safety.
- The illustrations used in this guide are representative examples. Refer to the Quick Reference Sheet (QRS) for each model for model specific information such as key identification points, component locations, etc.

Reading this manual

■Explains symbols used in this manual

Symbols	Meanings
	■Explains something that, if not obeyed, could cause death or serious injury to people.
	■Explains something that, if not obeyed, could cause damage to or a malfunction in the vehicle or its equipment.
	■Explains things not found in the explanations of functions or operation methods, or other convenient-to-know items.
	■Indicates a description note for components that are subject to unintended deployment, operation, potential explosions or parts that may fly off.
	■Indicates a description note for components that may cause electric shock.
	■Indicates a description note for components that may leak.

Table of Contents

Table of Contents

Table of Contents

Emergency Response Key Points

Table of Contents

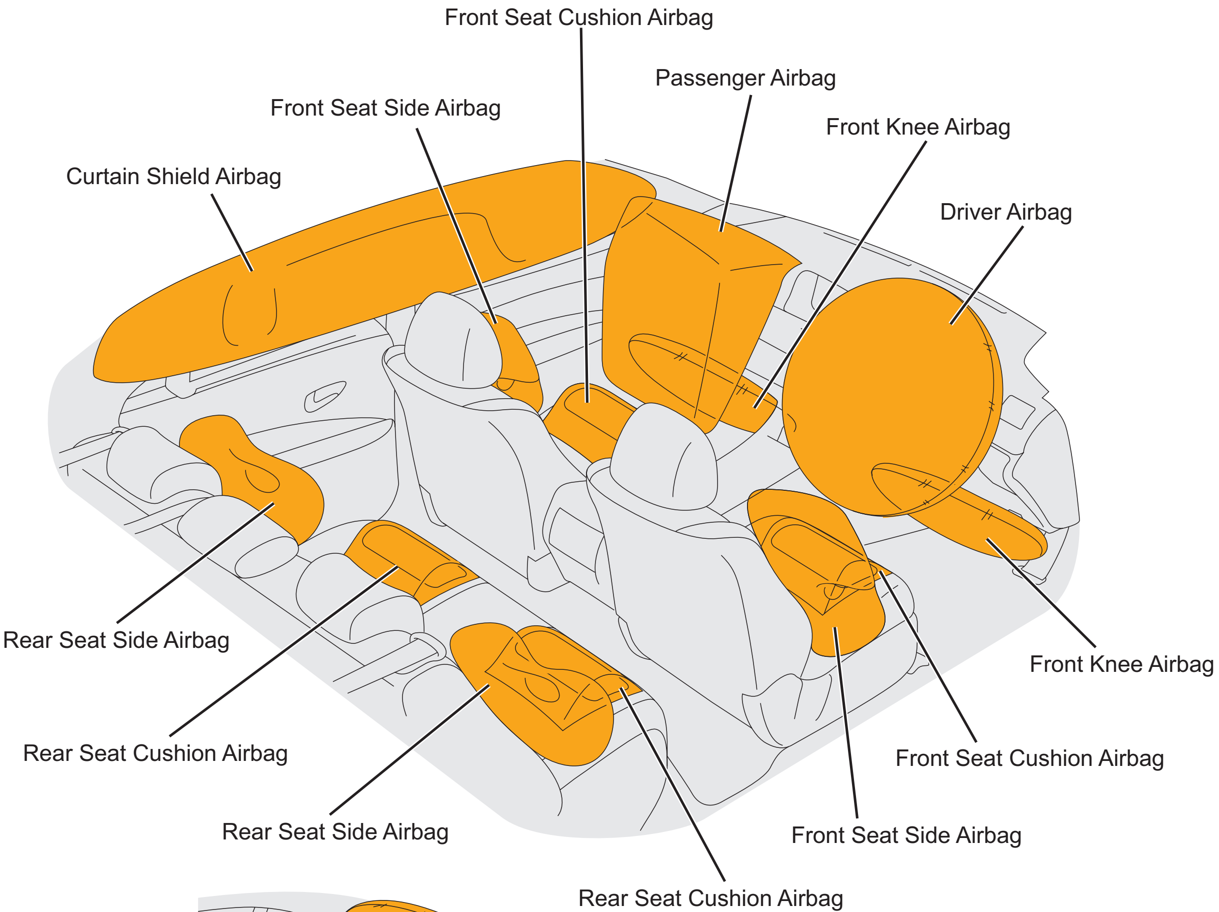
Damaged Vehicle Handling Key Points

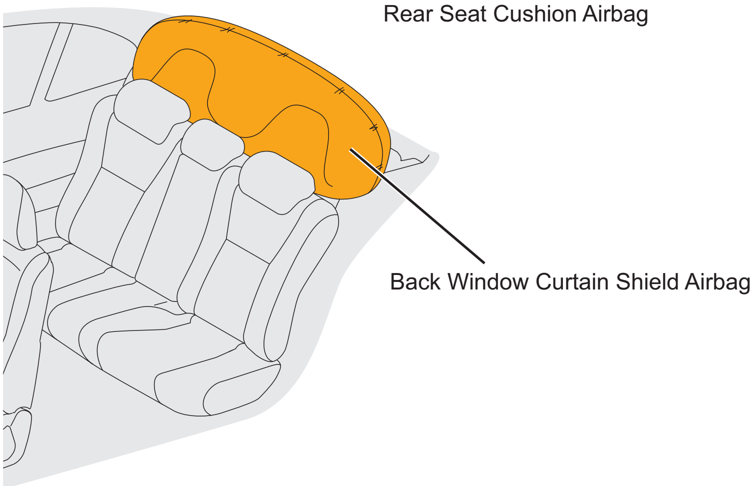
Components Requiring Special Attention

- The construction and functions of components requiring special attention during emergency response are described in this section.

SRS Airbags

- When a vehicle receives a strong impact that can cause serious injury to the occupants, the SRS airbags deploy and the seatbelts restrain the occupants to reduce impact to the body.
Refer to the QRS for each model for the type and location of each SRS airbag.





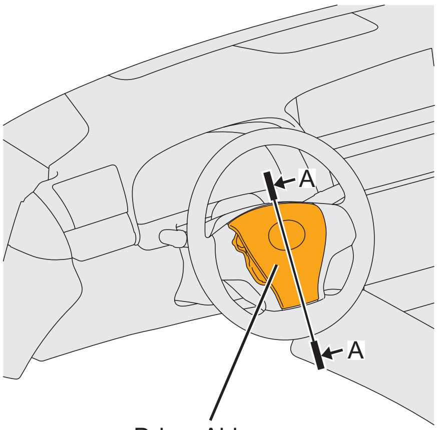
- The SRS airbags consist of an inflator (explosive), a bag and other components and are non-serviceable.
- When an airbag sensor detects a strong impact, an ignition signal is sent to an inflator. When the inflator is ignited, gas is generated to inflate a bag, helping reduce the impact to an occupant.

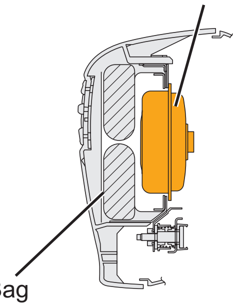
WARNING

- The SRS airbag may remain powered for up to 90 seconds after the vehicle is shut off and disabled (see page 69). Wait at least 90 seconds before starting any operation. Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from unintentional deployment of the SRS airbag.
- Depending on the circumstances surrounding a collision, such as vehicle speed, point of impact, occupant detection etc., SRS airbags will not always be deployed. If an inflator of the undeployed SRS airbag is breached, the powder inside the inflator may ignite resulting in unintentional SRS airbag deployment. To prevent serious injury or death from unintentional SRS airbag deployment, avoid breaching the inflators.
- Immediately after an SRS airbag is deployed, the components are extremely hot and may cause burns if touched.
- If an SRS airbag deploys with all doors and windows closed, inflation gas may cause breathing difficulty.
- If residue that is produced during SRS airbag deployment comes in contact with skin, rinse it off immediately to prevent skin irritation.

Driver Airbag

- A driver airbag is mounted in the steering wheel pad and activated in the event of a frontal collision.

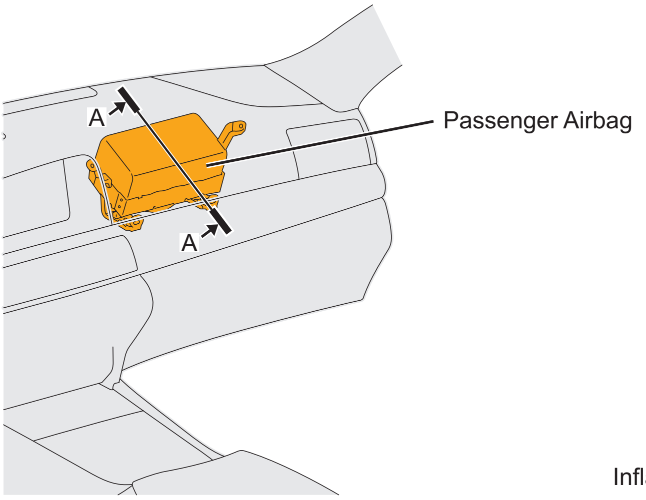


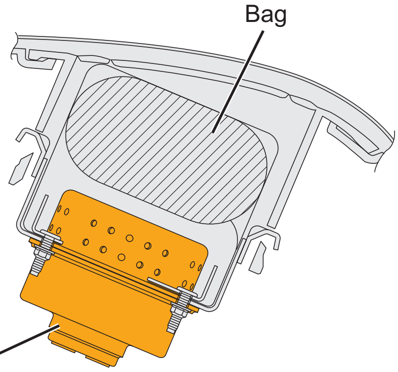


A-A Cross Section

Passenger Airbag

■ A passenger airbag is mounted in the upper portion of the passenger side instrument panel and activated in the event of a frontal collision.

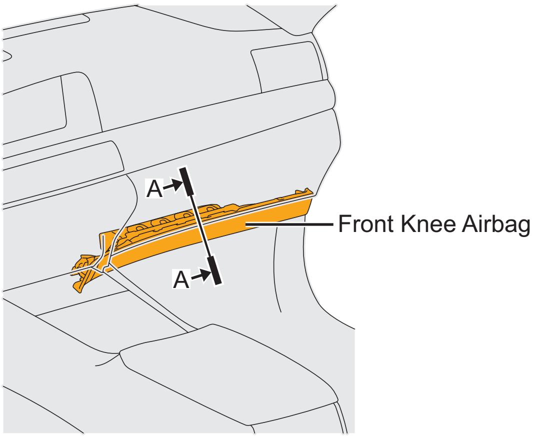


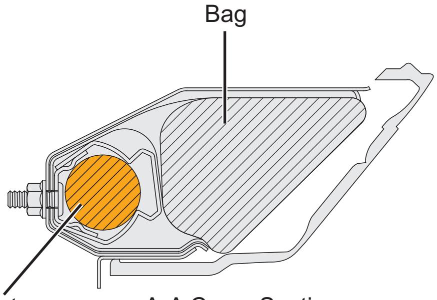


A-A Cross Section

Front Knee Airbag

■ Front knee airbags are mounted in the lower portion of the instrument panel on the driver side and the front passenger side, and activated in the event of a frontal collision.

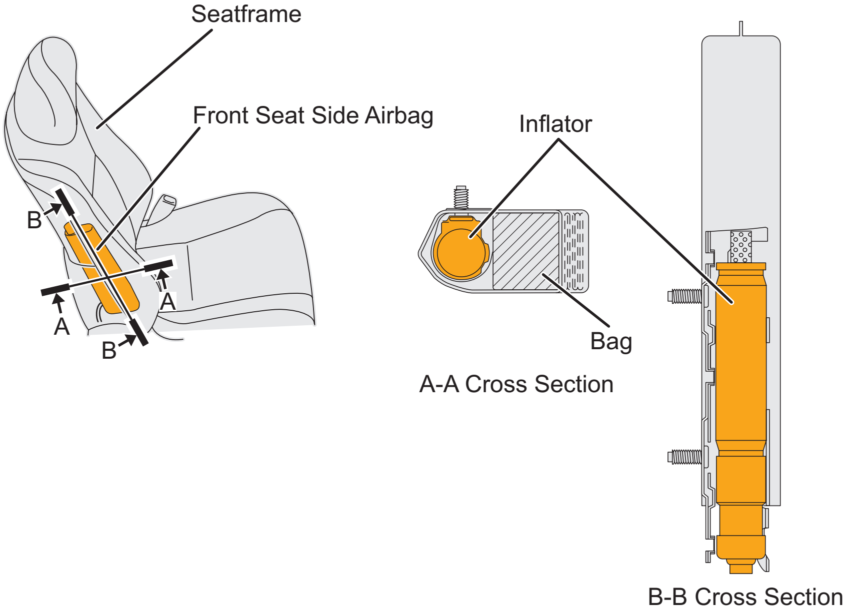




A-A Cross Section

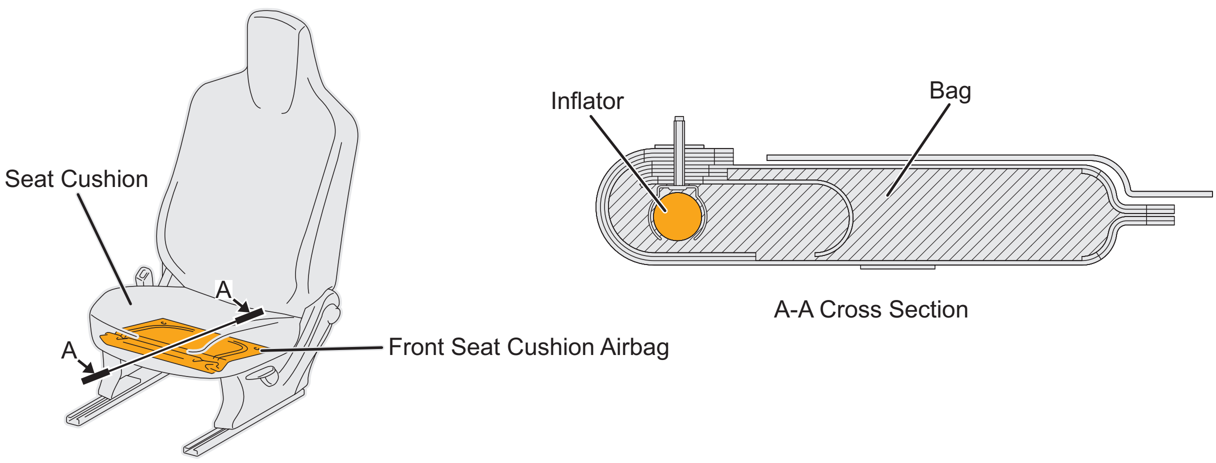
Front Seat Side Airbag

- Front seat side airbags are mounted in the seatframe of the driver seat and the front passenger seat, and activated in the event of a side collision.
- In some vehicles, front seat side airbags are also activated in the event of a frontal collision.



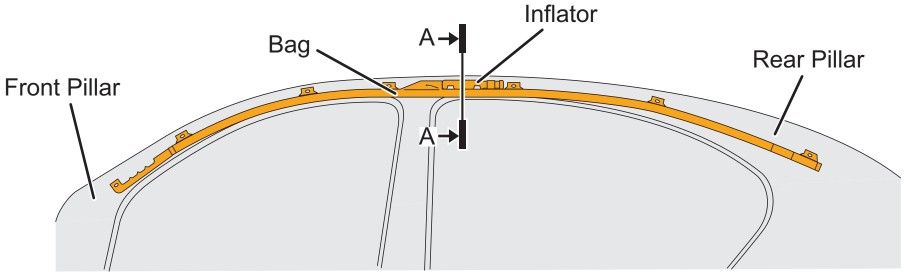
Front Seat Cushion Airbag

- Front seat cushion airbags are mounted in the seat cushion of the driver seat and the front passenger seat, and activated in the event of a frontal collision.

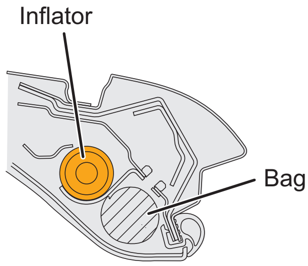


Curtain Shield Airbag

- Curtain shield airbags are mounted in the area between the front pillar and rear pillar on the driver side and the front passenger side, and activated in the event of a side collision.
- In some vehicles, curtain shield airbags are also activated in the event of a frontal collision.



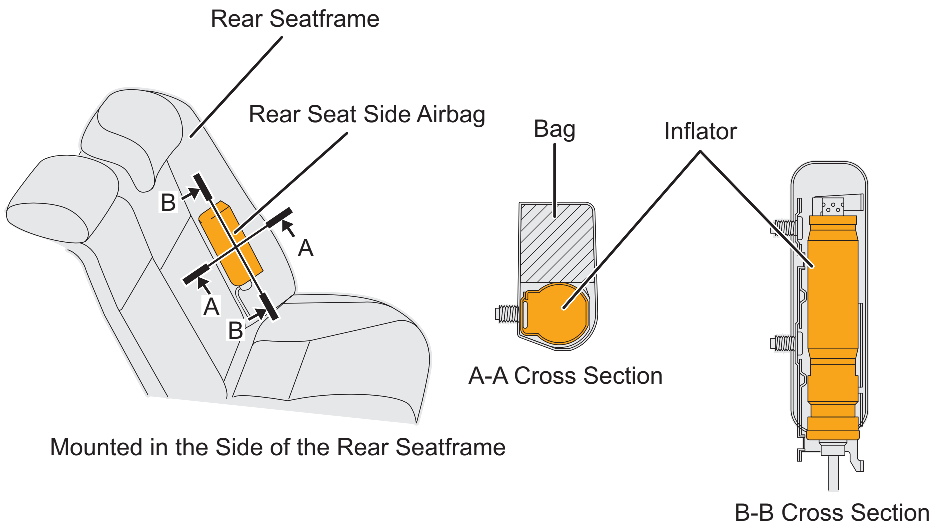
Curtain Shield Airbag

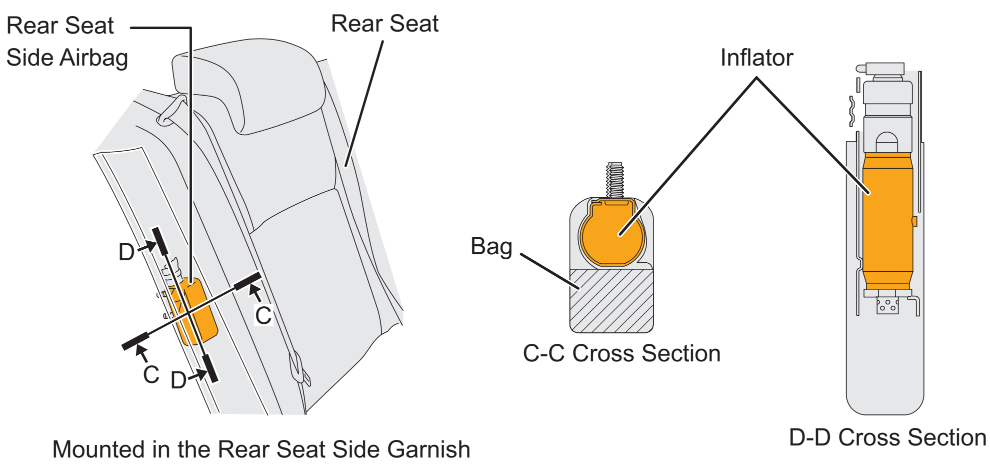


A-A Cross Section

Rear Seat Side Airbag

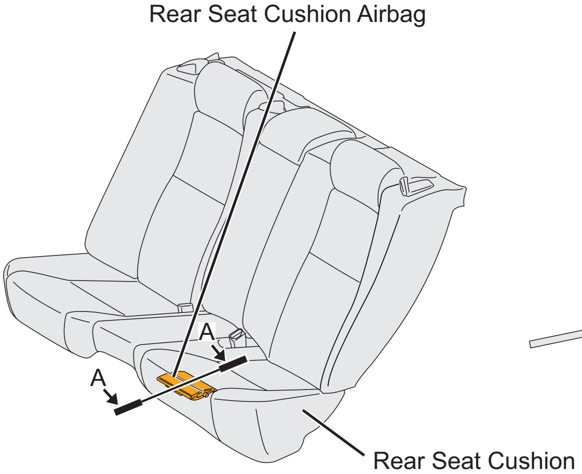
- Rear seat side airbags are mounted in the sides of the rear seatframe or rear seat side garnish and activated in the event of a side collision.
- In some vehicles, rear seat side airbags are also activated in the event of a frontal collision.

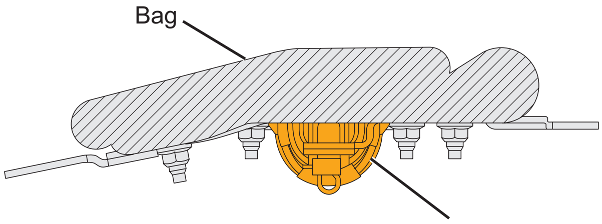




Rear Seat Cushion Airbag

■ Rear seat cushion airbags are mounted in the rear seat cushions and activated in the event of a frontal collision.

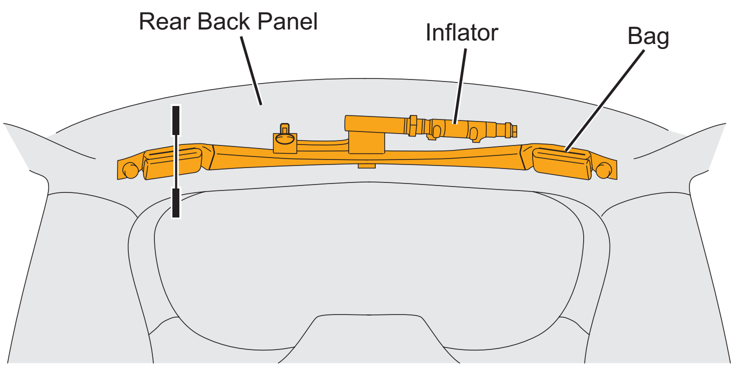




A-A Cross Section

Back Window Curtain Shield Airbag

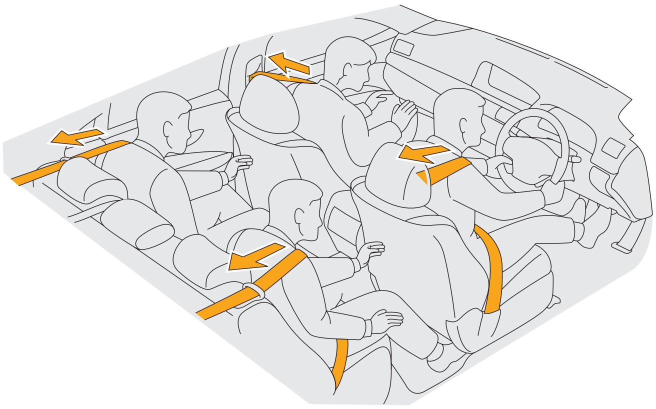
■ A back window curtain shield airbag is mounted in the upper portion of the rear back panel (back door mounting section) and activated in the event of a rear collision.



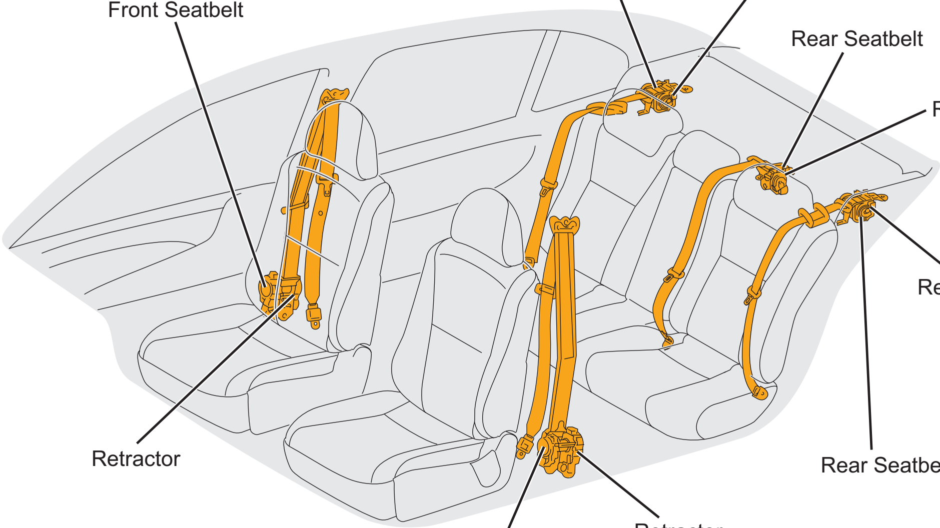
Back Window Curtain Shield Airbag

Seatbelt Pretensioner

- When the vehicle receives a strong impact from the front, the seatbelts are retracted to optimally restrain the occupants.
- In some vehicles, seatbelt pretensioners are also activated in the event of a side collision.



- A pretensioner mechanism is built into the retractor of each of the front seatbelts. Some models have a seatbelt pretensioner mechanism in the rear seatbelts.
- The pretensioner mechanism consists of a gas generator, a piston and a pinion gear.
- When an airbag sensor detects a strong impact, an ignition signal is sent to a gas generator. When the gas generator is ignited, gas is generated and its pressure rotates a gear that retracts the seatbelt.

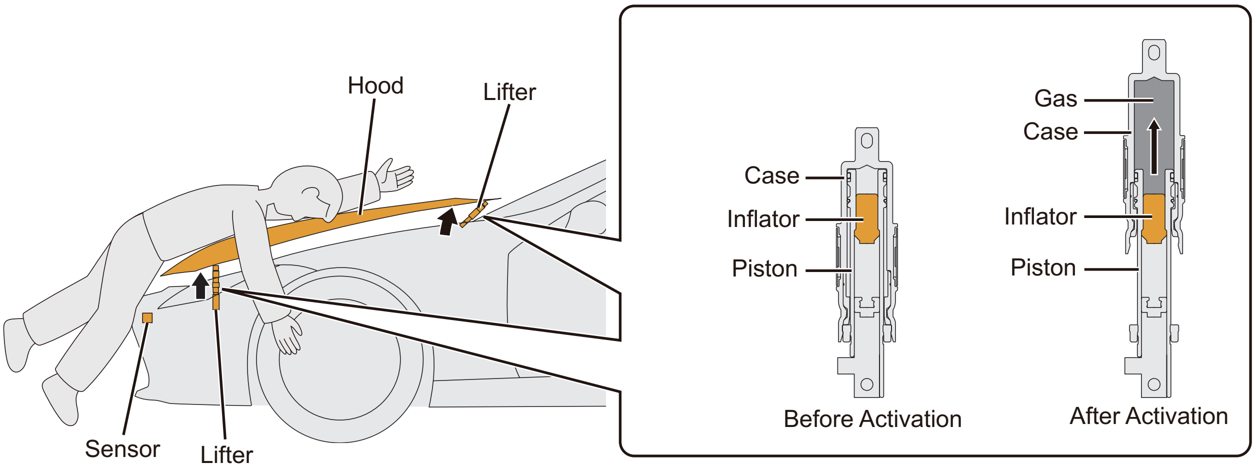


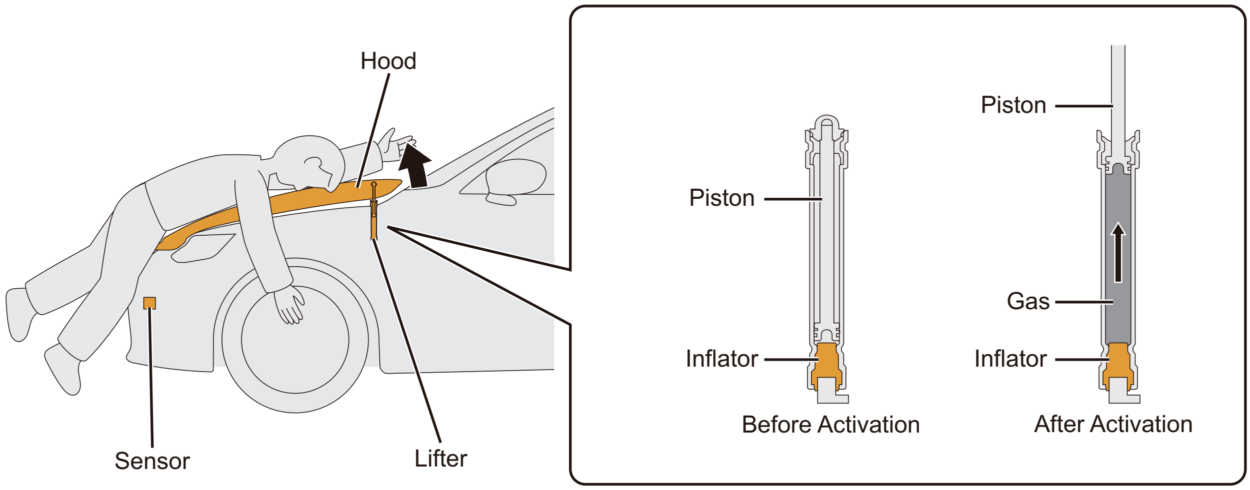
- Refer to the QRS for each model for locations of the seatbelt pretensioners.

- The seatbelt pretensioners may remain powered for up to 90 seconds after the vehicle is shut off and disabled (see page 69). Wait at least 90 seconds before starting any operation. Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from unintentional actuation of the seatbelt pretensioner.
- To prevent serious injury or death from unintentional seatbelt pretensioners actuation, avoid breaching the seatbelt pretensioners.

Pop Up Hood

- During a frontal collision, the pop up hood lifts the entire hood or the rear end, ensuring ample space inside the engine room and contributing to reduced collision impact to the head of pedestrians.
- When the sensor inside the front bumper detects a strong impact, an ignition signal is sent to the inflator. When the inflator is ignited, the piston inside the lifter is pushed up, lifting the hood.





WARNING

- The pop up hood may remain powered for up to 90 seconds after the vehicle is shut off and disabled (see page 69). Wait at least 90 seconds before starting any operation. Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from unintentional actuation of the pop up hood.
- If a lifter is cut, the pop up hood inflator may unintentionally deploy. To prevent serious injury or death from unintentional pop up hood actuation, avoid breaching the lifters.
- If the hood release lever is pulled after the pop up hood is activated, the hood may rise more, possibly resulting in an injury.
- After the pop up hood is activated, the hood cannot be lowered by hand. If the hood is pushed down excessively, it may be deformed, possibly resulting in an injury.
- Immediately after the pop up hood is activated, the lifters are very hot and may cause burns if touched.

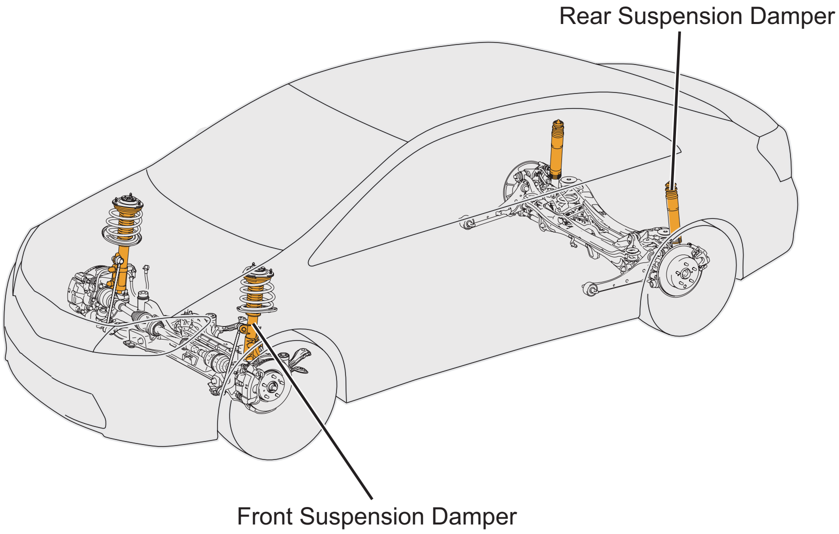
Gas-filled Damper

- Gas-filled dampers are used in various components, such as in the suspension (shock absorbers), engine hood stays, and for other various purposes. Nitrogen (N2) gas is used in these dampers.
- Nitrogen (N2) gas is colorless, odorless and harmless.
- Refer to the QRS for each model for the location of these gas-filled dampers.

> **WARNING**
> - If a gas-filled damper is heated in an event of a vehicle fire, the damper may explode due to expanded nitrogen (N2) gas, possibly causing an injury.
> - If a gas-filled damper is cut, nitrogen (N2) gas may cause metal shavings from the cut to scatter. Wear appropriate safety gear such as safety glasses when cutting a gas-filled damper.

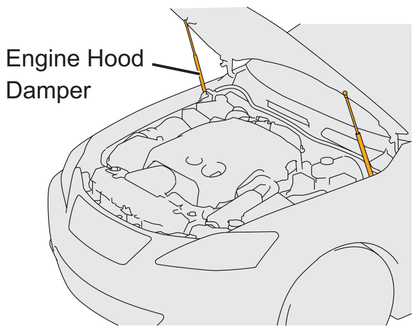
Front and Rear Suspension Dampers

- Suspension dampers are installed in the front and the rear suspension.



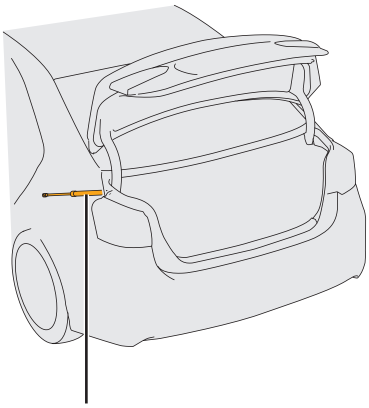
Engine Hood Damper

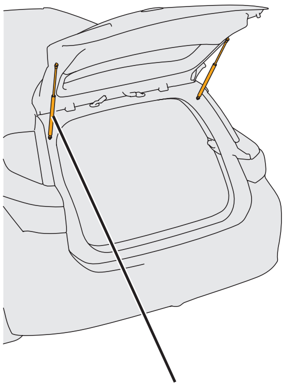
- Gas-filled dampers are installed as the stays for the engine hood.

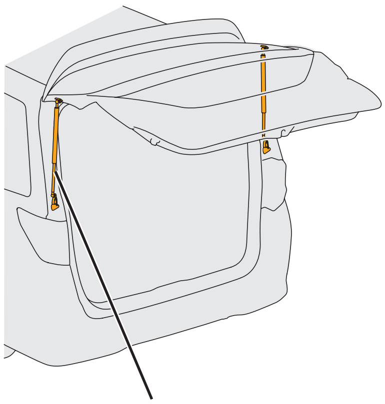


Luggage Compartment, Hatchback Door, Back Door Dampers

- Gas-filled dampers are installed as the stays for the luggage compartment, the hatchback door and the back door.

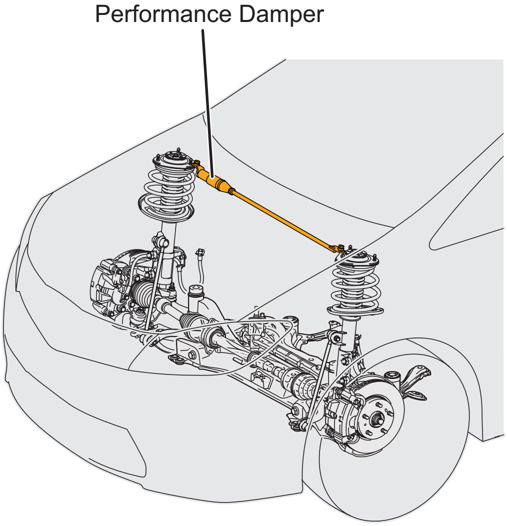


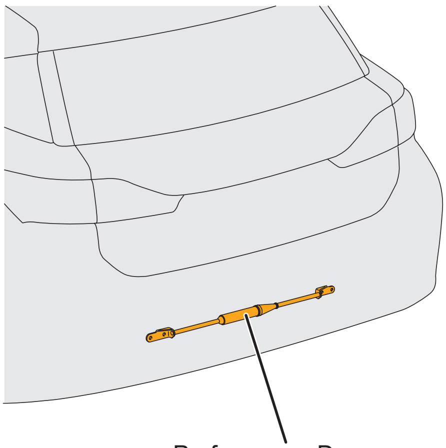




Performance Damper

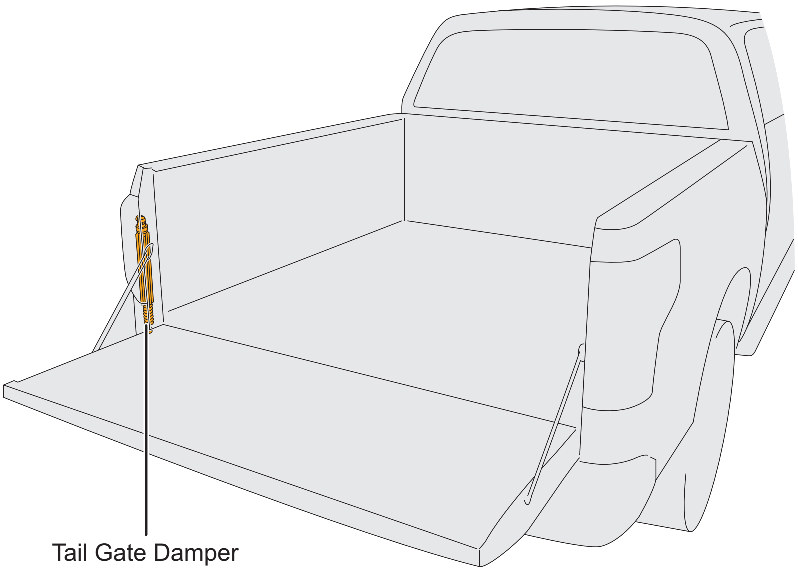
- Performance dampers are installed across the front and the rear suspension towers and between the right and left sides of the rear lower structural frame (near the rear bumper).

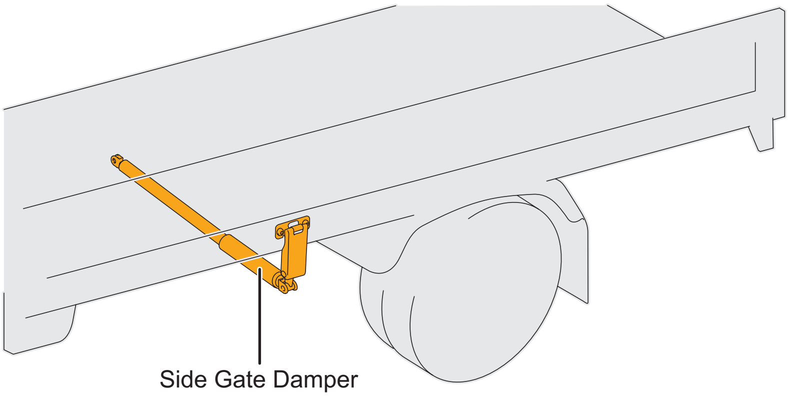




Tail Gate Damper, Side Gate Damper

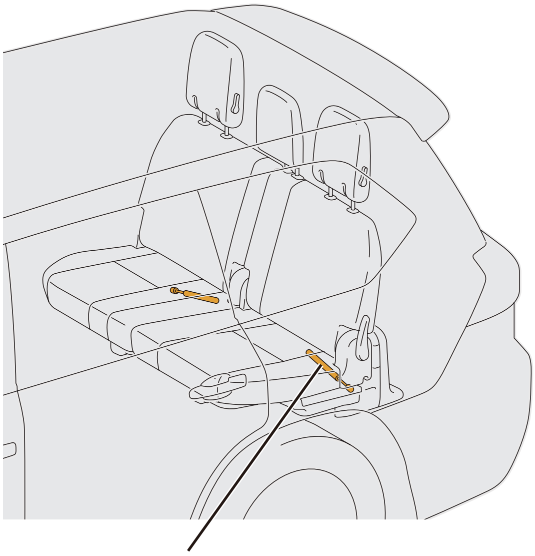
■ Gas-filled dampers are installed as the stays for the tail gate and side gate.

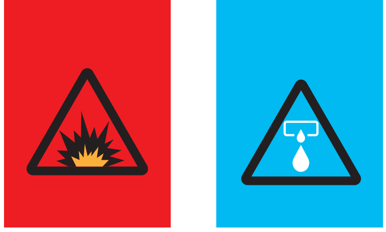




Seat Damper

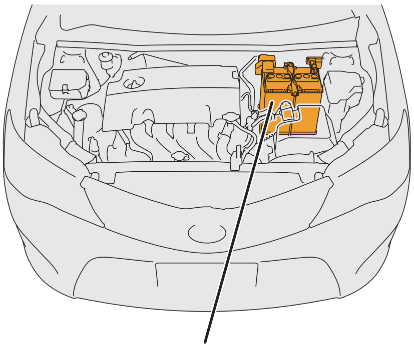
■ Seat dampers are equipped to the lower surface of the seat.

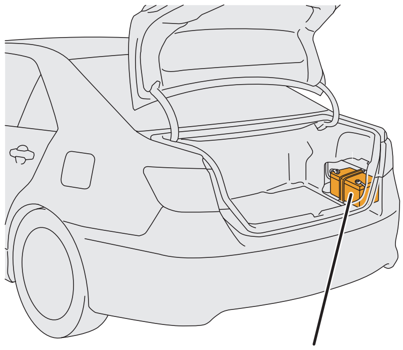




12 V Battery

- The 12 V battery supplies power to the ECUs that control various systems and auxiliary components such as the power door lock, power window, power tilt and telescopic steering, power seat, etc.
- To ensure safe emergency response operations, it is necessary to completely shut off the vehicle (see page 69). Disconnect the negative battery terminal from the 12 V battery before performing work and shut off the power to the electrical system to prevent electrical fires and to keep the vehicle from starting.
- 12 V battery electrolyte contains dilute sulfuric acid.
- Depending on the model the 12 V battery is installed in the engine compartment, luggage compartment, under the rear seats, etc.
- Refer to the QRS for each model for locations of the 12 V battery.





WARNING

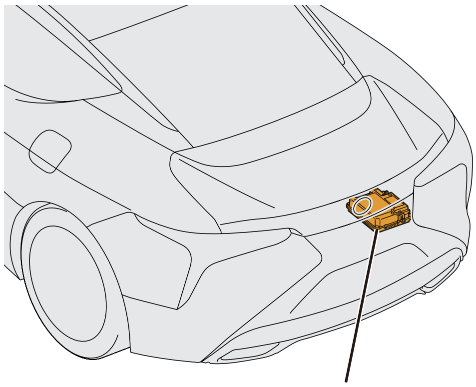
- There is a possibility of explosion due to ignition of the hydrogen gas generated from the 12 V battery. Therefore, do not allow any open sparks or open flames nearby the 12 V battery.
- Dilute sulfuric acid may cause irritation of the skin if contacted. Wear appropriate protective equipment such as rubber gloves and safety goggles when there is a risk of touching electrolyte.

NOTICE

- Once the 12 V battery is disconnected (see page 69), power controls will not operate. To facilitate emergency response operations, lower the windows, open the back door, unlock the doors and take other necessary actions before shutting off the vehicle.
- 12 V battery electrolyte contains ingredients that damage painted surfaces. If any comes in contact with the vehicle body, discoloration or other damage may occur.

Sub-battery

- A sub-battery is installed in vehicles equipped with an electro shiftmatic system and electric parking brake.
- Dual systemization of the 12 V battery power supply enables the parking brake lock operation when the 12 V battery malfunctions.
- By disconnecting the nagative (-) terminal of the 12 V battery and shutting of the electricity for 10 minutes or more, the protection relay inside the sub-battery is released and the voltage drops to 0 V.
- 10 nickel-metal hydride automotive batteries are connected in series in the sub-battery, ensuring a 12 V power source.
- A strong alkaline (pH 13.5) potassium hydroxide water solution is used as the sub-battery electrolyte. The electrolyte is soaked into non-woven fabric. However, if the sub-battery is damaged in any way, it may leak.
- Sub-battery is installed in the lower part of the trunk room.



WARNING

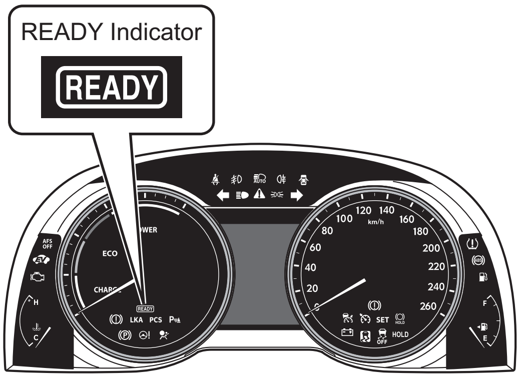
- There is a possibility of explosion due to ignition of the hydrogen gas generated from the sub-battery. Therefore, do not allow any open sparks or open flames nearby the sub-battery.
- Strong alkaline (pH 13.5) potassium hydroxide water solution is harmful to the human body. In cases where touching the electrolyte is unavoidable or there is a danger of it being touched, perform work wearing appropriate protective equipment such as rubber gloves and protective glasses.

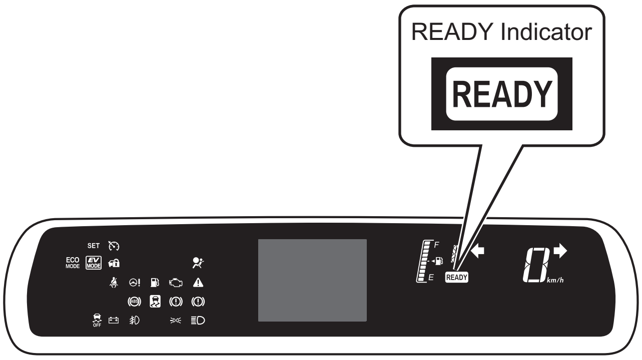
NOTICE

- After the negative (-) terminal of the 12 V battery has been disconnected and the power has been shut off, approximately 12 V is maintained between the positive (+) terminal and negative (-) terminal of the sub-battery for up to approximately 10 minutes.

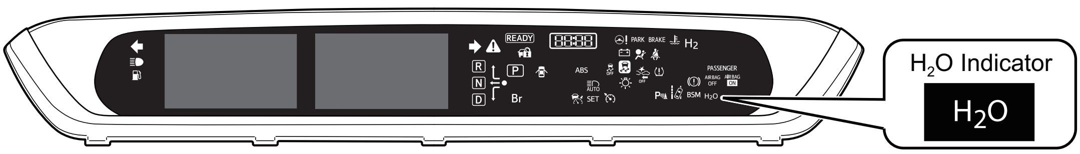
High Voltage System

- Hybrid vehicles (HV), plug-in hybrid vehicles (PHV), electric vehicles (EV) and fuel cell vehicles (FCV) use a motor driven by high voltage electricity (over 144 V, up to 650 V) to generate the driving torque. These vehicles are equipped with high voltage electrical components such as a high voltage battery, inverter/converter, transmission/transaxle (electric motor), A/C compressor, charger and voltage inverter as well as high voltage power cables.
- Refer to the Fuel Cell (FC) system (P35) for information on the high voltage parts specific to fuel cell vehicles (FCV).
- High voltage electrical components can be indicated by markings on their case/cover. High voltage power cables are indicated by an orange color.
- The cases/covers of the high voltage electrical components are insulated from the high voltage conductors inside the components. The vehicle body is insulated from the high voltage electrical components, and is safe to touch during normal conditions.
- The READY indicator in the combination meter turns on while the high voltage system is operating.





- The high voltage system is deactivated when the ignition switch or power switch is turned OFF. If an impact is detected (SRS airbag is activated) or if a high voltage leakage is detected, the high voltage system is automatically deactivated. When the high voltage is shut off, the READY indicator turns off. However, if the remote air conditioning system or plug-in charging system are being used, even if the READY indicator turns off, the high voltage system may still be active.
- For fuel cell vehicles (FCV), even if the READY indicator turns off, the high voltage system may still be active if the H_2O indicator in the combination meter is illuminated.



- Refer to the QRS for each model for the locations of the high voltage electrical components.

WARNING

- The high voltage system may remain charged for up to 10 minutes after the vehicle is shut off and disabled (see page 69). Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from severe burns and electric shock from the high voltage electrical system.
- To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components.
- When the person(s) in charge of handling the damaged vehicle is away from the vehicle, other person(s) may accidentally touch the vehicle and be electrocuted, resulting in severe injury or death. To avoid this danger, display a “HIGH VOLTAGE DO NOT TOUCH” sign to warn others (print and use page 25 of this guide).

CAUTION:
HIGH-VOLTAGE
DO NOT TOUCH.
Person in charge:

CAUTION:

HIGH-VOLTAGE

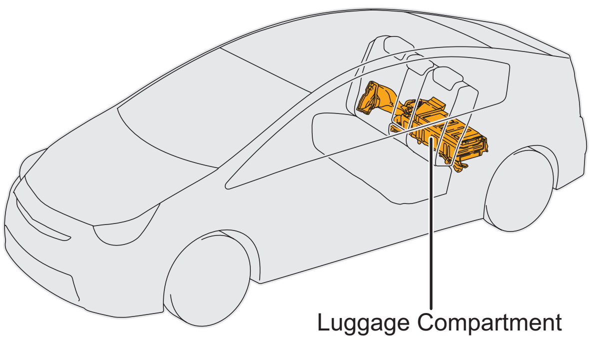
DO NOT TOUCH.

Person in charge: ____________________

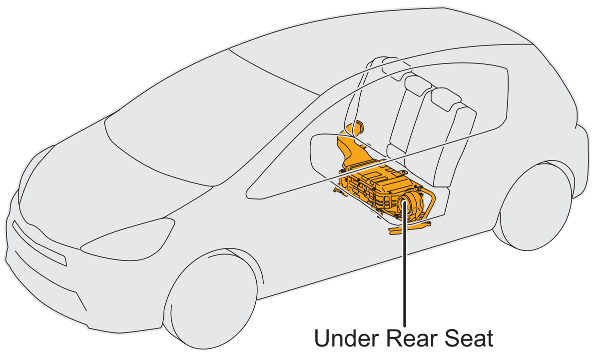
When performing work on the HV system, fold this sign and put it on the roof of the vehicle.

High Voltage Battery

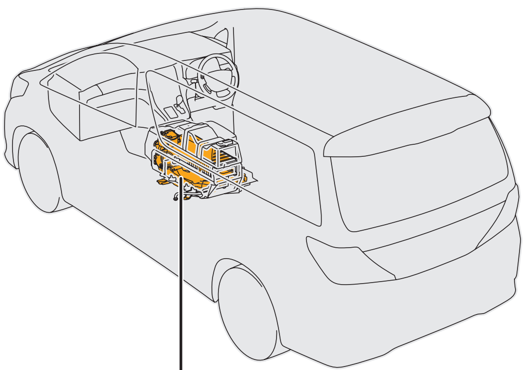
- The high voltage battery for the motor stores high voltage electricity (144 to 310.8 V). Depending on the model the battery is installed in the luggage compartment, under the rear seats, under the center console or under the floor.



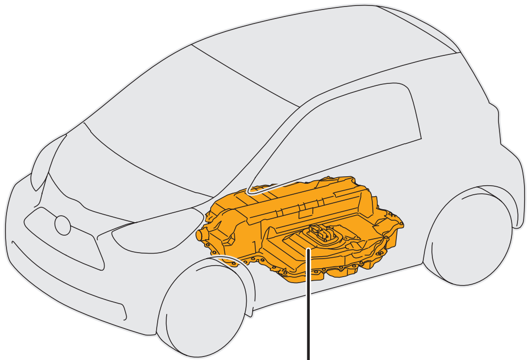
Luggage Compartment



Under Rear Seat

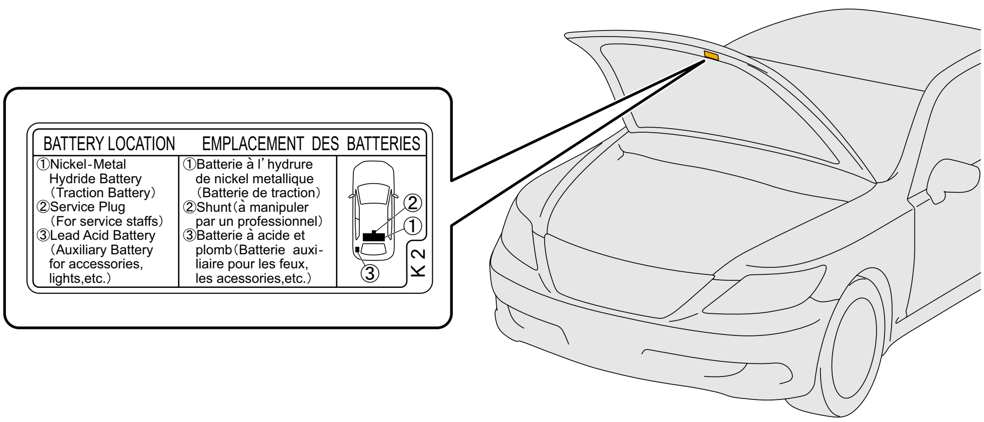


Under Center Console



Undercarriage

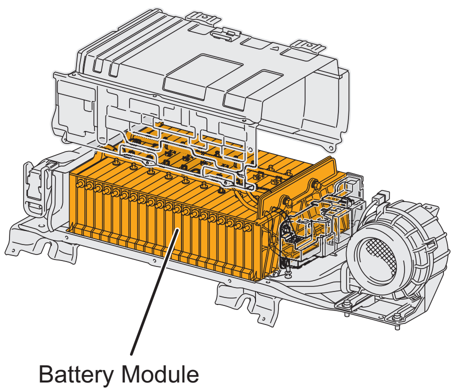
- An under-hood label shows the location of the high voltage battery.

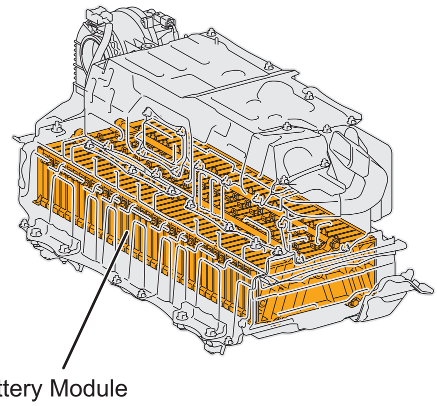


■ A Nickel-metal hydride (Ni-MH) battery or lithium ion (Li-ion) battery is used as the high voltage battery.

1. Nickel-metal hydride (Ni-MH) battery

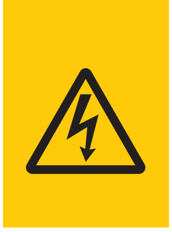
- Ni-MH batteries consist of 20 to 40 modules, each consisting of six 1.2 V cells, connected in series to obtain high voltage (144 to 288 V).
- The battery modules are contained within a metal case and accessibility is limited.
- A catastrophic crash that would breach both the metal battery pack case and a metal battery module would be a rare occurrence.
- The Ni-MH battery contains a strong alkaline electrolyte (pH 13.5). The electrolyte, however, is absorbed in the cell plates and will not normally spill or leak out even if a battery module is cracked.
- Electrolyte leakage from the HV battery pack is unlikely due to its construction and the amount of available electrolyte contained within the Ni-MH modules. Any spillage would not warrant a declaration as a hazardous material incident.





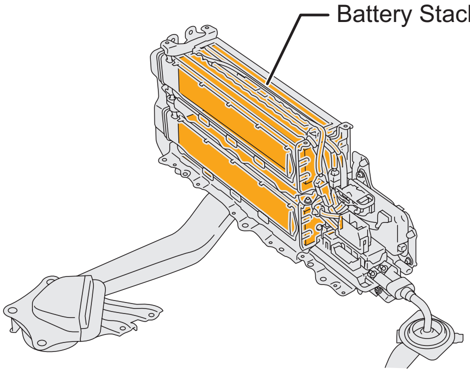

WARNING

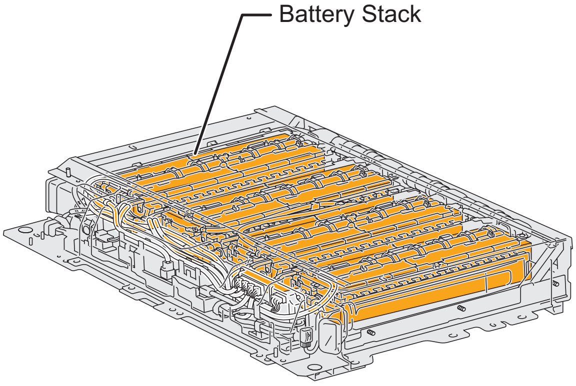
■ Strong alkaline electrolyte (pH 13.5) is harmful to the human body. To avoid injury by coming in contact with the electrolyte, wear appropriate protective equipment such as rubber gloves and safety goggles when there is a risk of touching electrolyte.



2. Lithium ion (Li-ion) battery

- Li-ion batteries consist of multiple stacks, each stack consisting of 14 to 42 cells. Two to four battery stacks are connected in series to obtain high voltage (201.6 to 310.8 V).
- The battery cells are contained within a case and accessibility is limited.
- A catastrophic crash that would breach both the metal battery stack case or battery frame and a metal battery cells would be a rare occurrence.
- The Li-ion battery electrolyte, mainly consisted of carbonate ester, is a flammable organic electrolyte. The electrolyte is absorbed into the battery cell separators, even if the battery cells are crushed or cracked, it is unlikely that liquid electrolyte will leak.
- Any liquid electrolyte that leaks from a Li-ion battery cell quickly evaporates.



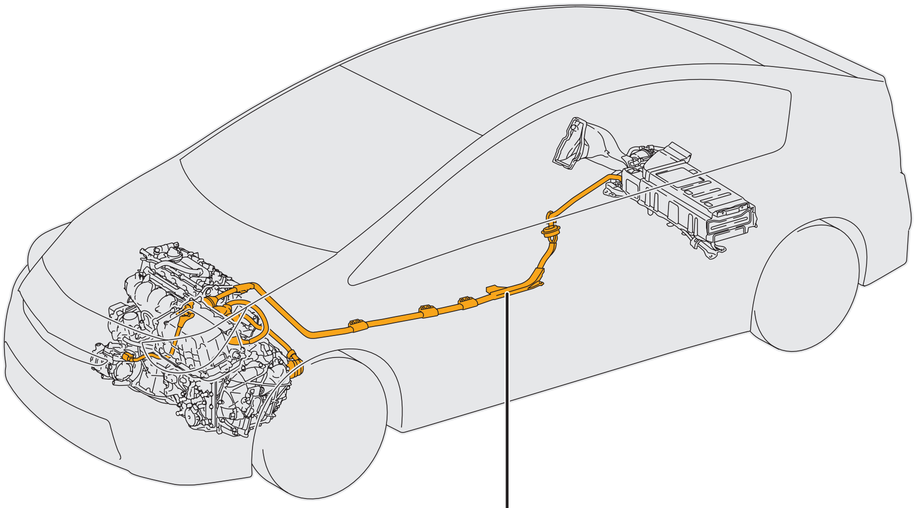


WARNING

- The flammable organic electrolyte which primarily contains carbonate ester is harmful to the human body. In case of contact with the electrolyte, it may irritate the eyes, nose, throat and skin. In case of contact with the smoke or vapor from leaked electrolyte or a burning battery, it may irritate the eyes, nose or throat. To avoid injury by coming in contact with the electrolyte or vapor, wear appropriate protective equipment such as rubber gloves, safety goggles, protective mask or SCBA when there is a risk of touching electrolyte.
- If the electrolyte spills, keep it away from fire and ensure the area is well ventilated. Absorb the electrolyte with a waste cloth or equivalent absorbing material and keep it in an airtight container until disposed of.

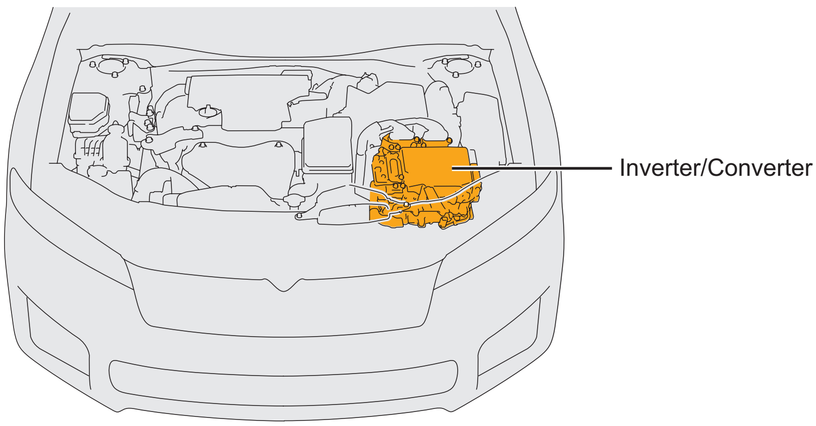
High Voltage Power Cable

- High voltage power cables are indicated by an orange color and are used to connect high voltage electrical components such as the high voltage battery inverter/converter, electric motor, A/C compressor and charger.
- The high voltage power cables are installed in the engine/motor compartment and in the center of the vehicle (routed through the center tunnel) or on either side away from the rocker panels.
- Also, high voltage cables are used in the plug-in charging system (refer to P32).



Inverter/Converter

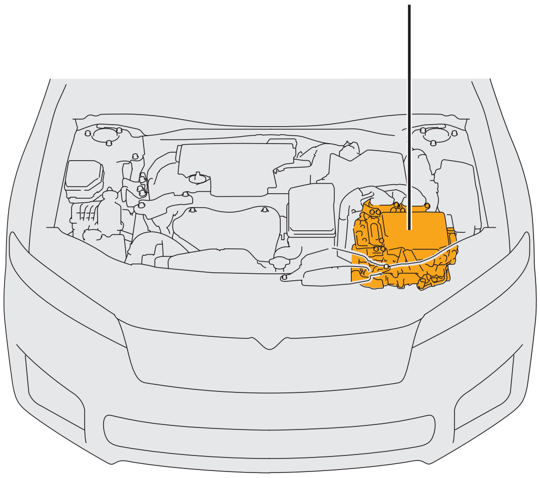
- The inverter/converter installed in the engine/motor compartment boosts and inverts the DC electricity from the high voltage battery to AC electricity that drives the electric motor.
- The inverter/converter of fuel cell vehicles (FCV) also supplies an electric current converted to AC to the FC air compressor.

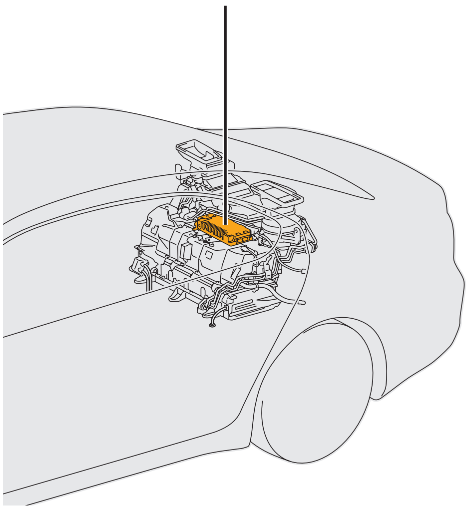


DC/DC Converter

■ The DC/DC converter lowers the DC electricity from the high voltage battery to supply it to electric accessories such as the headlights and power windows, and to charge the 12 V battery.

■ The DC/DC converter is built into the inverter/converter or installed in the area near the high voltage battery on some models.

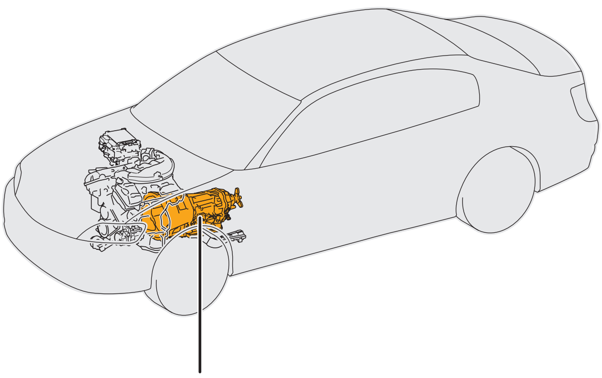


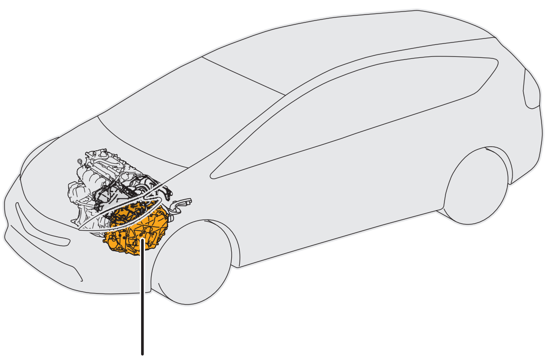


HV/EV/FCV Transmission
HV/EV/FCV Transaxle

■ The HV/EV/FCV transmission/transaxle contains an electric motor/generator that is powered by output voltage (up to 650 V) from the inverter/converter, and charges the high voltage battery.

■ The HV/EV/FCV transmission/transaxle is installed in the engine compartment or motor compartment. Location varies depending on layout.

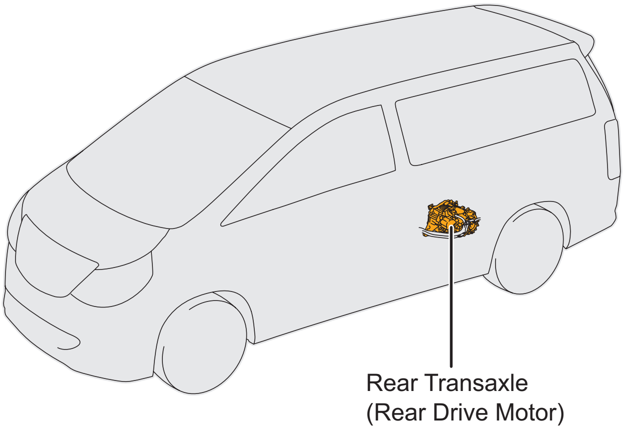




Rear Drive Motor

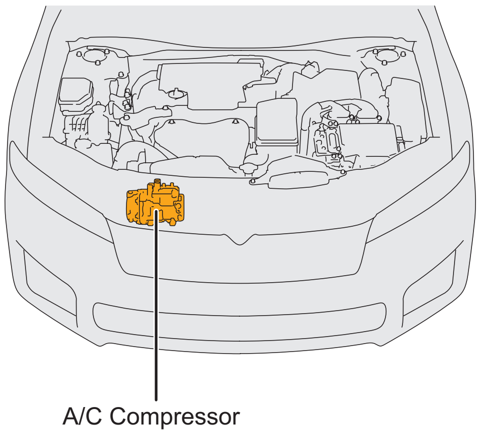
■ The rear drive motor is powered by output voltage (up to 650 V) from the inverter/converter.

■ It is built into the rear transaxle and located above the rear driveshafts.



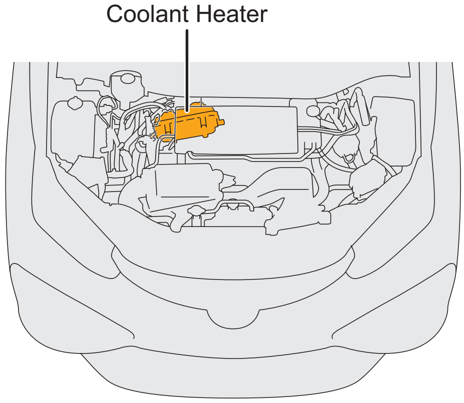
A/C Compressor

■ The A/C compressor used on hybrid vehicles (HV), electric vehicles (EV) and fuel cell vehicles (FCV) contains an electric motor that is powered by electricity from the high voltage battery. It is installed in the engine/motor compartment.



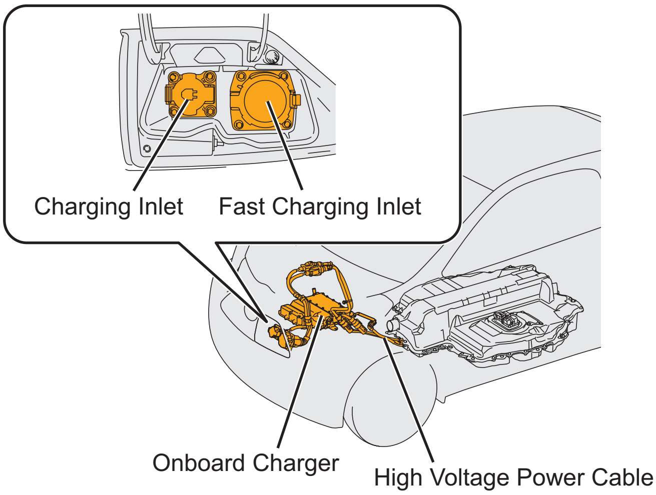
Coolant Heater

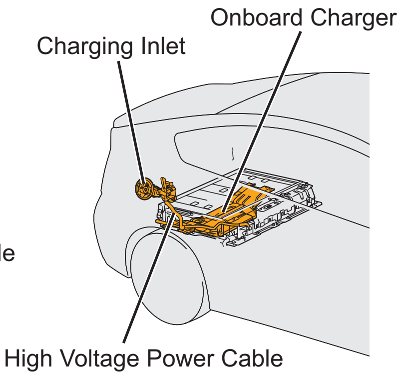
- Fuel cell vehicles (FCV) is equipped with a coolant heater to heat the coolant, installed inside the motor compartment.
- The coolant heater is operated using the power from the high voltage battery.

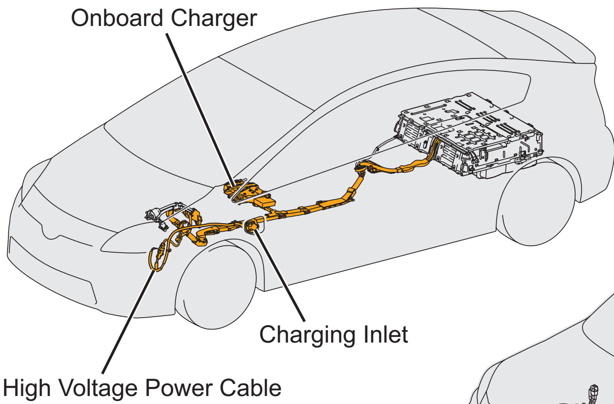


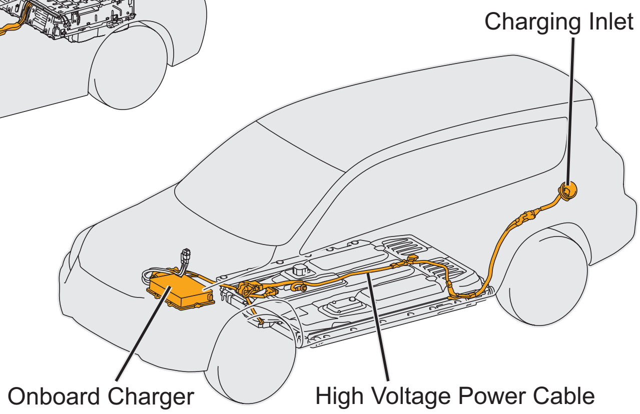
Plug-in Charging System

- Plug-in hybrid vehicles (PHV) and electric vehicles (EV) are equipped with a plug-in charging system in order to charge the high voltage battery from an external power source.
- The plug-in charging system is mainly comprised of an onboard charger and charging inlet.
- The onboard charger converts the AC supplied from an external power source to DC, boosts it, and then uses it to charge the high voltage battery.
- The charger inlet receives the charge to the high voltage battery from an external power source. Also, some electric vehicles have a separate fast charging inlet which can be used at fast chargers (DC 500 V).
- The orange power cables are connected to the charging inlet, which is supplied high voltage during charging.







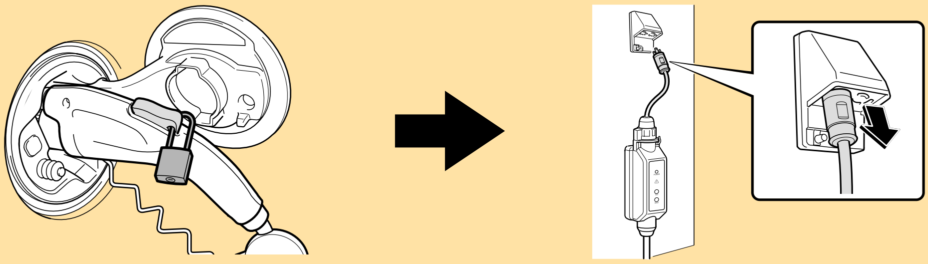


WARNING

■ To prevent serious injury or death from severe burns or electric shock, shut off the utility circuit supplying power to the charge cable before disconnecting it if the vehicle, charge cable or charger is submerged in water.

NOTICE

■ If the lock of the charge cable assembly connector cannot be released, turn OFF or unplug the external charger, or turn its main breaker OFF.



■ The lock of the charge cable assembly connector cannot be released during fast charging. If charging does not stop even when the charger is turned OFF, turn its main breaker OFF.

Fuel Cell (FC) System

- Fuel cell vehicles (FCV) use a motor for driving force in the same way as hybrid vehicles. In order to drive the motor, a high voltage (over 200 V, up to 650 V) is used. Not having an engine, the vehicle uses a motor driven by the power generated by a chemical reaction between the hydrogen fuel and oxygen in the air.
- Fuel cell vehicles (FCV) are equipped with dedicated high voltage components such as an FC stack, hydrogen pump, FC water pump, FC water pump and hydrogen pump inverter, FC boost converter and FC air compressor.
- To use hydrogen for power generation, fuel cell vehicles (FCV) are equipped with hydrogen pipes and hydrogen-related parts such as an FC stack, hydrogen tanks, etc.
- The hydrogen tanks are filled with high pressure hydrogen gas (a maximum of 70 MPa (714 kgf/cm^2, 10,153 psi) at 15°C (59°F)).
- The hydrogen-related parts are inside cases/covers. Also, some of the insulation on high-pressure hydrogen pipes is in red.
- Hydrogen gas is colorless, odorless, and harmless.
- Hydrogen gas is flammable, and can ignite in a wide range of concentrations (4 to 74.5%). However, it diffuses easily and tends not to accumulate, so a small amount of leak would quickly dissipate to a concentration that cannot ignite.
- In the case of hydrogen leakage, the hydrogen detector equipped on the vehicle detects the hydrogen leak and shuts off the supply of hydrogen to prevent a mass leak. Also, hydrogen-related parts are located outside the cabin to allow leaked hydrogen to be easily diffused.
- If a collision is detected, the supply of hydrogen is shut off to prevent a mass leak due to vehicle damage.
- For details about the installation locations of hydrogen-related parts, refer to the QRS (Quick Reference Sheet) for the vehicle.

WARNING

- If the sound of hydrogen leaking (a loud hissing sound) can be heard when working on the vehicle, or if the hydrogen concentration around the vehicle exceeds 4% when measured with a hydrogen concentration detector, immediately step away from the vehicle as there is a chance that the hydrogen gas may ignite.
- Even after the vehicle is stopped (refer to P69), hydrogen remains inside the FC stack, hydrogen tanks and other hydrogen-related parts, as well as inside the hydrogen pipe. In order to avoid fires and explosions, never cut or damage these hydrogen-related parts or the hydrogen pipe.
- When the person(s) in charge of handling the damaged vehicle are away from the vehicle and someone else accidentally approaches or touches the vehicle, death or serious injury may occur due to electrocution, a rupture, an explosion or fire. To avoid this danger, display “HIGH VOLTAGE DO NOT TOUCH” and ”HIGH-PRESSURE GAS DO NOT TOUCH” signs to warn others (print and use page 25 and 36 of this guide).

CAUTION:
HIGH-PRESSURE GAS
DO NOT TOUCH.
Person in charge:

CAUTION:

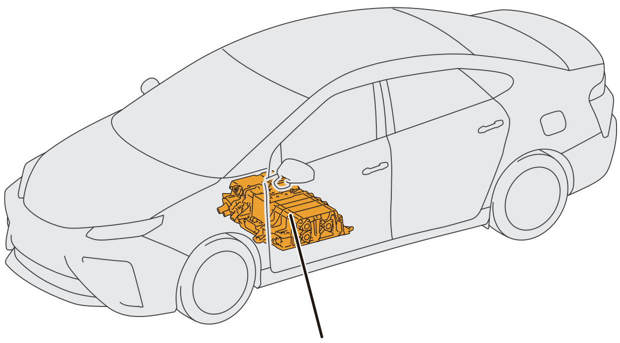
HIGH-PRESSURE GAS

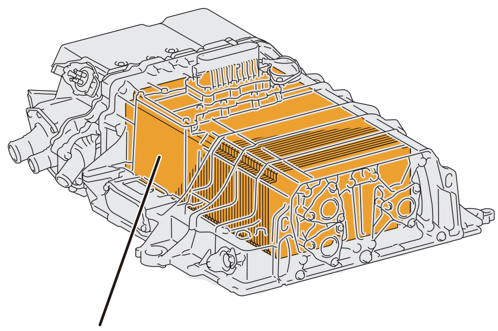
DO NOT TOUCH.

Person in charge: ____________________

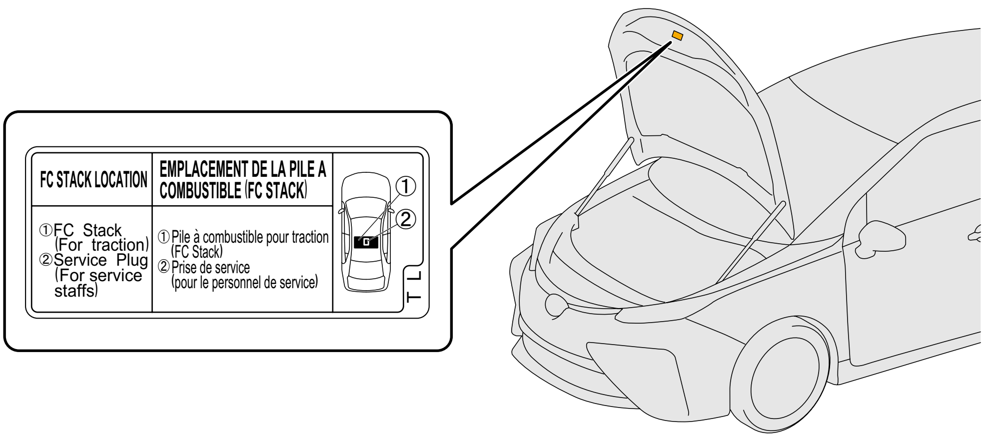
FC Stack

- The FC stack is a device to generate electricity through the chemical reaction between hydrogen and oxygen. Using the hydrogen supplied by the hydrogen tank and oxygen in the air drawn in from outside the vehicle, a high voltage of 200 V or higher is generated.
- The FC stack is installed underneath the floor.
- The FC stack generates power using so called “cells”, which are comprised of an electrolyte membrane sandwiched by separators. A few hundred cells are connected in a row to generate a high voltage.
- The cells are contained inside a metal case so that they are not easily touched.
- Water is generated through the chemical reaction between hydrogen and oxygen during power generation, and discharged via the discharge outlet.



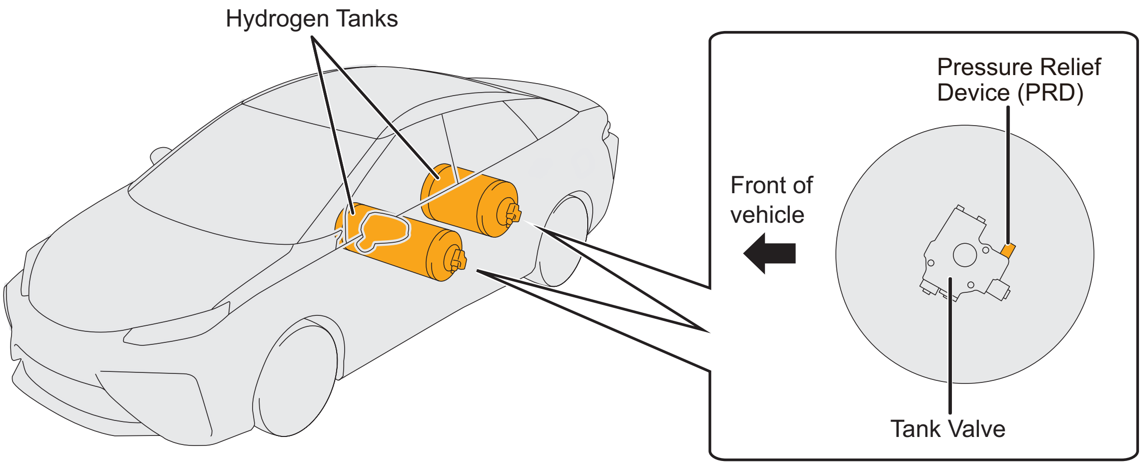


- An under-hood label shows the location of the FC stack.



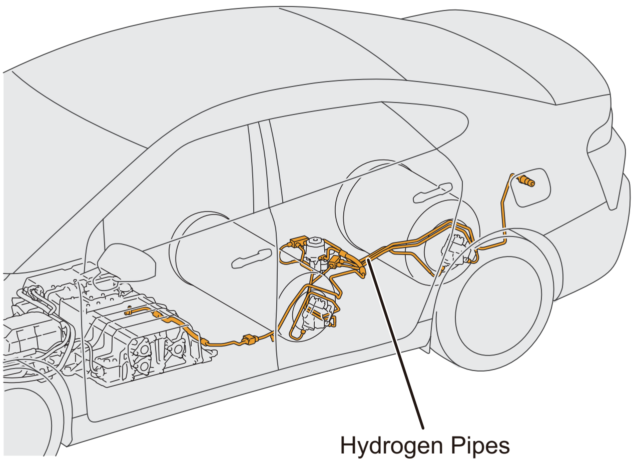
Hydrogen Tank

- The hydrogen tanks are filled with high pressure hydrogen gas (a maximum of 70 MPa (714 kgf/cm^2, 10,153 psi) at 15°C (59°F)) that is supplied to the FC stack.
- The hydrogen tanks are made of carbon fiber-reinforced plastic and located underneath the floor.
- The hydrogen detector used to detect hydrogen leaks is located near the tanks. If a specified concentration of hydrogen leakage is detected, the FC system cuts off the supply of hydrogen.
- Each tank is equipped with a pressure relief device (PRD) in order to prevent an explosion when the temperature of the hydrogen reaches abnormal levels due to a vehicle fire. The pressure relief device will open at approximately 110°C (230°F) to release the hydrogen gas in the tank outside of the vehicle.



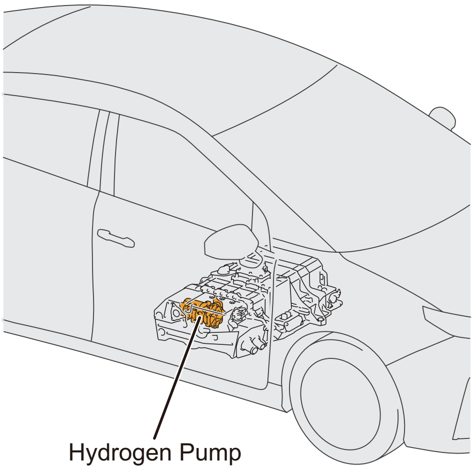
Hydrogen Pipes

- The hydrogen pipes connect the hydrogen-related parts such as the FC stack and hydrogen tanks.
- The hydrogen pipes are located underneath the floor.
- Some of the high-pressure hydrogen pipes are identified in red.



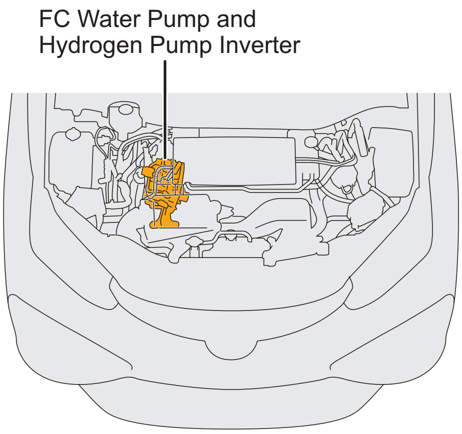
Hydrogen Pump

- The hydrogen pump circulates the hydrogen supplied from the hydrogen tanks into the FC stack.
- The hydrogen pump has a built-in motor that is operated using the high voltage from the FC water pump and hydrogen pump inverter. The hydrogen pump is installed underneath a cover at the side of the FC stack.



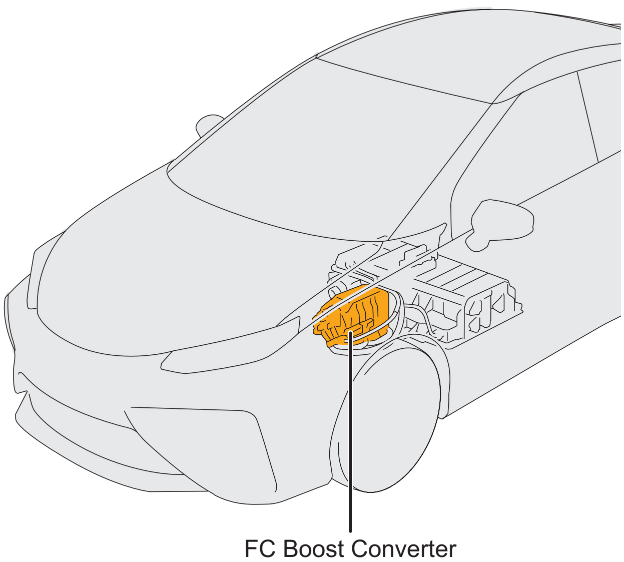
FC Water Pump and Hydrogen Pump Inverter

- The FC water pump and hydrogen pump inverter converts DC from the high voltage battery to AC, and supplies this current to the hydrogen pump and FC water pump.
- The FC water pump and hydrogen pump inverter is installed in the motor compartment.



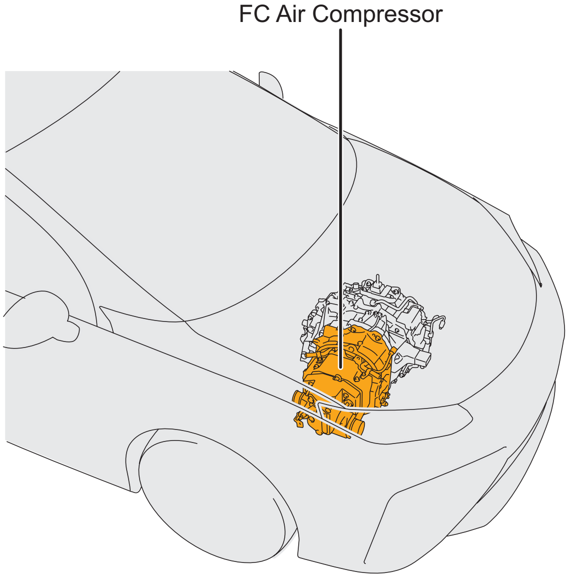
FC Boost Converter

- The FC boost converter increases the voltage of DC generated by the FC stack to a maximum of 650 V for motor operation, and then supplies this current to the inverter/converter.
- The FC boost converter is installed in the center tunnel (outside the cabin).



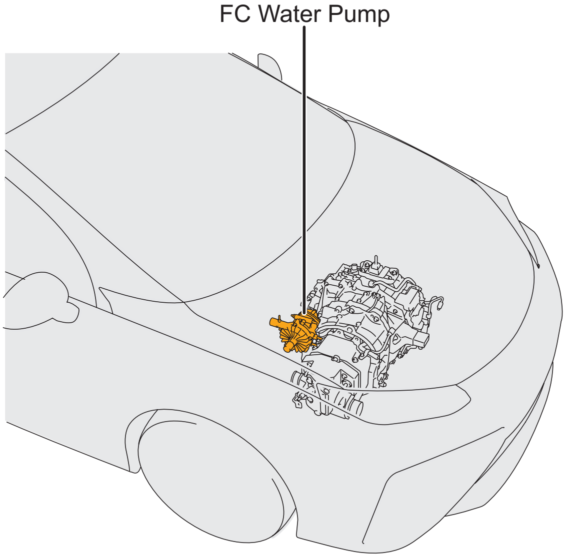
FC Air Compressor

- The FC air compressor supplies air (oxygen) to the FC stack.
- The FC air compressor has a built-in motor which is driven using the output voltage from the inverter/converter (up to 650 V), and is installed in the motor compartment.



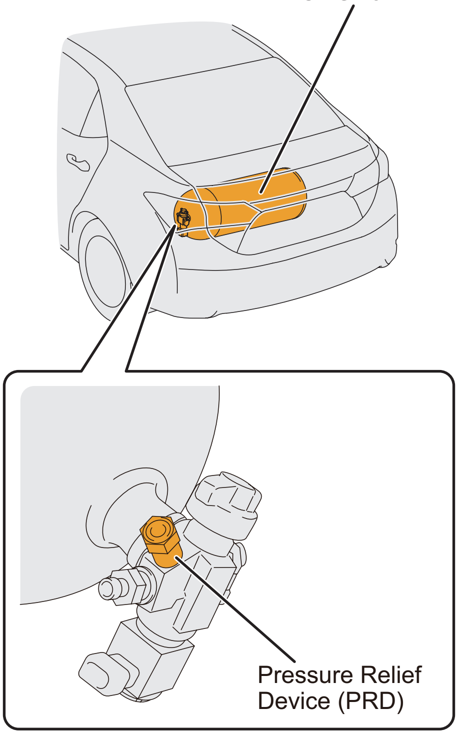
FC Water Pump

- The FC water pump circulates the coolant to cool the FC stack.
- The FC water pump has a built-in motor which is driven using the high voltage from the FC water pump and hydrogen pump inverter, and is installed in the motor compartment.



CNG Tank

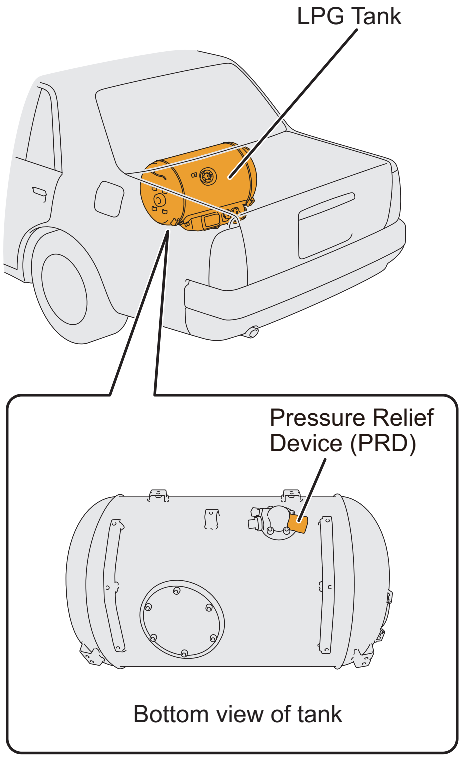
- The Compressed Natural Gas (CNG) tank is filled with compressed natural gas that is used as fuel for the engine at a maximum pressure of 20 MPa (204 kgf/cm^2, 2,900 psi).
- The CNG tank is made of metal and located in the luggage compartment, etc.
- The CNG tank is equipped with a pressure relief device (PRD) in order to prevent an explosion when the temperature of the natural gas reaches abnormal levels due to a vehicle fire. The pressure relief device will open at approximately 110°C (230°F) to release the natural gas in the tank outside of the vehicle.
- Natural gas is flammable and can ignite within a concentration of 5.3 to 15.0%.
- Natural gas mainly consists of methane, is harmless and diffuses upwards as it is lighter than air. Also, the gas is infused with a smell so that a leak can be quickly detected.



- If the sound of natural gas leaking (a loud hissing sound) can be heard when working on the vehicle, or if the smell of natural gas is present, immediately step away from the vehicle as there is a chance that the natural gas may ignite.

LPG Tank

- The Liquefied Petroleum Gas (LPG) tank is filled with compressed liquefied propane, butane, etc. that is used as fuel for the engine at a pressure of 1 MPa (10.2 kgf/cm^2, 145 psi) or less.
- The LPG tank is made of metal and located in the luggage compartment, etc.
- The LPG tank is equipped with a pressure relief device (PRD) in order to prevent an explosion when the pressure of the LPG reaches abnormal levels due to a vehicle fire. The pressure relief device will open when the pressure in the tank reaches a certain pressure to release the gas in the tank outside the vehicle.
- LPG is flammable and can ignite within a concentration of 2.4 to 9.5%.
- The main components of LPG, propane and butane are harmless and remain close to the ground as they are heavier than air. Also, the gas is infused with a smell so that a leak can be quickly detected.

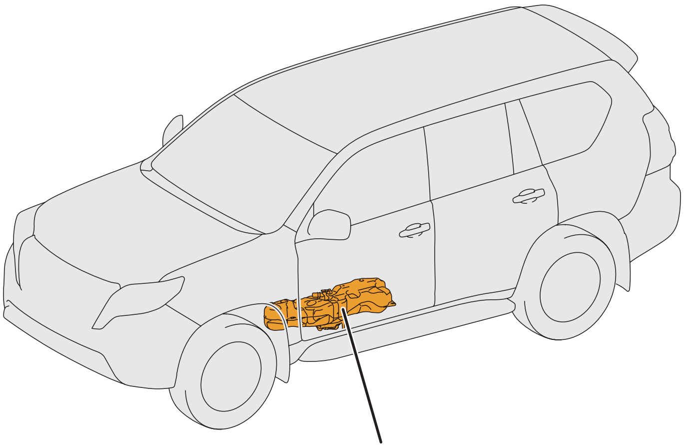


WARNING

- If the sound of LPG leaking (a loud hissing sound) can be heard when working on the vehicle, or if the smell of LPG is present, immediately step away from the vehicle as there is a chance that the LPG may ignite.

Urea Selective Catalytic Reduction (SCR) System

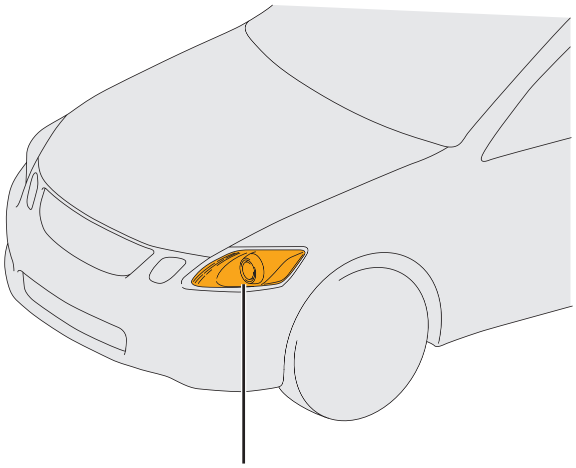
- The urea Selective Catalytic Reduction (SCR) system reduces harmful nitrogen oxides (NOx) in the exhaust gas using a urea solution.
- The urea solution is stored in the urea tank installed below the floor, etc.
- The urea solution is a colorless, odorless and harmless liquid. However, when the temperature is high, such as in the summer, there is a possibility that an irritating odor is produced by the thermolysis of urea solution.
- The urea solution is noncombustible. However, if the urea solution is heated due to a fire, etc., it breaks down and may emit a harmful gas.



- If you come in contact with smoke or vapor from a burning urea tank, it may irritate the eyes, nose or throat. To avoid injury by coming in contact with the smoke or vapor from a burning urea tank, wear appropriate protective equipment such as rubber gloves, safety goggles, a protective mask or SCBA when there is a risk of contacting the smoke or vapor.

High Intensity Discharge (HID) Headlights

- Headlights use High Intensity Discharge (HID) bulbs, which emit light by creating an electric discharge between electrodes inside the bulbs.
- When the HID headlights are turned on, high voltage of approximately 20,000 to 30,000 V is generated instantaneously. During illumination, the voltage from the 12 V battery is boosted to a maximum of 45 V in the electric circuit of the discharge headlights to drive the discharge headlights.

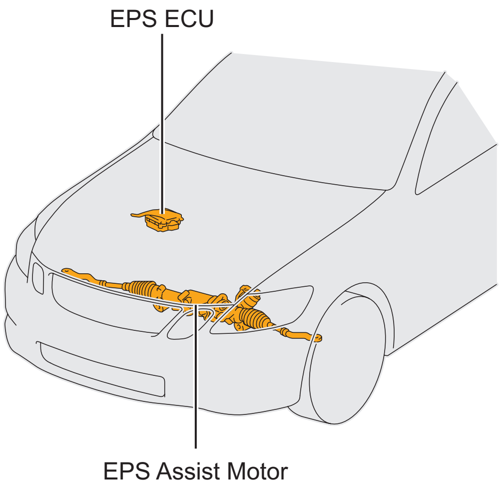


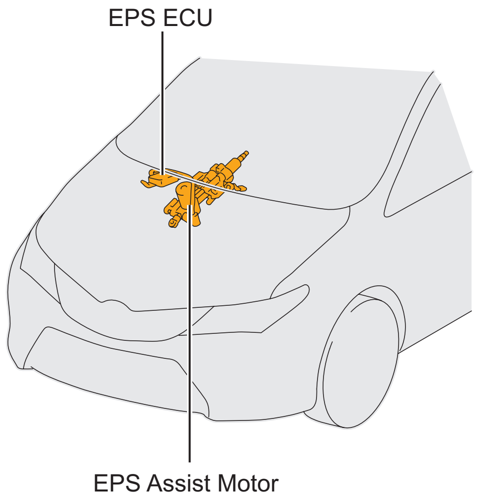
WARNING

- To prevent serious injury or death from electric shock, avoid touching, cutting, or breaching the bulb, socket, electric circuit and components of the headlights.
- To prevent burns, avoid touching the metal parts on the back of the headlights and the high voltage sockets while the discharge headlights are turned on or immediately after they are turned off.

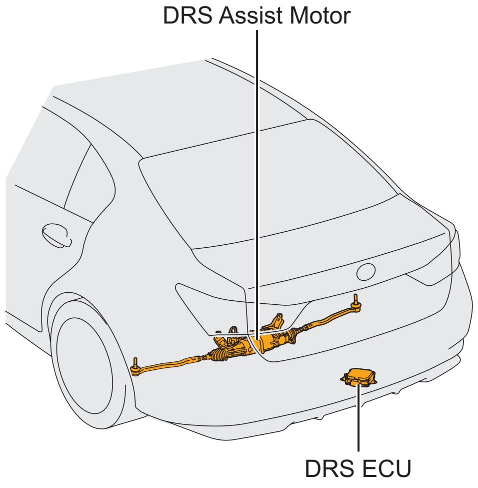
Electric Power Steering (EPS)

- The Electric Power Steering (EPS) system uses 12 V voltage which has been boosted to up to 46 V by the EPS ECU to drive an EPS assist motor.
- The EPS assist motor is built into the steering gear box or steering column.
- Some hybrid models use voltage from the high voltage battery to drive the EPS assist motor by lowering it to up to 46 V using an EPS the DC/DC converter.
- A wire which conducts up to 46 V connects the EPS ECU in the engine compartment or the instrument panel to the EPS assist motor.

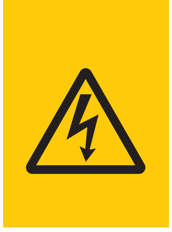




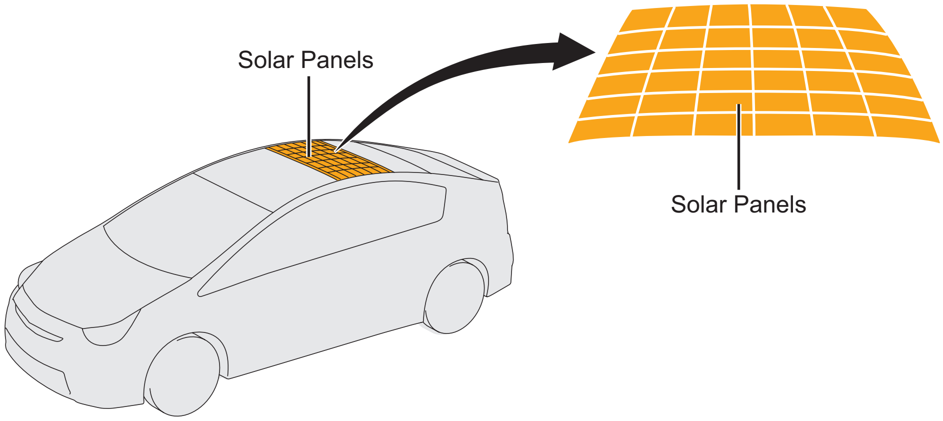
- The Dynamic Rear Steering (DRS) system equipped on some vehicle models uses 12 V voltage which has been boosted to up to 34 V by the DRS ECU to drive the DRS assist motor.



Solar Powered Ventilation System



- The solar powered ventilation system uses solar panels on the vehicle roof to generate up to 27 V of electricity. This electricity is used to power an electric fan which ventilates the cabin while the vehicle is parked in the hot sun.

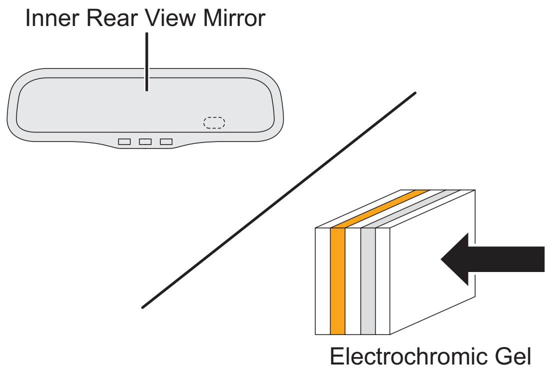


WARNING

- The solar panels generate electricity with even a small amount of sunlight. To stop generation of electricity, cover the solar panels completely with a material that will block sunlight.

EC Mirror

■ The inner rear view mirror has an auto glare-resistance function, which automatically changes the reflection rate of the mirror. This is done by controlling voltage applied to an electrochromic gel inside the mirror, according to the brightness sensed by a light sensor.



■ The electrochromic gel contains organic solvents.

> **WARNING**
>
> ■ Organic solvents may cause irritation of the skin if contacted. Wear appropriate protective equipment such as rubber gloves and safety goggles when there is a risk of touching electrochromic gel.

Structural Reinforcements

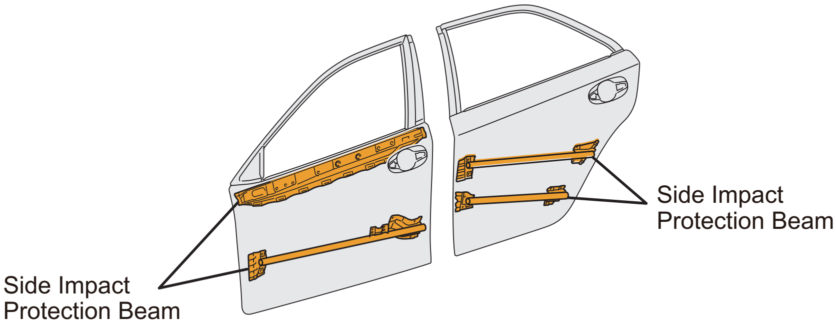
- A side impact protection beam and ultra high tensile strength sheet steel that are stronger than normal steel sheets are used as structural reinforcements.
- Refer to the QRS for each model for locations of the side impact protection beams and ultra high tensile strength sheet steel.

NOTICE

- Because the strength of side impact protection beam and ultra high tensile strength sheet steel is higher than sheet steel and high tensile strength sheet steel, it is difficult to cut through side impact protection beam and ultra high tensile strength sheet steel with conventional cutters. Avoid side impact protection beam and parts made from ultra high tensile strength sheet steel when cutting a vehicle.

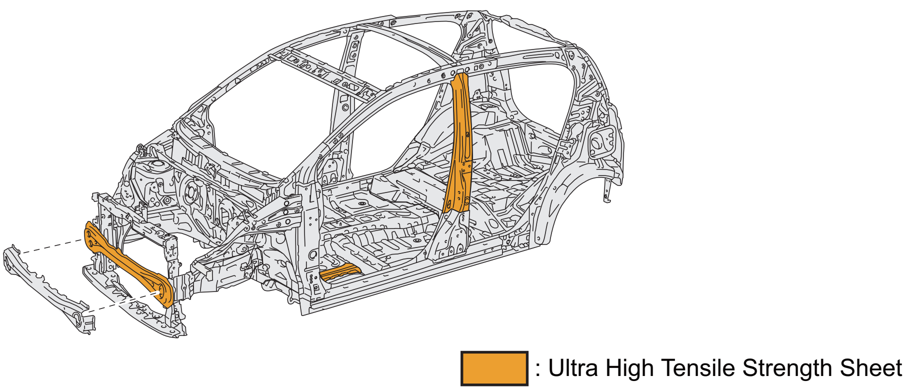
Side Impact Protection Beam

- Side impact protection beams are located inside the door.



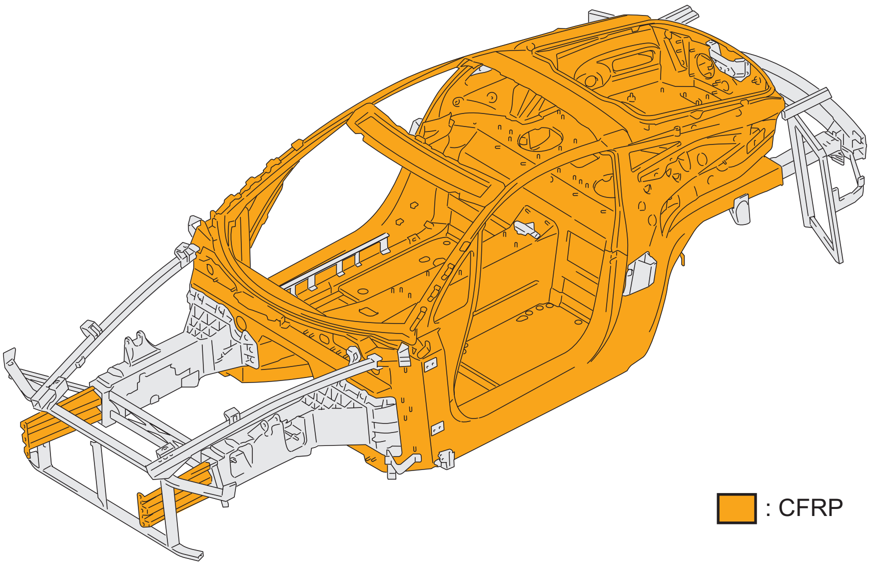
Ultra High Tensile Strength Sheet

- Ultra high tensile strength sheet steel, which is approximately 1.5 times higher strength (1.5 GPa (15,296 kgf/cm^2, 217,557 psi) class) than standard high tensile strength sheet steel (under 1 GPa (10,197 kgf/cm^2, 145,038 psi) class), is used for some body structural components on certain models.



Carbon Fiber Reinforced Plastic (CFRP)

- Lightweight and highly rigid Carbon Fiber Reinforced Plastic (CFRP) is used for some body structural parts of certain models.
- CFRP can be cut and deformed using cutters for rescue operations.



WARNING

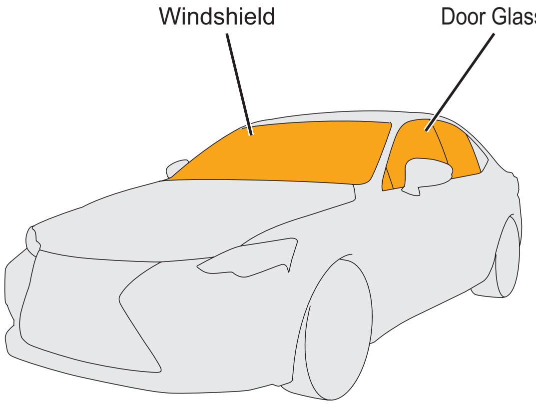
- Cutting CFRP using a grinder or a saw will create carbon fiber dust. Wear appropriate protective equipment such as a dust mask and safety gloves when cutting CFRP.
- CFRP is conductive. If carbon fiber dust attaches to an electrical circuit, a short circuit may result. Keep electrical circuits free from carbon fiber dust when cutting CFRP.

Window Glass

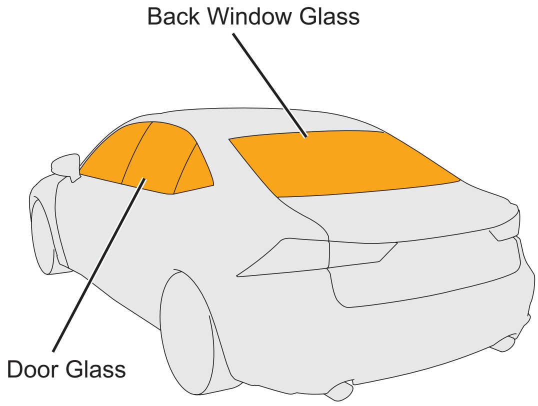
■ Laminated glass and tempered glass are widely used for vehicle windows.

*Laminated glass is mainly used for the windshield. It is also used for the door glass on some vehicles.

■ Tempered glass is mainly used for the door glass, the roof glass and the back window glass.

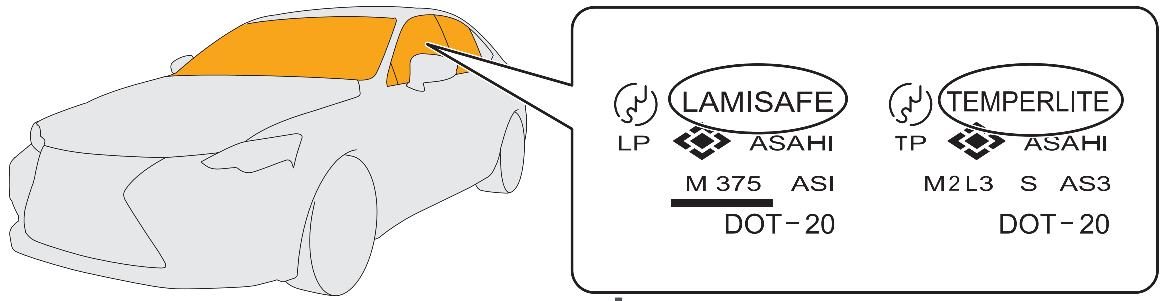


Laminated Glass Applications



Tempered Glass Applications

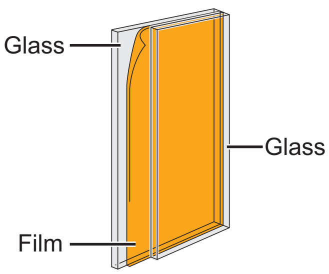
■ Laminated glass and tempered glass are indicated respectively by “LAMISAFE” or “TEMPERLITE” printed on glass.



Laminated Glass

■ Laminated glass consists of 2 layers of glass with a film in-between. Objects that strike the glass are less like to penetrate the glass and glass shards tend to remain adhered to the film.

< LAMISAFE Structure >



< Broken Laminated Glass >

Tempered Glass

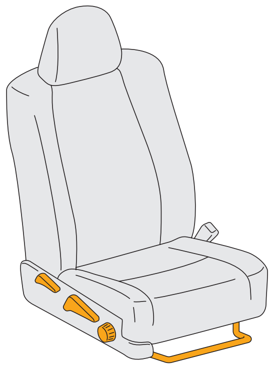
■ Tempered glass is heated to near softening temperature, then rapidly cooled down to make it 3 to 5 times stronger than normal glass. When tempered glass is broken, it will break into very small pieces.

NOTICE

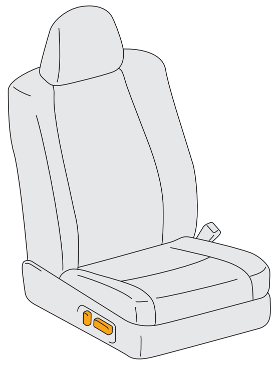
■ Laminated glass consists of 2 layers of glass bonded together with a film. It does not break easily even when struck by an object.

Front Seat

■ Two types of front seats, a manual seat and a power seat, are available. When adjusting the seat position, a lever or a knob is operated for the manual seat and a switch is operated for the power seat.



Manual Seat



Power Seat

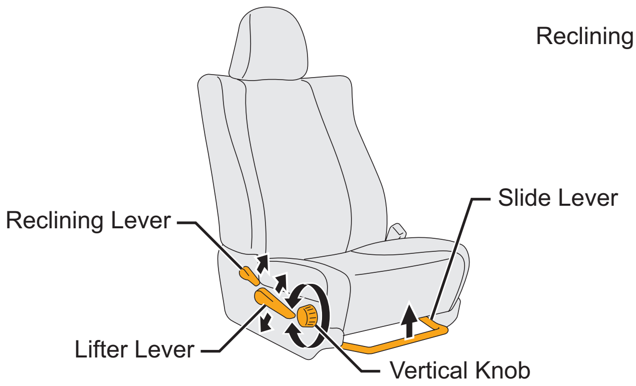
Manual Seat

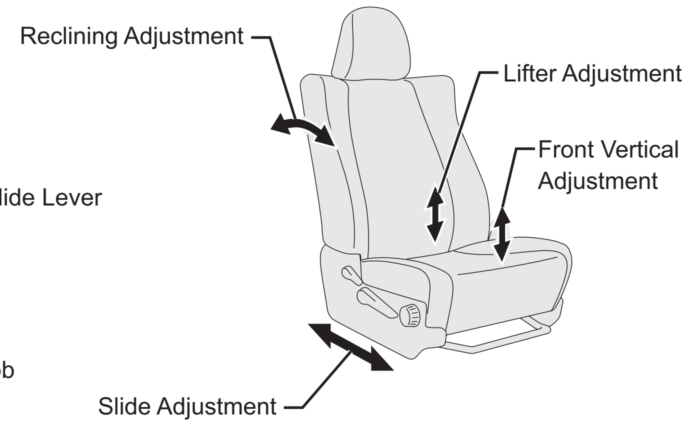
■ The seat can be moved forward/backward by lifting the slide lever (slide adjustment).

■ The seatback can be tilted forward/backward by lifting the reclining lever (reclining adjustment).

■ The seat cushion can be raised/lowered by repeatedly pulling up/pushing down on the lever (lifter adjustment).

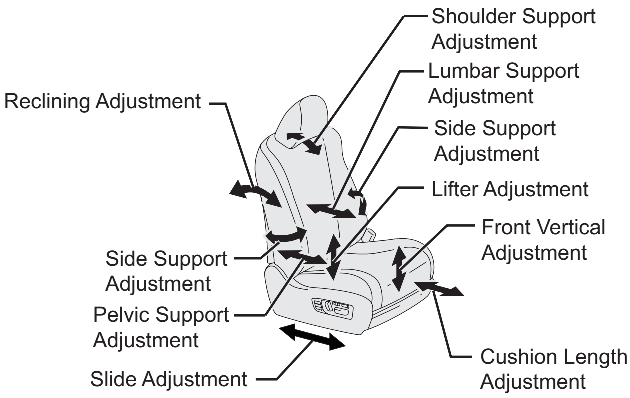
■ The front end of the seat cushion can be raised/lowered by turning the vertical knob (front vertical adjustment).

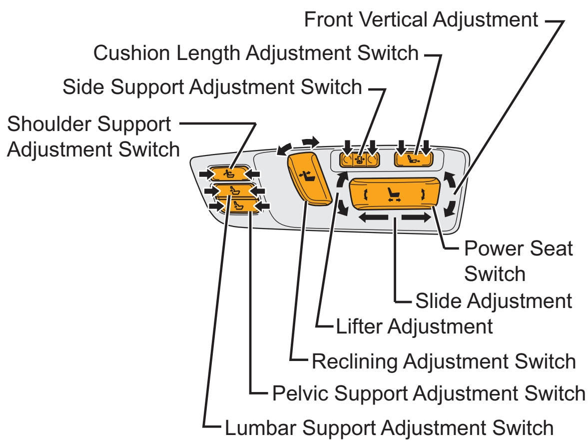




Power Seat

- The seat can be moved forward/backward using the slide function of the power seat switch (slide adjustment).
- The entire seat cushion can be raised/lowered using the lifter function of the power seat switch (lifter adjustment).
- The front end of the seat cushion can be raised/lowered using the front vertical function of the power seat switch (front vertical adjustment).
- The seatback can be tilted forward/backward by operating the reclining adjustment switch (reclining adjustment).
- The lumbar support position can be moved forward/backward by operating the lumbar support adjustment switch (lumbar support adjustment).
- The side support position can be moved right/left by operating the side support position adjustment switch (side support adjustment).
- The pelvic support position can be moved forward/backward by operating the pelvic support position adjustment switch (pelvic support adjustment).
- The shoulder support position can be moved forward/backward by operating the shoulder support position adjustment switch (shoulder support adjustment).
- The length of the seat cushion can be adjusted by operating the cushion length adjustment switch (cushion length adjustment).

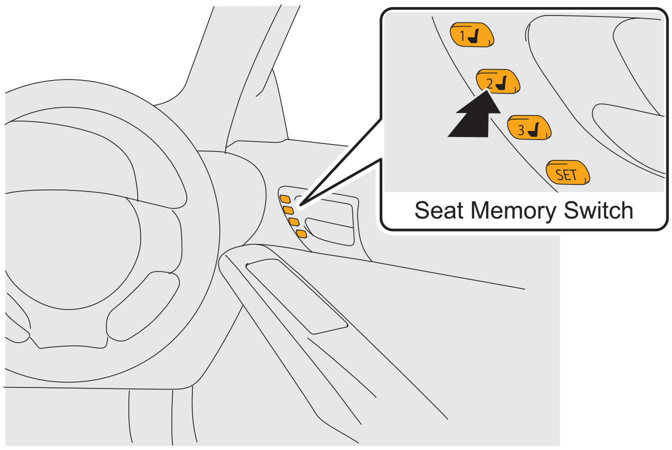




NOTICE

- The seat position adjustment functions of a power seat will be disabled when the 12 V battery is disconnected.

■ When a vehicle is equipped with the driving position memory function, the driver seat automatically moves backward when the power switch is turned off (auto away function) and moves forward when the power switch is turned on (IG) (auto return function). Whether or not the vehicle is equipped with the driving position memory function can be confirmed by the existence of memory switches in the upper door trim.

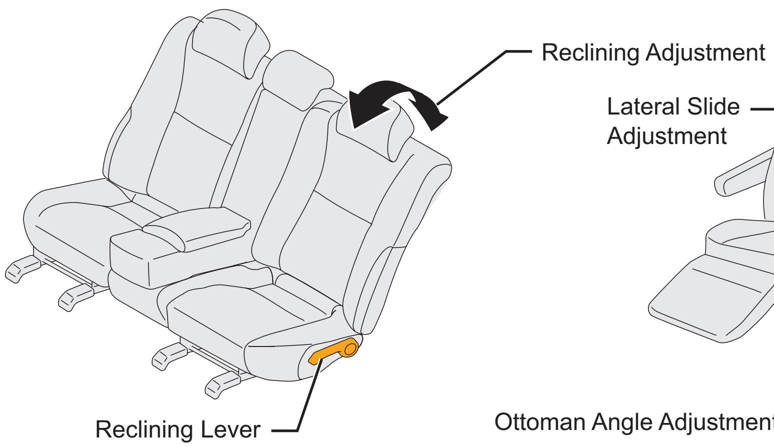


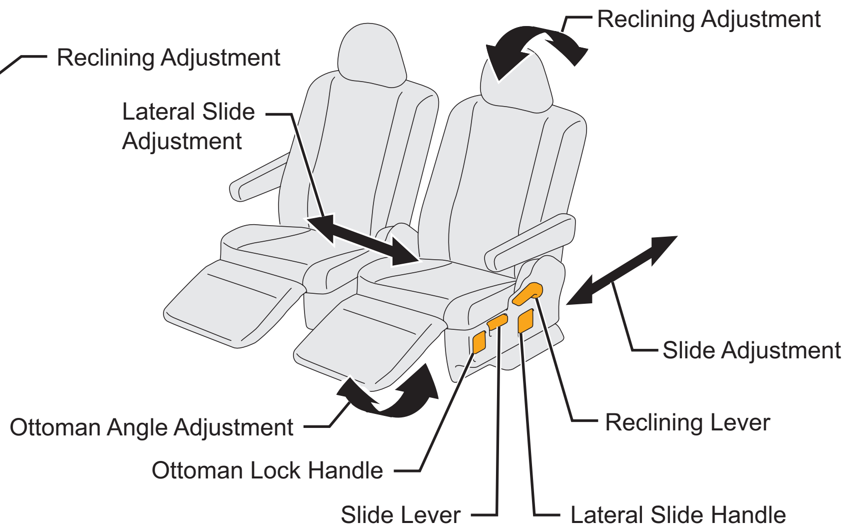
Rear Seat

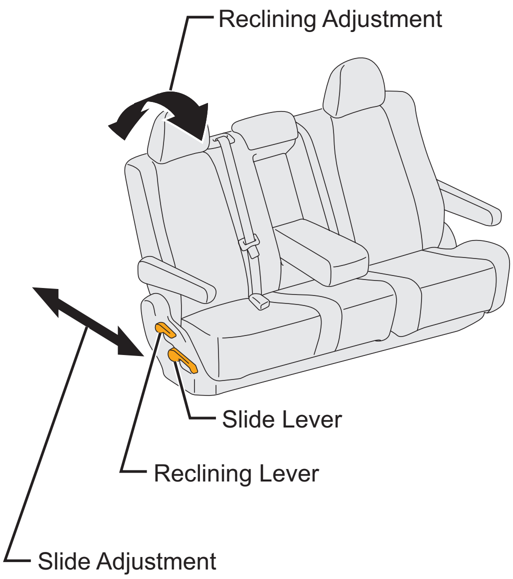
- Two types of rear seats, a manual seat and a power seat, are available. When adjusting the seat position, a lever or a knob is operated for the manual seat and a switch is operated for the power seat.

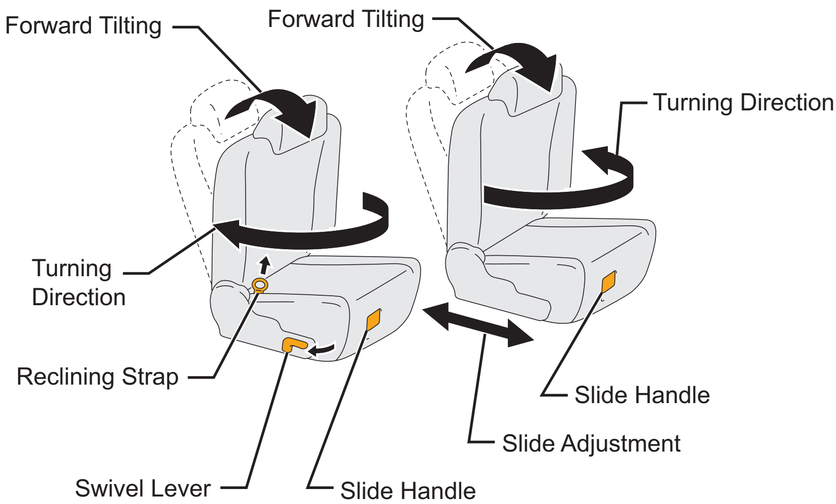
Manual Seat

- The seat can be moved forward/backward by lifting the slide lever (slide adjustment).
- The seatback can be tilted forward/backward by lifting the reclining lever (reclining adjustment).
- The seat can be tilted forward by pulling the reclining strap.
- The seat can be moved leftward/rightward by lifting the lateral slide handle (lateral slide adjustment).
- The ottoman can be raised/lowered by lifting the ottoman lock handle (ottoman angle adjustment).
- The seat can be turned around by operating the swivel lever.



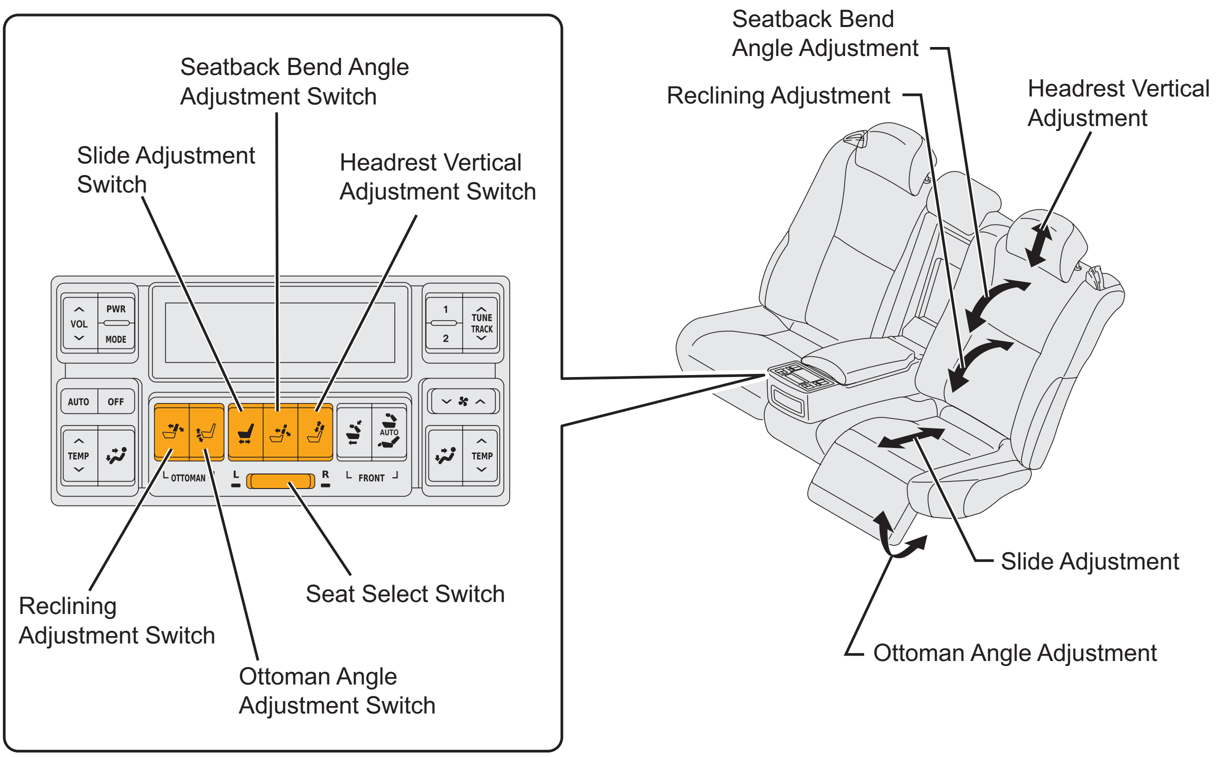






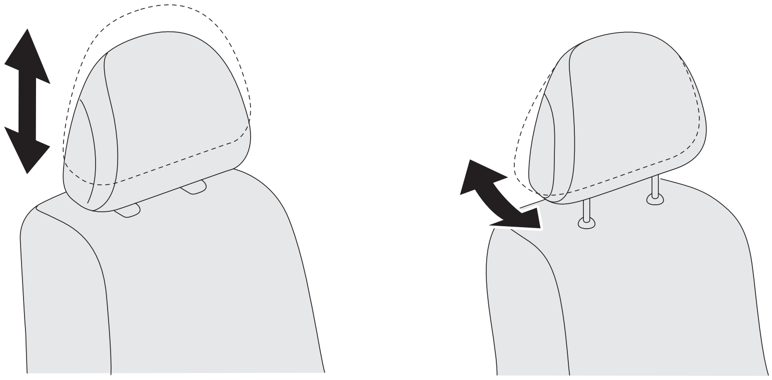
Power Seat

- The seat can be moved forward/backward by operating the slide adjustment switch (slide adjustment).
- The seatback can be tilted forward/backward by operating the reclining adjustment switch (reclining adjustment).
- The ottoman can be raised/lowered by operating the ottoman angle switch (ottoman angle adjustment).
- The angle of the upper seatback can be adjusted vertically by operating the seatback bend angle switch (seatback bend angle adjustment).
- The headrest can be raised/lowered by operating the headrest vertical adjustment switch (headrest vertical adjustment).



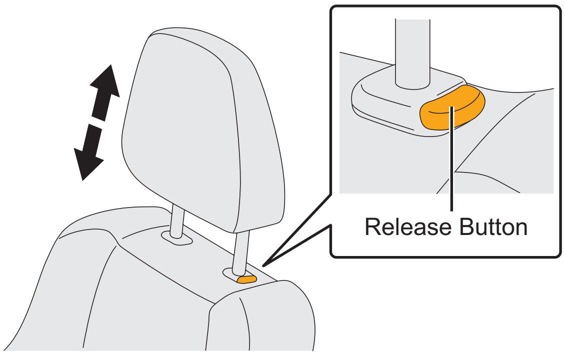
Headrest

- The position of the headrests can be adjusted vertically and horizontally.
- Two types of headrests, a manual headrest and a power headrest, are available. Vertical adjustment of the headrest is performed by hand on manual headrests or by operating a switch on power headrests. Horizontal adjustment can be performed by hand only.

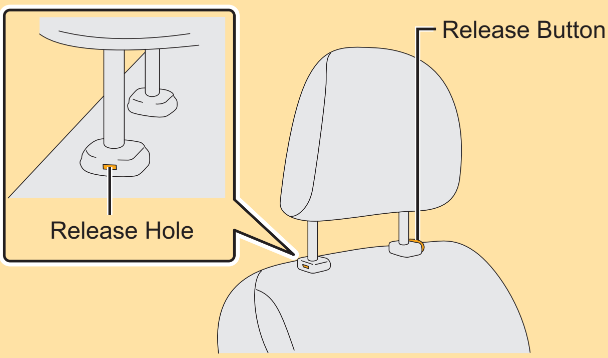


Manual Headrest

- When raising a manual headrest, pull up the headrest by hand. When lowering, push down the headrest while pushing the release button. To remove the headrest, pull out the headrest while pushing the release button.

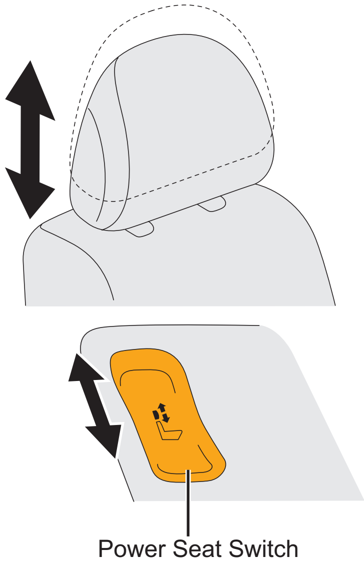


- If the headrest cannot be removed by pushing the release button, insert a screwdriver into the release hole provided on the opposite side of the headrest from the release button to release the lock and pull out the headrest.



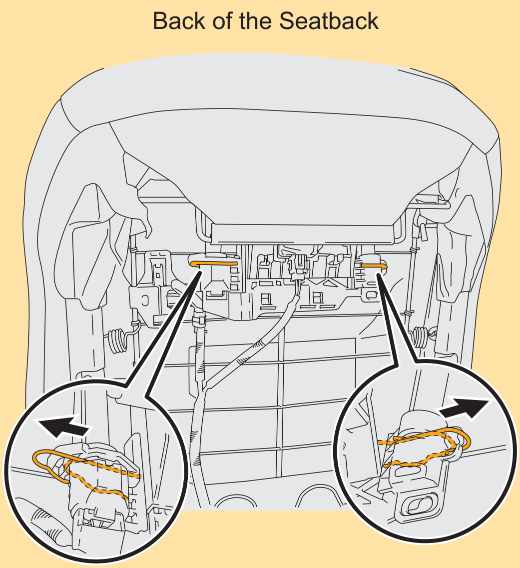
Power Headrest

■ When raising a power headrest, raise/lower the headrest by operating the power seat switch located on the side of the seat.



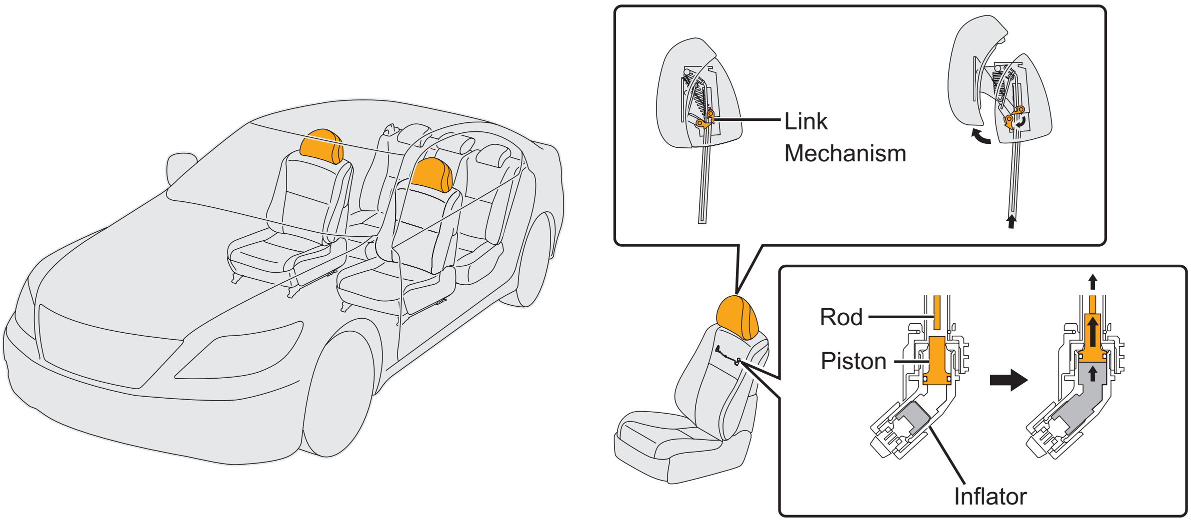
NOTICE

■ To remove the headrest, disengage the pins located inside the seatback and pull out the headrest.



Active Headrest System

- The active headrest system is built into the front headrests.
- The active headrest system consists of an inflator, a rod and a link mechanism.
- When the airbag sensor detects a rear impact, an ignition signal is sent to the inflators to activate the active headrest system. When an inflator is ignited, pressure inside the inflator rises, pushing up a piston. As the piston rises, the rod in the headrest stay is pushed up, a lock is released via the link mechanism and the headrest is pushed forward by a spring, helping reduce the possibility of whiplash injuries.



WARNING

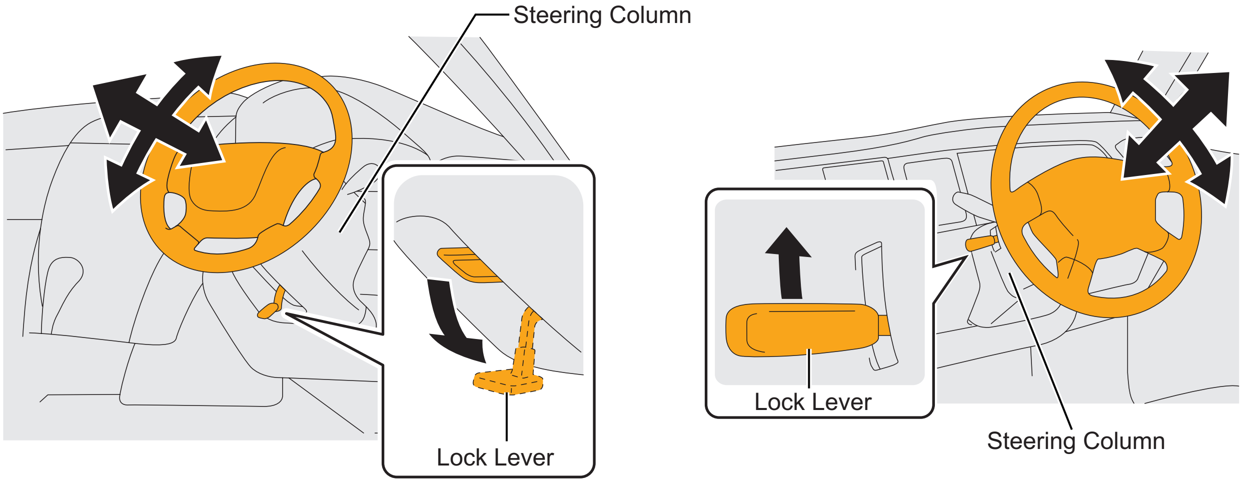
- The active headrest system may remain powered for up to 90 seconds after the vehicle is shut off and disabled (see page 69). Wait at least 90 seconds before starting any operation. Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from unintentional actuation of the active headrest.
- If an inflator is cut, the active headrest inflator may unintentionally deploy. To prevent serious injury or death from unintentional active headrest actuation, avoid breaching the inflators.

Tilt & Telescopic Steering

- The steering column has a tilt mechanism, which enables vertical adjustment of the steering wheel position, and a telescopic mechanism, which enables horizontal adjustment of the steering wheel position.
- Two types of tilt & telescopic steering, manual tilt & telescopic steering and power tilt & telescopic steering, are available. When adjusting the position of the steering wheel, a lever is operated for the manual tilt and telescopic mechanisms and a switch is operated for the power tilt and telescopic mechanisms.
- Some vehicles have only tilt or telescopic mechanism, not both. Also, some vehicles have a fixed type steering column (not equipped with tilt & telescopic mechanism), and some vehicles power mechanism is only for tilt or telescopic function.

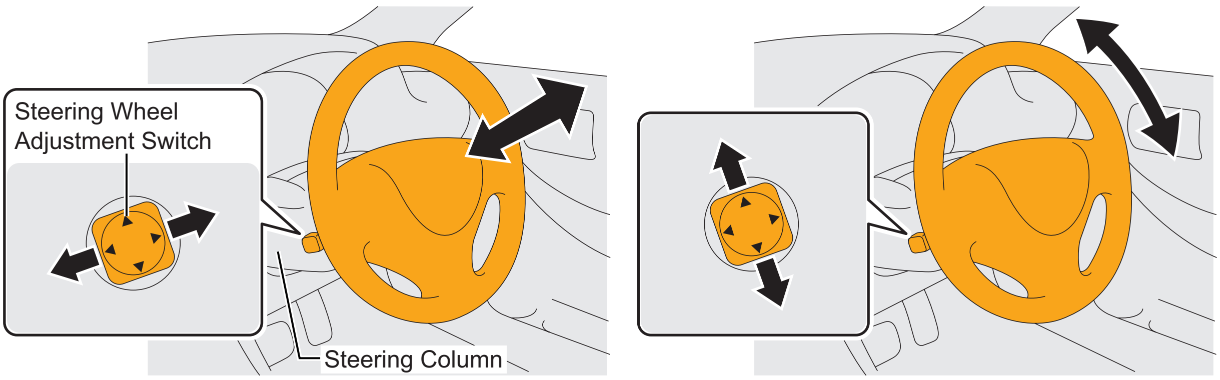
Manual Tilt & Telescopic

- The manual tilt & telescopic steering is provided with a lock lever under or side of steering column for releasing the lock when adjusting the steering wheel position.
- When the lock lever is operated, the lock is released, allowing adjustment of the steering wheel position. After adjustment, the steering wheel can be locked in the desired position by returning the lock lever.



Power Tilt & Telescopic

- The power tilt & telescopic steering is provided with a switch on the steering column for adjusting the steering wheel position.
- The steering wheel can be moved to a desired position by operating the switch.



Telescopic Mechanism   Tilt Mechanism

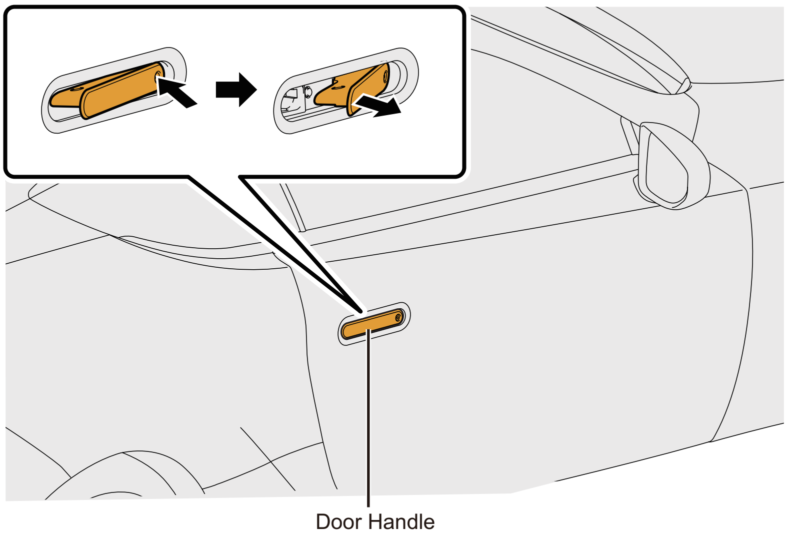
Doors

- The door is opened by operating the handle on the door.
- Some models are equipped with an access door (double door), which is opened using the inner door handle, or a back door, which is opened by using the back door handle after lowering the back window glass.

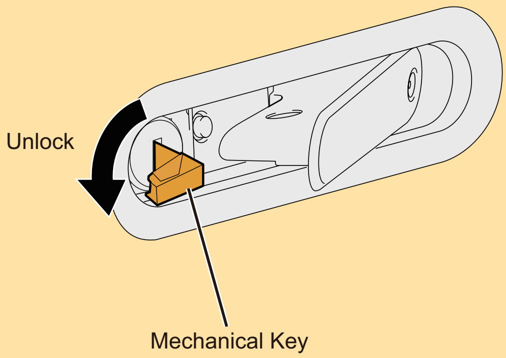
Flush Handle Type

- When voltage is not supplied, such as when the terminal of the 12 V battery is disconnected, the flush handle will not be deployed electrically. In this case, the door handle must be opened manually.

  1. The retracted door handle can be pulled out by pushing on the front end.
  2. The door can be opened by pulling more on the pulled out door handle.

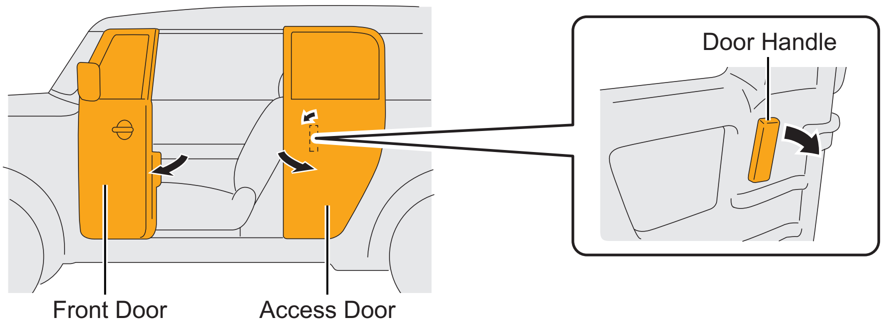


- If the door lock is engaged, insert the mechanical key into the flush handle to release the lock.



Access Door (Double door)

1. Open the front door as much as possible.
2. Pull the door handle on the access door forward.
3. Open the access door.

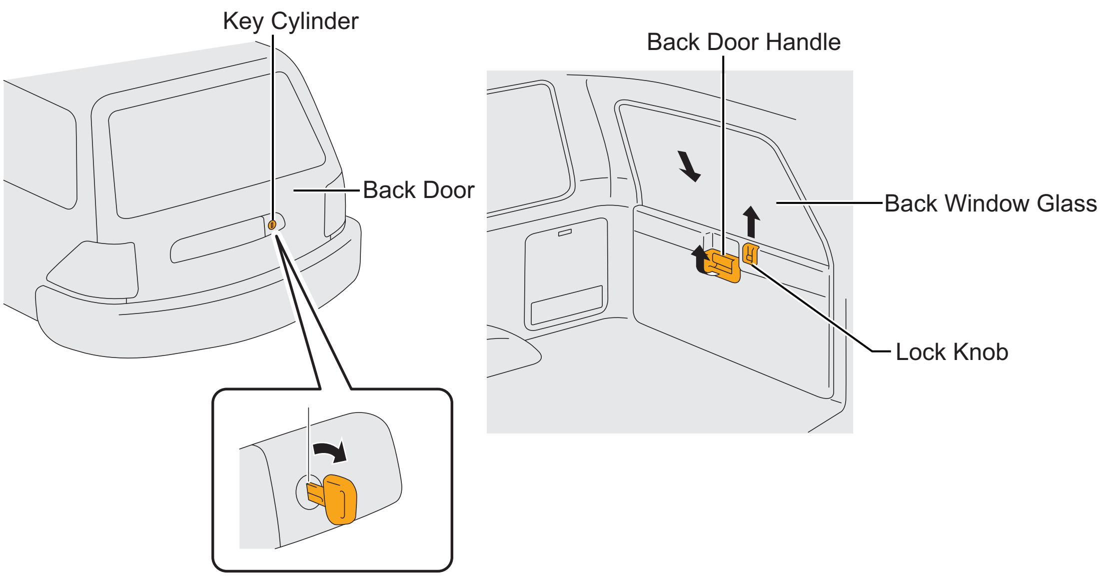


WARNING

■ Before opening either access doors, make sure the front seatbelt is unfastened. If the access door is opened with the front seatbelt fastened, the seatbelt may be locked and squeeze the front occupant, resulting in a serious injury.

Back Door

1. Insert a key into the key cylinder in the back door then turn the key clockwise to lower the back window glass.
2. Pull up the lock knob on the back door to release the lock.
3. Pull up the back door handle to open the back door.



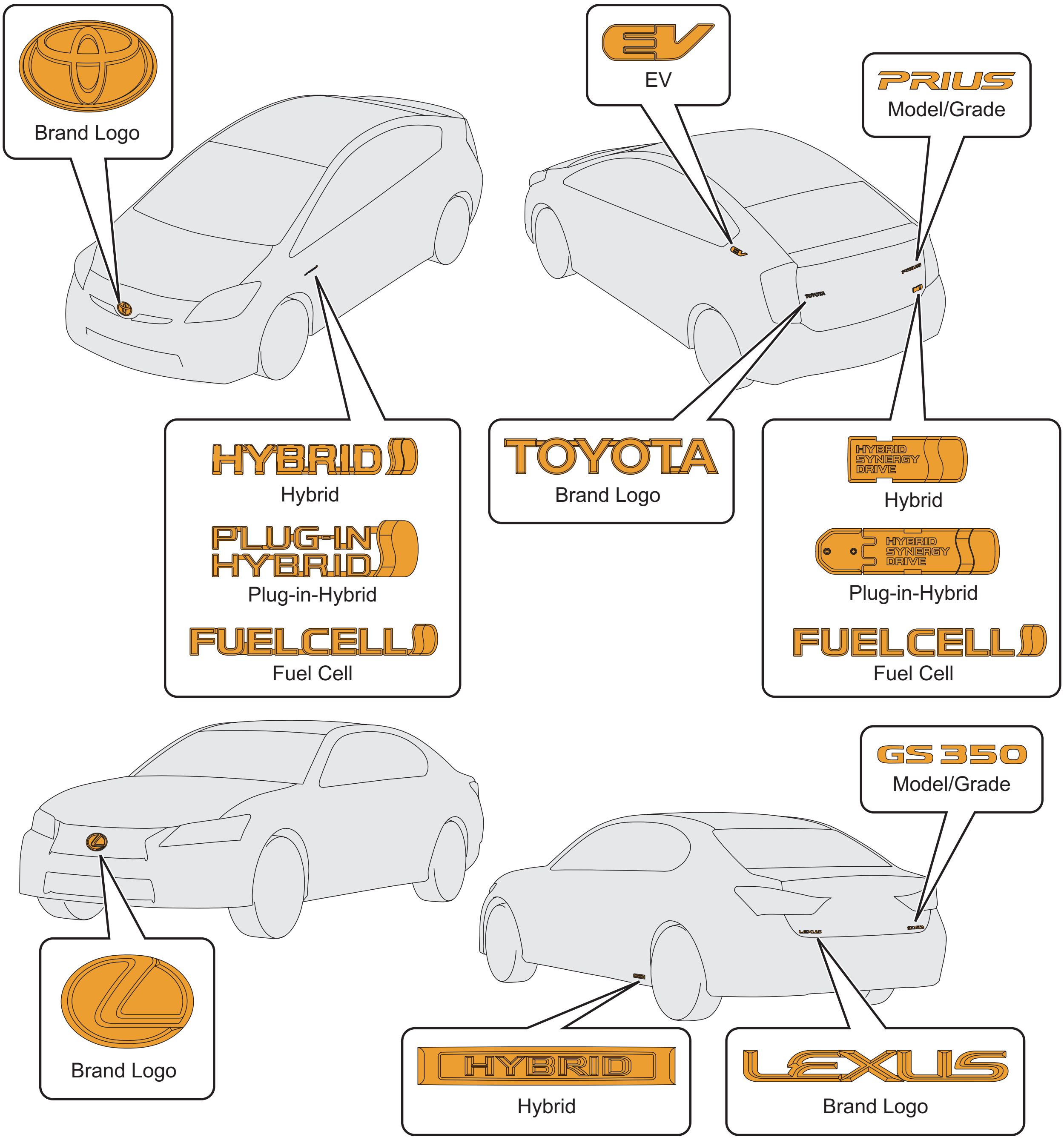
Emergency Response Key Points

- Procedures and points to be noted when handling TOYOTA/LEXUS vehicles during emergency response are provided in this section.
- Refer to the Quick Reference Sheet (QRS) for each model for model specific information such as vehicle identification points, component locations, etc.

Vehicle Identification

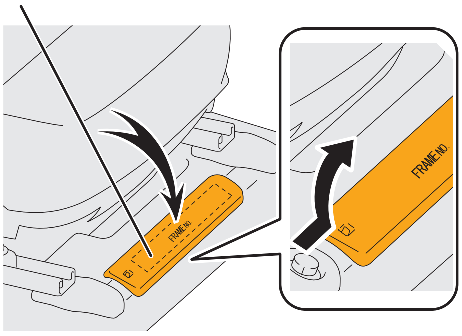
Appearance and Logos

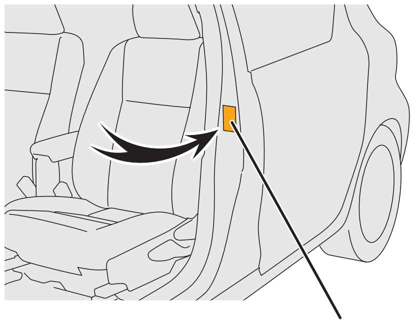
- Identify the vehicle type based on exterior features and logos on the body.
- Logo marks represent the make, model, grade, and the vehicle type (hybrid/electric/fuel cell) if it uses a high voltage electrical system.
- Logo marks are attached to the trunk lid, back door/hatch, rocker panels, front grille and fender.

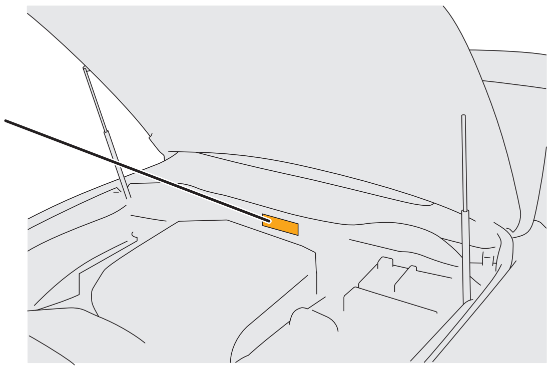


Frame Number

- A frame number is stamped on the name plate attached to the engine compartment and front passenger door pillar.
- Characters before a hyphen (e.g.: ○○○○○ for the frame number ○○○○○-ΔΔΔΔΔ) represent the vehicle model.
- When a cover is installed under the driver seat, a frame number is stamped on the frame underneath the cover.

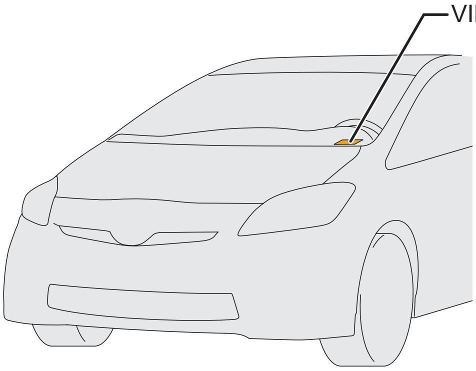


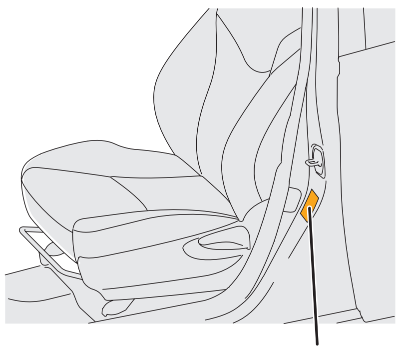




Vehicle Identification Number (VIN)

- The VIN is stamped on the name plate attached to the windshield cowl and driver door pillar.
- The vehicle model can be identified by the VIN.



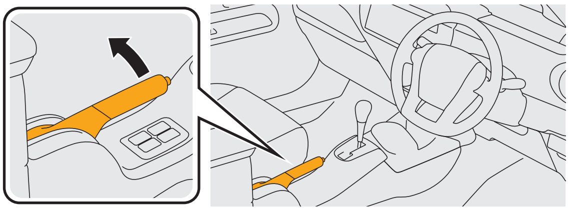


Immobilize Vehicle

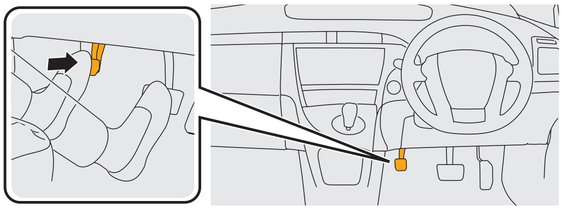
■ On arrival, completely immobilize the vehicle by following procedures 1, 2 and 3 to ensure safe emergency response operations.

1. Chock wheels and set the parking brake.

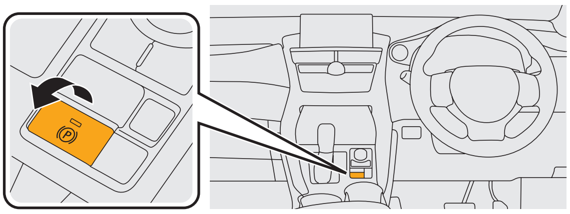
   ■ The following types of parking brakes are available. Operate the parking brake accordingly.



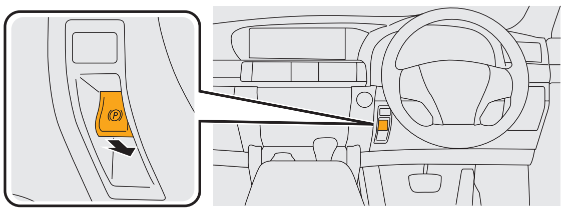
Lever Type



Foot Pedal Type



Switch Type
(Pull-type Switch)



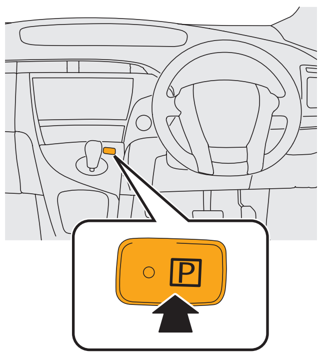
Switch Type
(Push-type Switch)

   ■ For vehicles with a switch type, operate the switch twice in order to make sure that the vehicle is securely fixed in place.

2. For automatic vehicles, move the shift lever to the park (P) position. For manual vehicles, shut off the vehicle (see page 69), then move the shift lever to the 1st or reverse (R).

   ■ Park (P) can be selected by the following methods. Operate the vehicle accordingly.

Shift Lever Type

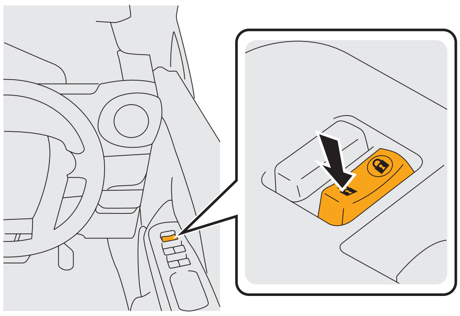


P Position Switch Type

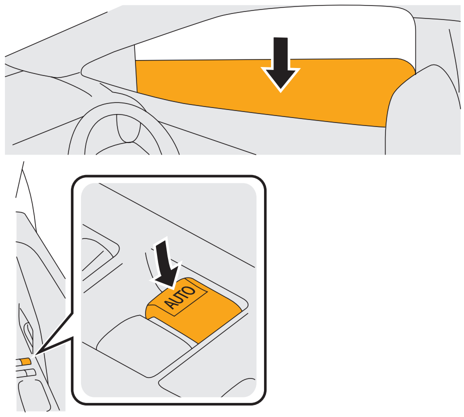
3. To facilitate emergency response operations, lower the windows, open the back door, unlock the doors and take other necessary actions before shutting off the vehicle.

■ The following systems are powered by the 12 V battery. Operate them as required before disconnecting the battery.

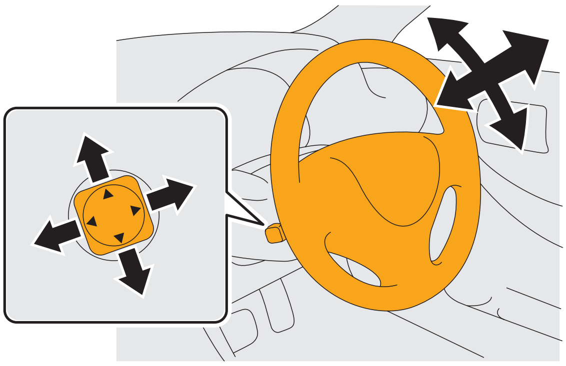
- Power door lock
- Power window
- Power tilt and telescopic steering
- Power seat



Door Unlock



Power Window Adjustment



Steering Wheel Adjustment

Seat Adjustment

NOTICE

■ Once the 12 V battery is disconnected (see page 69), power controls will not operate.

Vehicle with High Voltage Battery

■ Hybrid vehicles (HV), plug-in hybrid vehicles (PHV), electric vehicles (EV) and fuel cell vehicles (FCV) are equipped with a high voltage electrical system (over 144 V, up to 650 V).

WARNING

■ To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components.

Vehicle with Hydrogen Gas

■ Fuel cell vehicles (FCV) carry compressed hydrogen gas. Before performing the normal procedures to immobilize the vehicle, follow the steps below first.

WARNING

■ Hydrogen gas is colorless, odorless and flammable.
■ Compared to gasoline or natural gas, hydrogen gas can ignite in a wide range of concentrations (4 to 74.5%). If the sound of hydrogen leaking (a loud hissing sound) can be heard when working on the vehicle, or if the hydrogen concentration around the vehicle exceeds 4% when measured with a hydrogen concentration detector, immediately step away from the vehicle as there is a chance that the hydrogen gas may ignite.

1. Confirm that there is no sound of hydrogen leakage (a loud hissing sound).
   - ■ When approaching the vehicle, approach from the front.
   - ■ If the sound of leakage can be heard, immediately step away from the vehicle, as the hydrogen may ignite.
   - ■ Confirm that the sound of leakage is no longer present before proceeding to the next procedure.
2. Using a hydrogen concentration detector, measure the hydrogen concentration around the vehicle, and confirm that it does not exceed 4%.
   - ■ If the concentration exceeds 4%, immediately step away from the vehicle, as the hydrogen may ignite.
   - ■ If a ventilator is available, fanning the area can reduce the hydrogen concentration. Blow the fan from the front toward the rear of the vehicle. When approaching the vehicle, approach from the direction where the wind is coming from.
   - ■ Measure the hydrogen concentration at regular intervals and confirm that the hydrogen concentration does not exceed 4% before proceeding to the next step.
3. Immobilize the vehicle according to the normal procedures.

Disable Vehicle

- To ensure safe emergency response operations, the vehicle must be completely turned off by shutting off the power from the fuel pump, SRS airbag, high voltage battery, plug-in charging system, etc.
- Confirm the vehicle status. If **any of the following conditions exist**, the vehicle may not shut off.

- Engine is running.
- Ignition switch is in ACC, ON or START position.
- Meters are illuminated.
- Air conditioning is operating.
- Audio system is operating.
- Wipers are operating.
- Navigation or other displays are turned on.

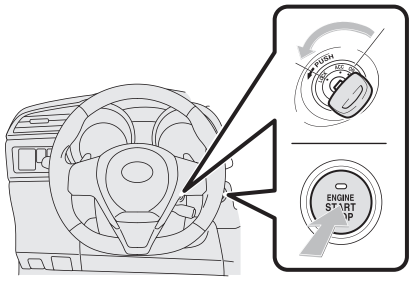
WARNING

- NEVER assume the vehicle is shut off simply because it is silent. If the vehicle is equipped with an idling stop system, or the vehicle is a hybrid vehicle (HV) or plug-in hybrid vehicle (PHV), the engine is silent while the vehicle is on. Make sure none of the above conditions exist.
- Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from unintentional deployment of the SRS airbags or unintentional actuation of the seatbelt pretensioners, pop up hood, or active headrests.

- Completely shut off the vehicle by following procedures 1 or 2.

Procedure 1

1. Turn the ignition switch to the LOCK (OFF) position or push the engine/power switch once to shut off the vehicle.



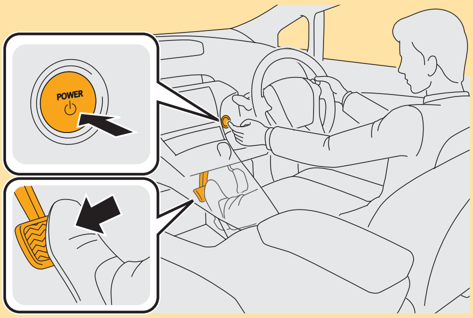
WARNING

- If the vehicle is equipped with an engine/power switch the vehicle is shut off when **ALL of the following conditions are met**. With all of the following conditions met, do not push the engine/power switch as the vehicle will start.
  - Engine is not running.
  - Meters are not illuminated.
  - Air conditioning is not operating.
  - Audio system is not operating.
  - Wipers are not operating.
  - Navigation and other displays are turned off.

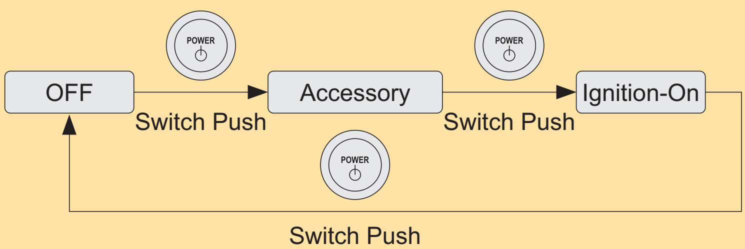
NOTICE

- The engine/power switch operates as follows.
  With the brake pedal (for automatic vehicles) or the clutch pedal (for manual vehicles) depressed:
  Vehicle Start → Stop → Start … is repeated every time the switch is pushed.

  With the brake pedal (for automatic vehicles) or the clutch pedal (for manual vehicles) released:
  Accessory → Ignition-On → Off → Accessory… is repeated.
- When in ”Accessory” mode, the radio and other accessory components are operational.
- When in “Ignition-On” mode, the power windows, wipers, heater/air conditioner fan and other components including SRS system are operational.
- The vehicle will not start if the brake pedal (for automatic vehicles) or the clutch pedal (for manual vehicles) is not depressed, even if the switch is pushed.



Brake Pedal Depressed



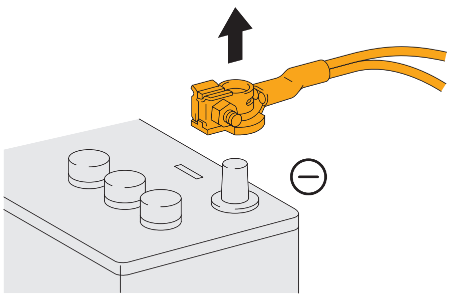
Brake Pedal Released

2. When the vehicle is equipped with an engine/power switch, keep the electrical key transmitter 5 meters (16.4 feet) or more away from the vehicle.

NOTICE

- If the electrical key transmitter is in the cabin or near the vehicle, the vehicle may start depending on what operations are performed. For example, if the engine/power switch is pushed.
- To prevent unexpected starting of the vehicle, place the electrical key transmitter outside of the detection area.

3. Disconnect the negative (-) terminal of the 12 V battery.
   - The 12 V battery is installed in the engine compartment, in the luggage compartment or under the rear seat.
   - Refer to the Quick Reference Sheet (QRS) for each model for the location of the 12 V battery.

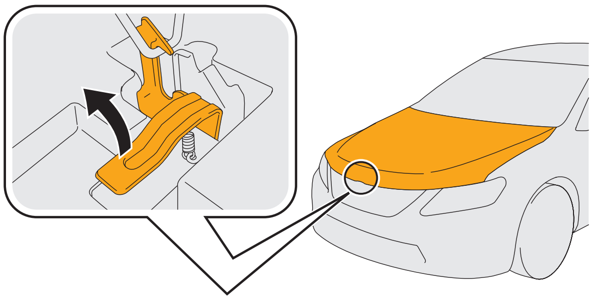


NOTICE

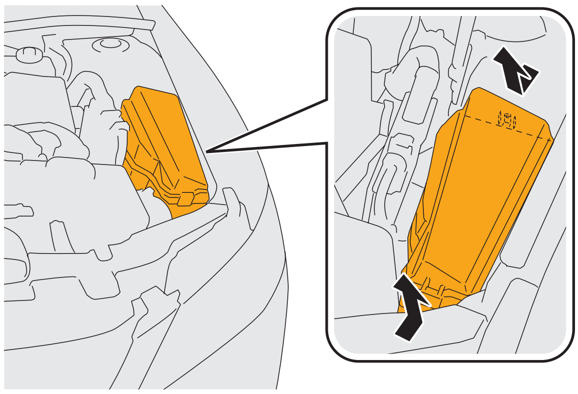
- Shut off the power to the electrical system to prevent electrical fires and to keep the vehicle from starting.
- After the negative (-) terminal of the 12 V battery has been disconnected and the power has been shut off, approximately 12 V is maintained between the positive (+) terminal and negative (-) terminal of the sub-battery for up to approximately 10 minutes.

Procedure 2 (Alternate if the ignition switch or power switch is inoperative)

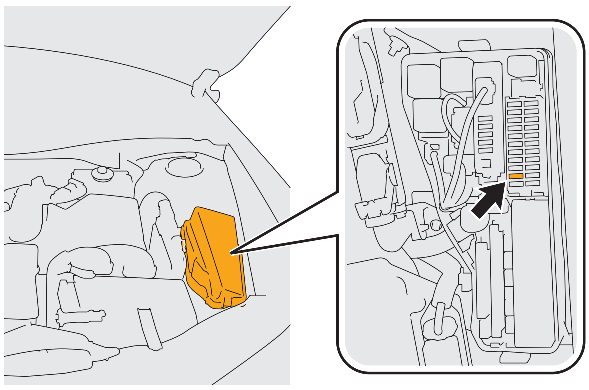
1. Open the hood. Remove the engine room covers, if any are present.



2. Remove the engine compartment fuse box cover.



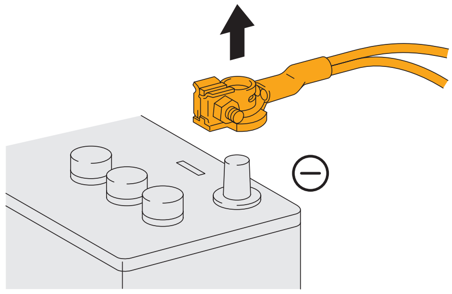
3. Remove the appropriate fuse.
   - Refer to the Quick Reference Sheet (QRS) for each model for the fuse to be removed.



NOTICE

- If the correct fuse cannot be identified, pull **ALL** fuses in the fuse box **until all of the following conditions are met**.
  - Engine is not running.
  - Meters are turned off.
  - Air conditioning is turned off.
  - Audio system is turned off.
  - Wipers are turned off.
  - Navigation and other displays are turned off.

4. Disconnect the negative (-) terminal of the 12 V battery.
   - The 12 V battery is installed in the engine compartment, in the luggage compartment or under the rear seat.
   - Refer to the Quick Reference Sheet (QRS) for each model for the location of the 12 V battery.



NOTICE

- Shut off the electrical system to prevent electrical fires and to keep the vehicle from starting.
- After the negative (-) terminal of the 12 V battery has been disconnected and the power has been shut off, approximately 12 V is maintained between the positive (+) terminal and negative (-) terminal of the sub-battery for up to approximately 10 minutes.

Vehicle with High Voltage Battery

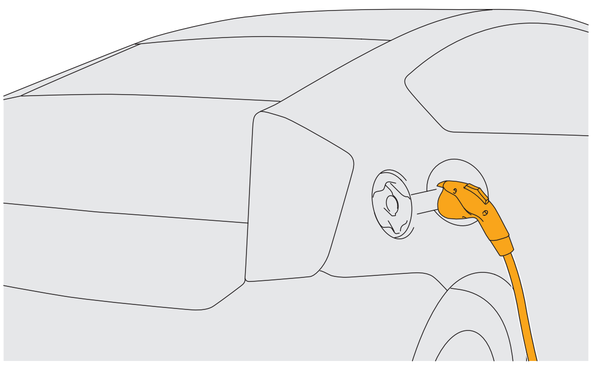
- Hybrid vehicles (HV), plug-in hybrid vehicles (PHV), electric vehicles (EV) and fuel cell vehicles (FCV) are equipped with a high voltage electrical system (over 144 V, up to 650 V).

WARNING

- The high voltage system may remain charged for up to 10 minutes after the vehicle is shut off and disabled (see page 69). Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from severe burns and electric shock from the high voltage electrical system.
- To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components.
- NEVER assume the hybrid vehicle (HV), plug-in hybrid vehicle (PHV) or electric vehicle (EV) is shut off simply because it is silent. Always observe the instrument cluster for the **READY** indicator status to verify whether the high voltage system is on or shut off. The high voltage system is shut off when the **READY** indicator is off.
- When the vehicle is equipped with a remote air conditioning system and the meters are illuminated, high voltage may be applied to the air conditioning system even though the **READY** indicator is off. Shut off and disable vehicle and ensure the meters are turned off.

Vehicle with Plug-in Charge System

- Plug-in hybrid vehicles (PHV) and electric vehicles (EV) are equipped with a system to charge the high voltage battery using power from an external power source.
- If a charge cable is connected to the charging inlet of the vehicle, disconnect the charge cable as follows to stop charging.

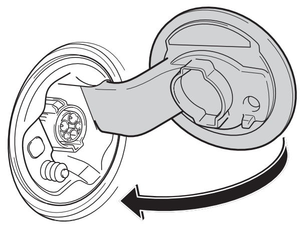


1. Push the latch release button on the top of the charge cable connector and pull it away from the charging inlet of the vehicle.

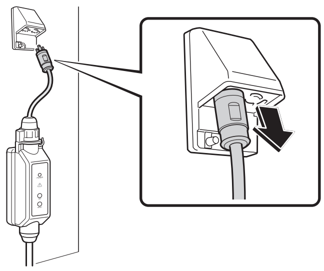
NOTICE

- If the lock of the charge cable assembly connector cannot be released, turn off the external charger.
- If the lock is still not released, stop charging by unplugging the external charger or turning the charger main breaker off. Then disconnect the charge cable assembly from the charge inlet.

2. Close the charging inlet cap and charging port lid.



3. Turn off the external charger by unplugging it or turning its main circuit circuit breaker off.



WARNING

- To prevent serious injury or death from severe burns or electric shock, shut off the utility circuit supplying power to the charge cable before disconnecting it if the vehicle, charge cable or external charger is submerged in water.

Vehicle with Hydrogen Gas

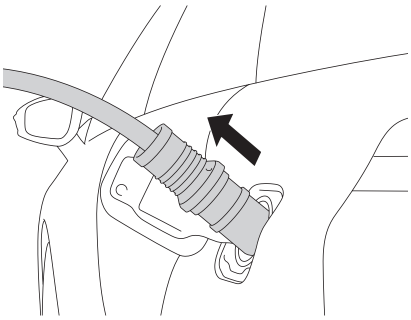
■ Fuel cell vehicles (FCV) carry compressed hydrogen gas. In order to abort refueling, follow the steps below.

1. Operate the hydrogen station to abort refueling.

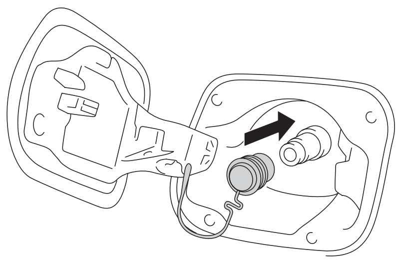
NOTE

■ Hydrogen inside the hose will depressurized and the filling nozzle can now be removed.

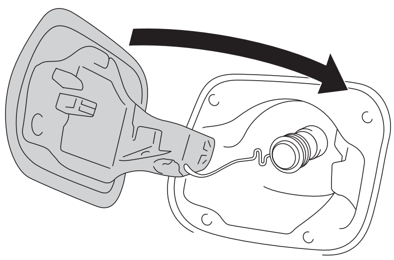
2. Remove the filling nozzle of the hydrogen station from the refueling port (receptacle).



3. Put the cap on the refueling port (receptacle).



4. Close the fuel door.

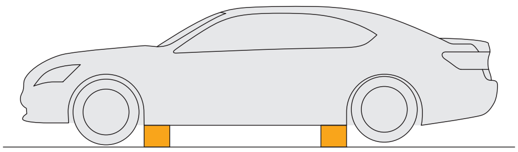


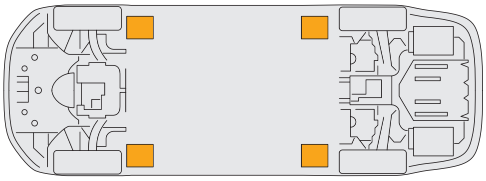
WARNING

■ For fuel cell vehicles (FCV), even if the READY indicator turns off, the high voltage system may still be active if the H_2O indicator in the combination meter is illuminated. Shut off and disable the vehicle and ensure the meters are turned off.

Stabilize Vehicle

■ Crib at four points directly under the front and rear pillars using wooden blocks or equivalent objects.





■ Do not place cribbing such as wooden blocks or rescue air lifting bags under the exhaust system, fuel system or high voltage power cables. Failure to do so may cause heat generation, bursting of the air lifting bags, damage to the high voltage power cables or damage to the hydrogen piping, resulting in a vehicle fire, crushing accident, electrical shock or gas leak, possibly leading to serious injury or death.

Access Patients

- Make sure that the vehicle is immobilized and disabled (see page 69), then open or remove windows and doors to access patients.
- Secure the necessary space for performing operations by adjusting the position of the steering wheel and seats and removing the head rests.
- Refer to “Components Requiring Special Attention” for details of adjustment and removal of components.

WARNING

- The SRS airbags, seatbelt pretensioners, pop up hood and active headrests may remain powered for up to 90 seconds after the vehicle is shut off and disabled (see page 69). Wait at least 90 seconds before starting any operation. Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from unintentional deployment of the SRS airbags or unintentional actuation of the seatbelt pretensioners, pop up hood or active headrests.
- Depending on the circumstances surrounding a collision, such as vehicle speed, point of impact, occupant detection etc., the SRS airbags, seatbelt pretensioners, pop up hood or active headrests will not always be activated and may remain active. If an unactivated inflator of these systems is cut, the powder inside the inflator may ignite resulting in airbag deployment. To prevent serious injury or death from unintentional SRS airbag deployment or unintentional actuation of the seatbelt pretensioners, pop up hood or active headrests, avoid breaching the inflators.
- Immediately after an SRS airbag is deployed or a seatbelt pretensioner, the pop up hood or an active headrest is actuated, the components are extremely hot and may cause burns if touched.
- If an SRS airbag deploys with all doors and windows closed, inflation gas may cause breathing difficulty.
- If residue that is produced during the operation of SRS airbags, seatbelt pretensioners, pop up hood or active headrests comes in contact with skin, rinse it off immediately to prevent skin irritation.

Vehicle with High Voltage Battery

- Hybrid vehicles (HV), plug-in hybrid vehicles (PHV), electric vehicles (EV) and fuel cell vehicles (FCV) are equipped with a high voltage electrical system (over 144 V, up to 650 V).

WARNING

- The high voltage system may remain charged for up to 10 minutes after the vehicle is shut off and disabled (see page 69). Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from severe burns and electric shock from the high voltage electrical system.
- To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components.

Vehicle with Hydrogen Gas

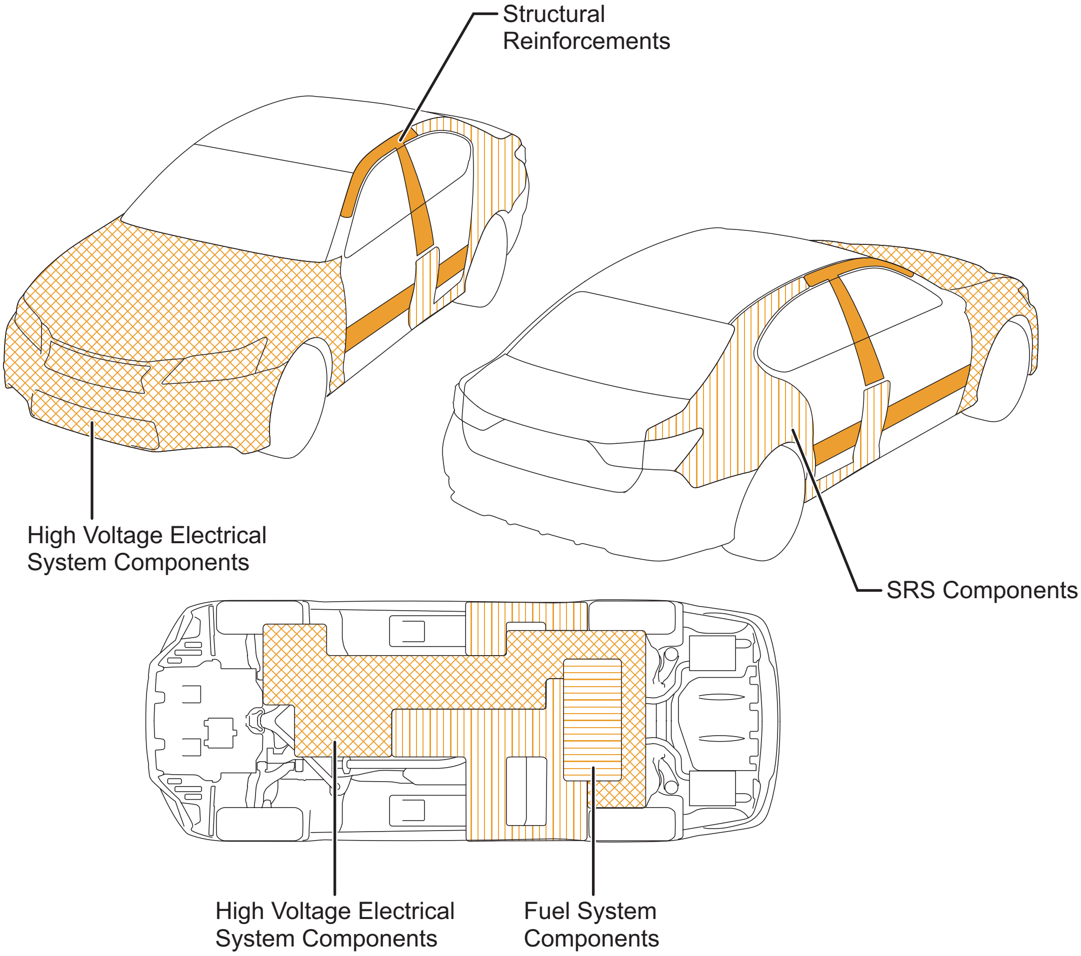
■ Fuel cell vehicles (FCV) carry compressed hydrogen gas.

WARNING

- Hydrogen gas is colorless, odorless and flammable.
- Compared to gasoline or natural gas, hydrogen gas can ignite in a wide range of concentrations (4 to 74.5%). If the sound of hydrogen leaking (a loud hissing sound) can be heard when working on the vehicle, or if the hydrogen concentration around the vehicle exceeds 4% when measured with a hydrogen concentration detector, immediately step away from the vehicle as there is a chance that the hydrogen gas may ignite.
- Even after the vehicle is stopped (refer to P69), hydrogen remains inside the FC stack, hydrogen tanks and other hydrogen-related parts, as well as inside the hydrogen pipe. In order to avoid fires and explosions, never cut or damage these hydrogen-related parts or the hydrogen pipe.
- If there is any hydrogen leakage, do not use any electrical or rescue equipment that may produce static electricity, as this may ignite the hydrogen.

Cut Vehicle

- Pay special attention to the location of structural reinforcements, fuel system, SRS and high voltage electrical system components when cutting a vehicle.
- Refer to the Quick Reference Sheet (QRS) for each model for model specific information such as component locations, etc.



WARNING

- To prevent serious injury from a fire caused by sparks, use a hydraulic cutter or other tools that do not generate sparks when cutting the vehicle.

NOTE

- If the SRS airbag, seatbelt pretensioner, pop up hood or active headrest has already been activated, the inflator can be cut.

Fire

■ During the initial attack on a fire, extinguish the fire with copious amounts of water. This will also cool down the vehicle.

WARNING

■ Plastic and other components will generate toxic gases when they melt. Wear appropriate protective equipment such as a protective mask when extinguishing a fire.

Fire Extinguisher

■ Water has been proven to be a suitable extinguishing agent.

■ Also use a fire extinguisher suitable for flammable liquid fires (burning of gasoline, grease, oil, etc.) and electrical fires (burning of electrical wiring, electric devices, etc.) as well as general fires (burning of solid objects, etc.).

Vehicle with High Voltage Battery

■ Hybrid vehicles (HV), plug-in hybrid vehicles (PHV), electric vehicles (EV) and fuel cell vehicles (FCV) are equipped with a high voltage battery.

■ Extinguish the fire with copious amounts of water to cool down the high voltage battery.

■ Refer to the Quick Reference Sheet (QRS) for each model for the high voltage battery location.

WARNING

■ To avoid serious injury or death from severe burns or electric shock, never breach or remove the high voltage battery assembly cover under any circumstances, including fire.

■ If only a small amount of water is used to extinguish a fire, a short circuit may occur in the high voltage battery, causing the fire to reignite.

NOTICE

■ It is recommended to allow the high voltage battery to burn itself out if it judged that it is difficult to apply copious amounts of water to the high voltage battery.

Vehicle with Lithium ion (Li-ion) Battery

WARNING

■ Burning Li-ion batteries may irritate the eyes, nose or throat. In case of contact with the vapor from the electrolyte, it may irritate the nose or throat. To avoid injury by coming in contact with the electrolyte or vapor, wear appropriate protective equipment such as rubber gloves, safety goggles, protective mask or SCBA when there is a risk of touching electrolyte.

Vehicle with Urea Solution

■ Urea solution equipped vehicles have a urea tank that stores urea solution.

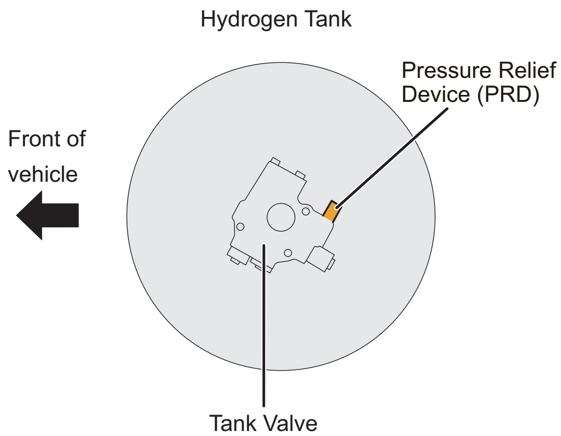
WARNING

■ The urea solution is noncombustible. However, if the urea solution is heated due to a fire, etc., it breaks down and may emit a harmful gas. If you come in contact with smoke or vapor from a burning urea tank, it may irritate the eyes, nose or throat.

■ To avoid injury by coming in contact with the smoke or vapor from a burning urea tank, wear appropriate protective equipment such as rubber gloves, safety goggles, a protective mask or SCBA when there is a risk of contacting the smoke or vapor.

Vehicle with Hydrogen Gas

- Fuel cell vehicles (FCV) carry compressed hydrogen gas.
- When dousing the vehicle, keep a distance in case of hydrogen igniting.
- Use larger amounts of water particularly on the vehicle's rear underfloor to cool the area where the hydrogen tanks are located.
- If the hydrogen is on fire, extinguishing the hydrogen flame completely could cause unburned hydrogen to accumulate and lead to a secondary explosion. Therefore, spray water to prevent the flame from spreading to surrounding areas, then wait for the hydrogen flame to naturally die down (burn itself out).
- In order to prevent an explosion when the temperature of the hydrogen reaches abnormal levels in case of a vehicle fire, the pressure relief devices (PRD) installed on the hydrogen tanks open when they exceed approximately 110°C (230°F), and the hydrogen inside the tank is released outside of the vehicle.
- A pure hydrogen fire is colorless and is not visible. However, in a vehicle fire, other flammable materials will also burn, allowing the fire to be visible.
- The temperature of a hydrogen fire itself is very high, but the amount of heat that radiates from the flame is small. It is unique in that it is difficult to feel the heat even in close proximity.



WARNING

- Hydrogen gas is colorless, odorless and flammable.
- Compared to gasoline or natural gas, hydrogen gas can ignite in a wide range of concentrations (4 to 74.5%). If the sound of hydrogen leaking (a loud hissing sound) can be heard when working on the vehicle, or if the hydrogen concentration around the vehicle exceeds 4% when measured with a hydrogen concentration detector, immediately step away from the vehicle as there is a chance that the hydrogen gas may ignite.

Submersion

■ Pull the vehicle out of water as much as possible. Immobilize the vehicle (see page 66) and disable the vehicle (see page 69) before starting any operation.

NOTICE

■ A short circuit due to electrical corrosion (wiring and circuit boards become corroded due to an electrochemical reaction with water) may cause a vehicle fire after some time has elapsed.

■ To prevent a vehicle fire, avoid turning the ignition switch or power switch of a submerged vehicle to ACC or ON.

Vehicle with High Voltage Battery

■ A partially or fully submerged hybrid vehicle (HV), plug-in hybrid vehicles (PHV), electric vehicle (EV) or fuel cell vehicle (FCV) does not have high voltage potential on the metal vehicle body, and is safe to touch.

■ It is safe to enter the water as the vehicle and water have the same electrical potential.

WARNING

■ Touching exposed orange high voltage power cables or high voltage components such as the high voltage battery may cause electrical shock due to a change in electrical potential.

■ To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or a high voltage components.

Spills

- Vehicles contain various fluids such as gasoline, coolant, engine oil, transmission oil, brake fluid, power steering fluid, window washer fluid and 12 V battery electrolyte.

Coolant

- Long Life Coolant (LLC) that is used to cool the engine and inverter contains ethylene glycol for freezing temperature control and anticorrosion additives for preventing metal components from corroding.

Lubrication Oil

- Engine oil, transmission oil and gear oil are used for lubrication and contain mineral oils and synthetic oils.

Brake Fluid

- Brake fluid contains several types of glycol-ether and anticorrosion additives for preventing metal components from corroding.

NOTICE

- Brake fluid contains ingredients that damage painted surfaces. If any comes in contact with the vehicle body, the paint may come off.

Power Steering Fluid

- Power steering fluid contain mineral oils and synthetic oils.

Window Washer Fluid

- Window washer fluid contains alcohol for freezing temperature control.

12 V Battery Electrolyte

- 12 V battery electrolyte contains dilute sulfuric acid.

WARNING

- Dilute sulfuric acid may cause irritation of the skin if contacted. Wear appropriate protective equipment such as rubber gloves and safety goggles when there is a risk of touching electrolyte.

NOTICE

- 12 V battery electrolyte contains ingredients that damage painted surfaces. If any comes in contact with the vehicle body, discoloration or other damage may occur.

Sub-battery Electrolyte

■ A strong alkaline (pH 13.5) potassium hydroxide water solution is used as the sub-battery electrolyte. The electrolyte is soaked into non-woven fabric. However, if the sub-battery is damaged in any way, it may leak.

WARNING

■ Strong alkaline (pH 13.5) potassium hydroxide water solution is harmful to the human body. In cases where touching the electrolyte is unavoidable or there is a danger of it being touched, perform work wearing appropriate protective equipment such as rubber gloves and protective glasses.

Vehicle with High Voltage Battery

■ There are 2 types of high voltage battery; the nickel-metal hydride type and the lithium ion type.

1. Nickel-metal hydride (Ni-MH) battery

- The Ni-MH battery contains a strong alkaline electrolyte (pH 13.5). The electrolyte is absorbed in the cell plates, but it may leak in case of damages to the high voltage battery. However, it would not be a large amount.
- Electrolyte leakage from the HV battery pack is unlikely considering the battery construction and the amount of electrolyte inside the module.
- Any spillage would not warrant a declaration as a hazardous material incident.

WARNING

■ Strong alkaline electrolyte (pH 13.5) is harmful to the human body. To avoid injury by coming in contact with the electrolyte, wear appropriate protective equipment such as rubber gloves and safety goggles when there is a risk of touching electrolyte.

2. Lithium ion (Li-ion) battery

- The Li-ion battery electrolyte, mainly consisted of carbonate ester, is a flammable organic electrolyte. The electrolyte is absorbed into the electrodes and the separators. It may leak in case of damages to the high voltage battery, but it would not be a large amount.
- Electrolyte will quickly evaporate if leaked from the battery cell.

WARNING

■ The flammable organic electrolyte which primarily contains carbonate ester is harmful to the human body. In case of contact with the electrolyte, it may irritate the eyes, nose, throat and skin. In case of contact with the smoke or vapor from leaked electrolyte or a burning battery, it may irritate the eyes, nose or throat. To avoid injury caused by coming in contact with the electrolyte or the vapor, wear appropriate protective equipment such as rubber gloves, safety goggles, protective mask or SCBA when there is a risk of touching electrolyte.

■ If the electrolyte is spilled, keep it away from fire and ensure the area is well ventilated. Absorb the electrolyte with a piece of cloth or equivalent absorbent material, and keep it in an airtight container for proper disposal.

Vehicle with Urea Solution

- Urea solution equipped vehicles have a urea tank that stores urea solution.
- The urea solution is a harmless noncombustible liquid. However, if the urea solution is heated due to a fire, etc., it breaks down and may emit a harmful gas.

WARNING

- If you come in contact with smoke or vapor from a burning urea tank, it may irritate the eyes, nose or throat. To avoid injury by coming in contact with the smoke or vapor from a burning urea tank, wear appropriate protective equipment such as rubber gloves, safety goggles, a protective mask or SCBA when there is a risk of contacting the smoke or vapor.

Vehicle with Hydrogen Gas

- The FC stack coolant used to cool the FC stack, etc. is colorless and transparent and contains ethylene glycol in order to lower the freezing point.

Gas Leaks

- There are various types of gas used in vehicles. For example, there is nitrogen (N2) gas used in gas filled dampers, refrigerant gas for air conditioners, and CNG, LPG and hydrogen gas.

Nitrogen (N2) Gas

- Nitrogen (N2) is used in gas filled dampers.
- The gas is colorless, odorless, and harmless.

Refrigerant Gas

- The refrigerant gas used in air conditioner is R-134a or R-1234yf.
- The gas is containing carbon and fluorine.
- The gas is colorless, odorless, and harmless.

Vehicle with CNG

- Compressed Natural Gas (CNG) is a flammable gas that mainly contains methane.
- The gas is colorless and harmless.
- The gas is infused with a smell so that a leak can be quickly detected.

WARNING

- If the sound of natural gas leaking (a loud hissing sound) can be heard when working on the vehicle, or if the smell of natural gas is present, immediately step away from the vehicle as there is a chance that the natural gas may ignite.

Vehicle with LPG

- Liquefied Petroleum Gas (LPG) is a flammable gas that mainly contains propane and butane.
- The gas is colorless and harmless.
- The gas is infused with a smell so that a leak can be quickly detected.

WARNING

- If the sound of LPG leaking (a loud hissing sound) can be heard when working on the vehicle, or if the smell of LPG is present, immediately step away from the vehicle as there is a chance that the LPG may ignite.

Vehicle with Hydrogen Gas

- Hydrogen gas is a flammable gas.
- The gas is colorless, odorless, and harmless.

> WARNING
>
> - If the sound of hydrogen leaking (a loud hissing sound) can be heard when working on the vehicle, or if the hydrogen concentration around the vehicle exceeds 4% when measured with a hydrogen concentration detector, immediately step away from the vehicle as there is a chance that the hydrogen gas may ignite.

Damaged Vehicle Handling Key Points

■ Points to be noted when handling damaged vehicles are provided in this section.

Towing Damaged Vehicle

- Loading a vehicle onto a car carrier (flat bed trailer) is the preferred method of towing.
- Only the FF (Front-engine Front-wheel drive) vehicles are available to tow with rear wheels on the ground.
- If towing the vehicle with all four wheels on the ground is unavoidable, release the parking lock, move the shift lever to neutral (N), and unlock the steering wheel first. The vehicle can then be towed at a low speed (below 30 km/h) for a distance of up to 80 km in a forward direction. (*Except vehicles with a high voltage battery. See page 93 for details.)
- Refer to the illustrations on the following page for correct and incorrect methods of towing FF (Front-engine Front-wheel drive), FR (Front-engine Rear-wheel drive), MR (Mid-engine Rear-wheel drive) and 4WD (Four Wheel Drive) vehicles.

WARNING

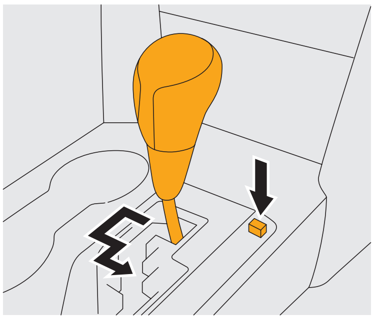
- When towing a vehicle with all four wheels on the ground, make sure the vehicle is in "Ignition-On" mode. If in "Off" mode, the steering wheel may lock, making the steering inoperative.

NOTICE

- Exceeding the towing distance or speed limit when towing a vehicle with all four wheels on the ground or towing a vehicle with the vehicle facing backwards, may damage the transmission or transaxle.
- When the vehicle is equipped with a stop and start system, towing the vehicle with all four wheels on the ground may damage the system.

Parking Lock

- The parking lock can be released by moving the shift lever from park (P) to neutral (N) while pushing and holding the "lock release button" on the shift gate.

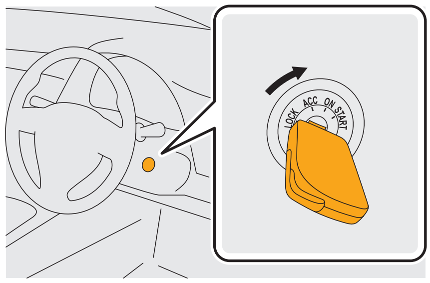


NOTICE

- The parking lock for vehicles equipped electric shift switches (vehicles with a P position switch) cannot be released while the 12 V negative (-) battery terminal is disconnected. When moving the vehicle, use a jack, etc.

Steering Wheel Lock

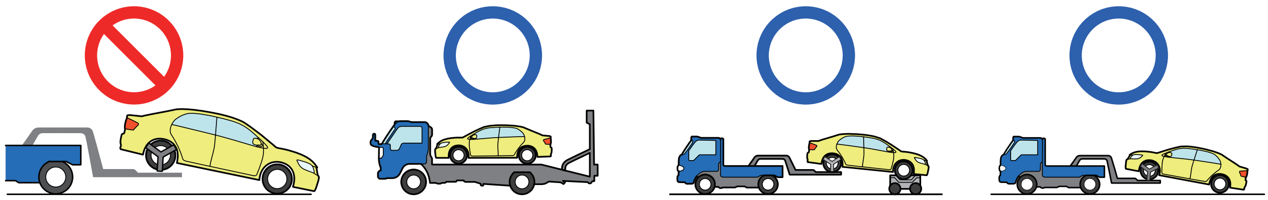
- The steering wheel can be unlocked by pushing the engine/power switch until in “Ignition-On” mode, or turning the ignition switch to any position other than “LOCK”.
- When it is difficult to release the lock, turn the steering wheel in either direction while pushing the engine/power switch or turning the key.



> NOTICE
>
> - When a vehicle is equipped with the electrical key transmitter system, the steering wheel cannot be unlocked if the negative (-) terminal of the 12 V battery is disconnected. Use wheel dollies or similar equipment when moving the vehicle.

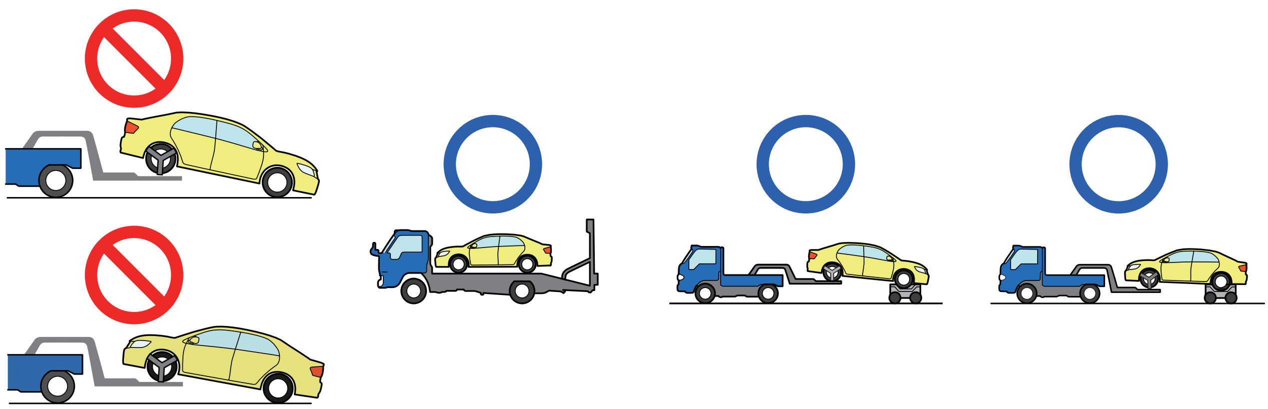
Precautions for FF (Front-engine Front-wheel drive) vehicle

- Tow the vehicle with the front wheels or all four wheels off the ground.



Precautions for FR (Front-engine Rear-wheel drive), MR (Mid-engine Rear-wheel drive) and 4WD (Four Wheel Drive) vehicles

- Tow the vehicle with all four wheels off the ground.



Vehicle with High Voltage Battery

- Make sure the negative (-) terminal of the 12 V battery is disconnected, then load the vehicle onto a car carrier (flat bed trailer).
- If towing the vehicle with all four wheels on the ground is unavoidable, only tow it for a short distance (such as to a car carrier (flat bed trailer)) in a forward direction at a low speed (below 30 km/h (18 mph)).
- Refer to the above illustrations for correct and incorrect methods of towing FF, FR and 4WD vehicles.

WARNING

- Hybrid vehicles (HV), plug-in hybrid vehicles (PHV), electric vehicles (EV) and fuel cell vehicles (FCV) are equipped with a high voltage electrical system (over 144 V, up to 650 V).
- To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components.

NOTICE

- If hybrid vehicles (HV), plug-in hybrid vehicles (PHV), electric vehicles (EV) or fuel cell vehicles (FCV) are towed with the drive wheels on the ground, it could have adverse effects on the high voltage system and damage it.

Storing a Damaged Vehicle

■ Drain gasoline, oil and other fluids, then disconnect the negative (-) terminal of the 12 V battery before storing a damaged vehicle.

Submerged Vehicle

■ In addition to the normal procedures, remove the water from the vehicle.

> **NOTICE**
>
> ■ A vehicle that has been submerged in water poses a threat of vehicle fire after some time for possible short circuits due to electrical corrosion (wiring and circuit boards to corrode in an electrochemical reaction with water). To store a vehicle that has been submerged in water, choose a well-ventilated place at least 15 meters (49.2 feet) away from other objects.
>
> ■ To prevent a vehicle fire, avoid turning the ignition switch or power switch of a submerged vehicle to ACC or ON.

Vehicle with High Voltage Battery

■ In addition to the normal procedures, remove the service plug from the high voltage battery before storing a damaged vehicle.

> **WARNING**
>
> ■ The service plug is a high voltage component. Touching it without appropriate protective equipment may result in serious injury or death from severe burns and electric shock from the high voltage electrical system. Wear appropriate protective equipment such as insulated gloves when touching the service plug.
>
> ■ The high voltage battery is still charged with high voltage electricity even after the vehicle is shut off, disabled (see page 69) and the service plug is removed from the high voltage battery.
>
> ■ To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components.
>
> ■ When the person(s) in charge of handling the damaged vehicle is away from the vehicle, other person(s) may accidentally touch the vehicle and be electrocuted, resulting in severe injury or death. To avoid this danger, display a “HIGH VOLTAGE DO NOT TOUCH” sign to warn others (print and use page 21 of this guide).

> **NOTICE**
>
> ■ A high voltage battery may cause a vehicle fire after some time for possible short circuits inside due to the impact of collision or electrical corrosion. To store a vehicle equipped with a high voltage battery, choose a well-ventilated place at least 15 meters (49.2 feet) away from other objects.

Vehicle with Hydrogen Gas

- In addition to the normal procedures, remove the service plug from the FC stack before storing a damaged vehicle.

WARNING

- The service plug is a high voltage component. Touching it without appropriate protective equipment may result in serious injury or death from severe burns and electric shock from the high voltage electrical system. Wear appropriate protective equipment such as insulated gloves when touching the service plug.
- To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components.
- When the person(s) in charge of handling the damaged vehicle are away from the vehicle and someone else accidentally approaches or touches the vehicle, death or serious injury may occur due to electrocution, a rupture, an explosion or fire. To avoid this danger, display “HIGH VOLTAGE DO NOT TOUCH” and ”HIGH-PRESSURE GAS DO NOT TOUCH” signs to warn others (print and use page 25 and 36 of this guide).

NOTICE

- Vehicles that are equipped with hydrogen gas may leak due to damage incurred during an accident. The remaining hydrogen may ignite causing a fire or explosion. Therefore, when storing a vehicle equipped with hydrogen gas, place it in a well ventilated area 15 meters or more away from other items and leave the windows or doors open.

Vehicle with Sub-battery

NOTICE

- Due to the impact during the collision and electrolytic corrosion of the sub-battery, a short circuit may occur internally causing a fire to occur after a certain amount of time elapses. When storing a vehicle equipped with a sub-battery, place it in a well ventilated area 15 meters or more away from other items.

DEPRESSURIZING THE HYDROGEN FUEL SYSTEM

Reference Material

Introduction to Fuel Cell Vehicles
January, 2018

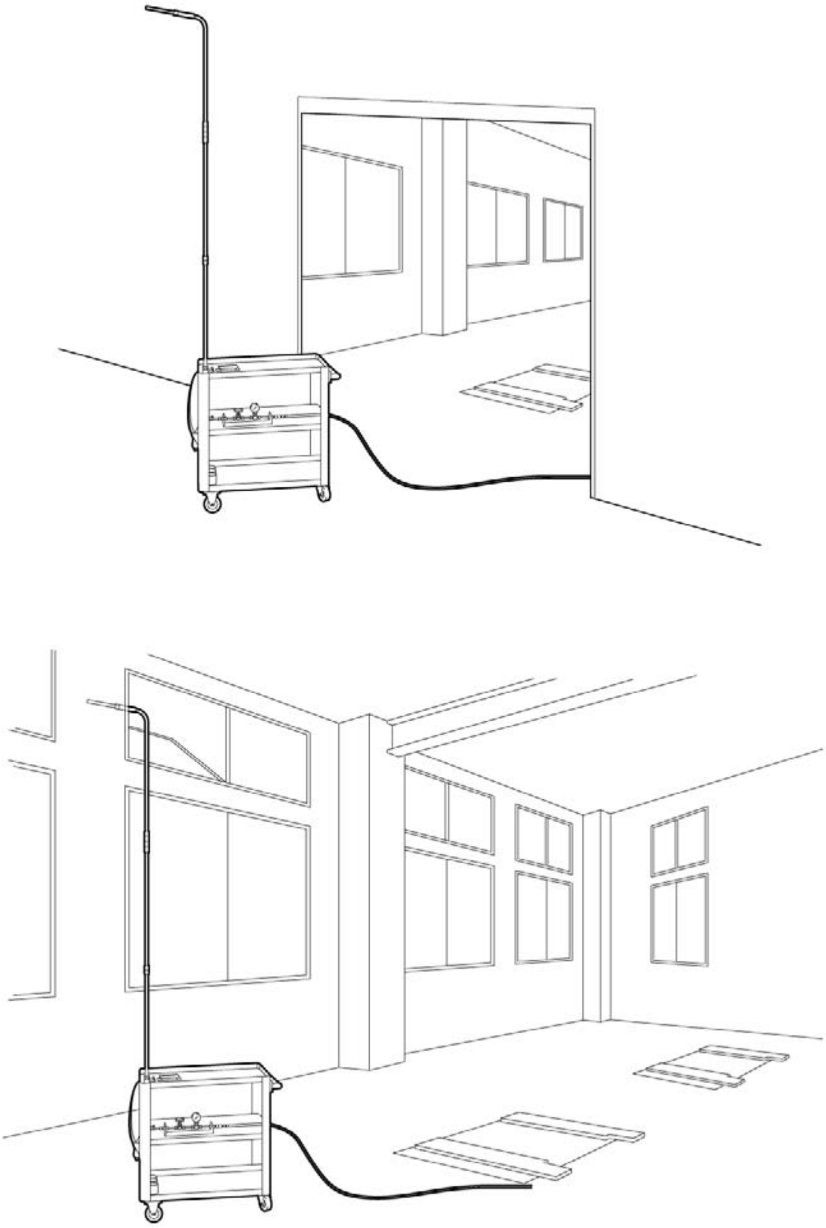
LOS ANGELES TRADE-TECH
LATTC
A Community College

2. PREPARE SST (HYDROGEN VENTING TOOL)

Hint:

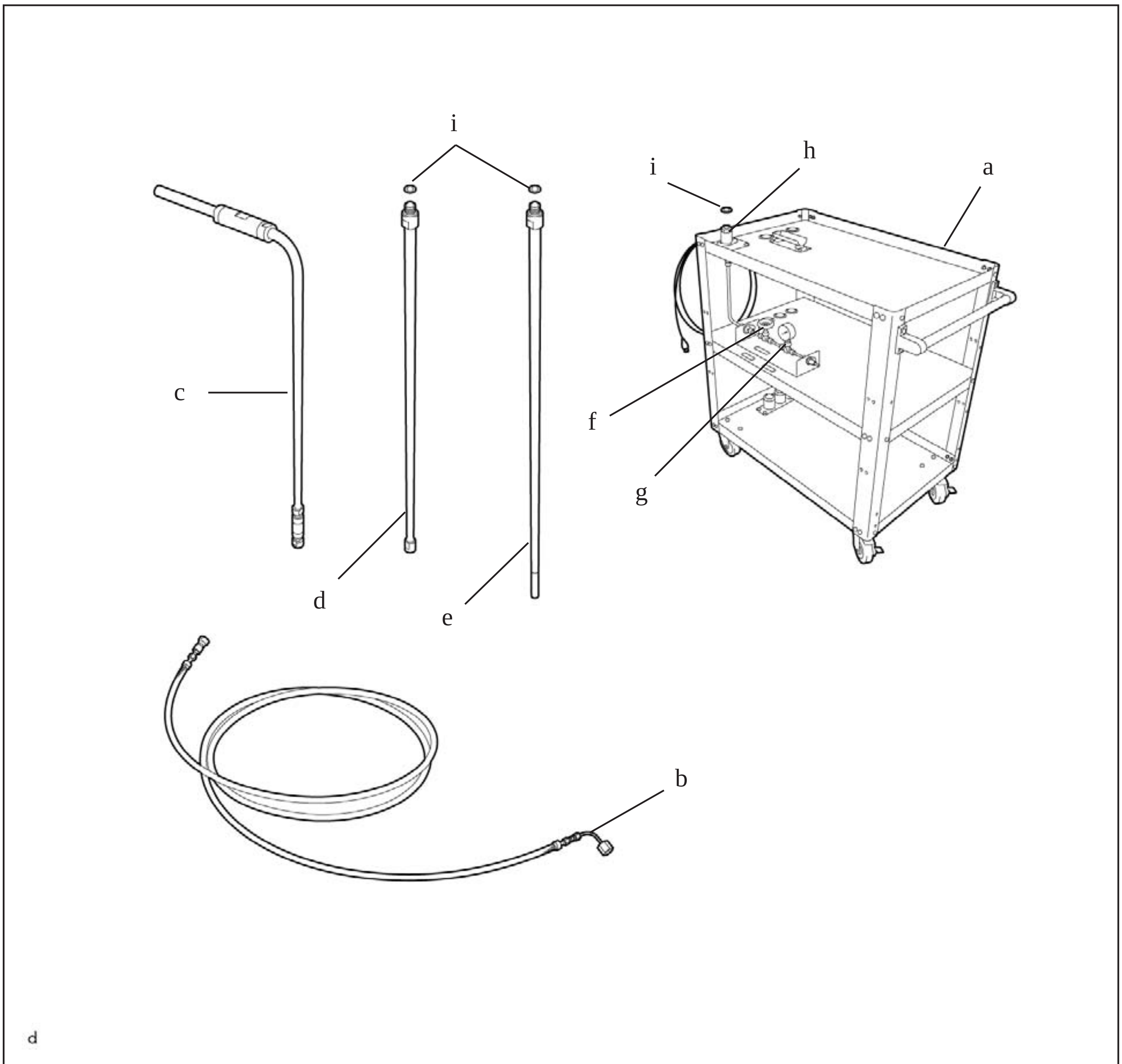
Before performing work, check the set up conditions of the SST (hydrogen venting tool).

<Hydrogen Gas Discharging Conditions>



a	Basic Conditions	b	Other than Basic Conditions (if mechanism cannot be set up outdoors)

(1) Check the assembly of the SST (hydrogen venting tool).



a	SST (Venting Stand)	b	SST (Flexible Hose)
c	SST (Upper Release Pipe)	d	SST (Middle Release Pipe)
e	SST (Lower Release Pipe)	f	Open/close Valve
g	Pressure Gauge	h	Discharge Pipe Support
i	SST (O Ring (Replace at time of using SST (hydrogen venting tool)))	-	-

SST

09404-62010 (09404-06010, 09404-06020, 09404-06030, 09404-06040, 09404-06050,09404-06060)

Make sure to replace the SST (3 O-rings) of the SST (hydrogen venting tool) with new ones.

(2) Remove the SST (O-ring) from the SST (middle release pipe).

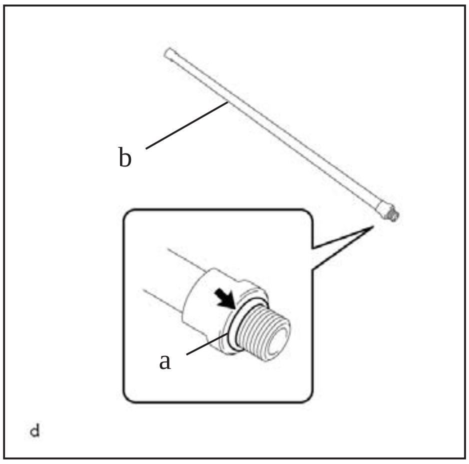
SST

09404-62010 (09404-06040, 09404-06060)

(3) Install a new SST (O-ring) to the SST (middle release pipe).

SST

09404-62010 (09404-06040, 09404-06060)



a	SST (O-ring)
b	SST (Middle Release Pipe)

(4) Remove the SST (O-ring) from the SST (lower release pipe).

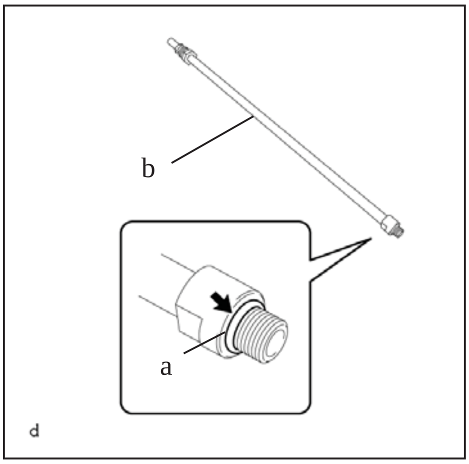
SST

09404-62010 (09404-06050, 09404-06060)

(5) Install a new SST (O-ring) to the SST (lower release pipe).

SST

09404-62010 (09404-06050, 09404-06060)

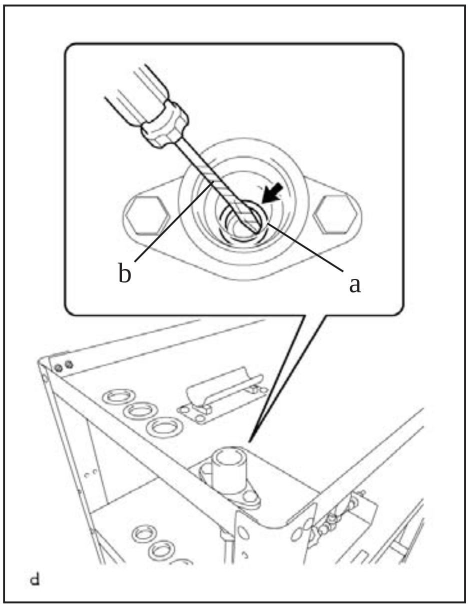


a	SST (O-ring)
b	SST (Lower Release Pipe)

(6) Using a thin-bladed screwdriver with its tip wrapped in protective tape, remove the SST (O-ring) from the release pipe support.

SST

09404-62010 (09404-06010, 09404-06060)

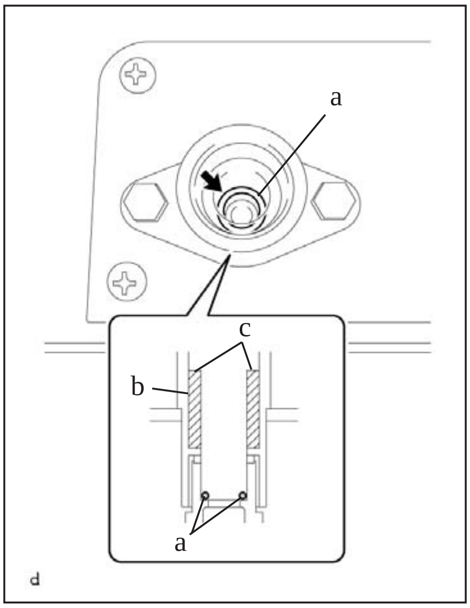


a	SST (O-ring)
b	Protective Tape

(7) As shown in the illustration, install a new SST (O-ring) to the release pipe support.

SST

09404-62010 (09404-06060)



a	SST (O-ring)
b	Release Pipe Support
c	Collar

(8) Connect each part of the SST (hydrogen venting tool) and prepare it for use.

i. Connect the SST (upper release pipe) and SST (middle release pipe), and using a thickness gauge, measure the clearance in the location shown in the illustration.

SST

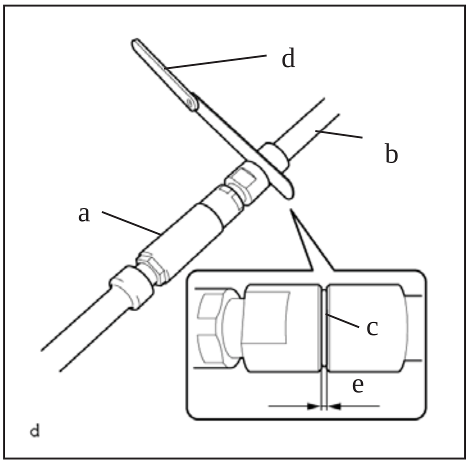
09404-62010 (09404-06030, 09404-06040, 09404-06060)

Discharge pipe connection clearance:

1.7 mm (0.0669 in.)

Notice:

Perform the procedure by hand. Do not use any tools.



a	SST (Upper Release Pipe)
b	SST (Middle Release Pipe)
c	SST (O-ring)
d	Thickness Gauge
e	1.7 mm (0.0669 in.)

ii. Connect the SST (middle release pipe) and SST (lower release pipe), and using a thickness gauge, measure the clearance in the location shown in the illustration.

SST

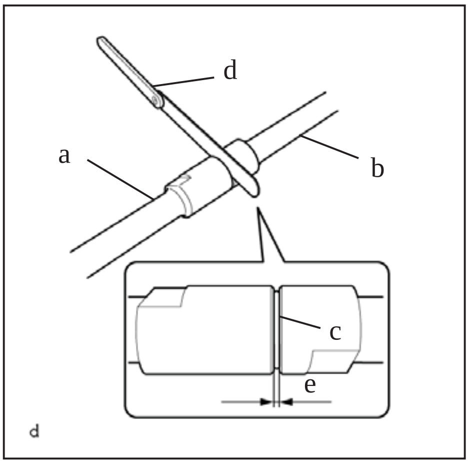
09404-62010 (09404-06040, 09404-06050, 09404-06060)

Discharge pipe connection clearance:

1.7 mm (0.0669 in.)

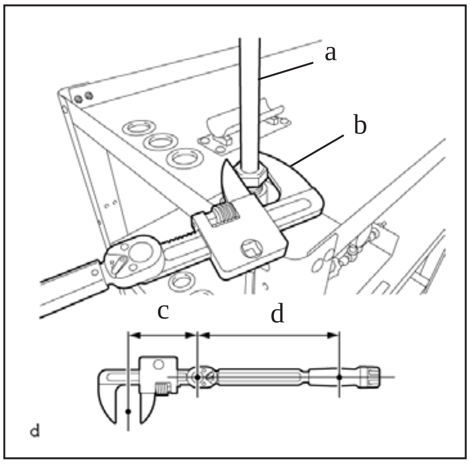
Notice:

Perform the procedure by hand. Do not use any tools.



a	SST (Middle Release Pipe)
b	SST (Lower Release Pipe)
c	SST (O-ring)
d	Thickness Gauge
e	1.7 mm (0.0669 in.)

iii. Connect the SST (lower release pipe) to the discharge pipe support, and using SST (variable open wrench), tighten the nut.



a	SST (Lower Release Pipe)
b	SST (Variable Open Wrench)
c	SST Fulcrum Length
d	Torque Wrench Fulcrum Length

SST

09922-10010

09404-62010 (09404-06050)

Torque:

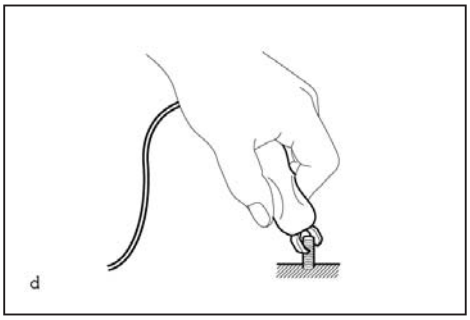
Specified tightening torque

20 N*m (204 kgf*cm, 15 ft.*lbf)

Hint:

- Calculate the torque wrench reading when changing the fulcrum length of the torque wrench.
- When using SST (fulcrum length of 136 mm (5.35 in.)) + torque wrench (fulcrum length of 180 mm (7.09 in.)): 11.4 N*m (116 kgf*cm, 8 ft.*lbf)

iv. Connect the ground wire.

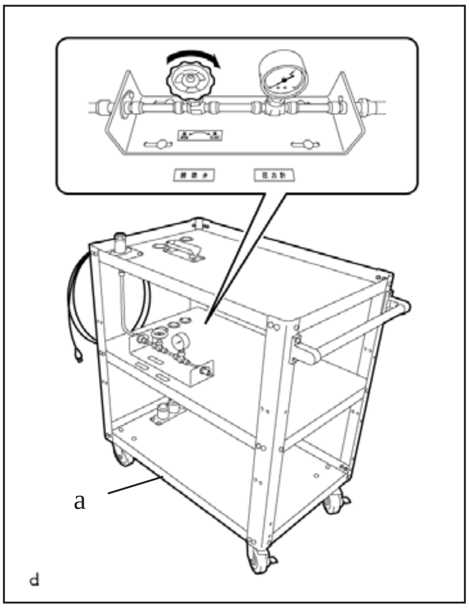


Notice:

Connect the ground wire to somewhere that will enable secure electrical grounding.

3. CONNECT SST (HYDROGEN VENTING TOOL)

(1) Check that the open/close valve of the SST (venting stand) is closed.

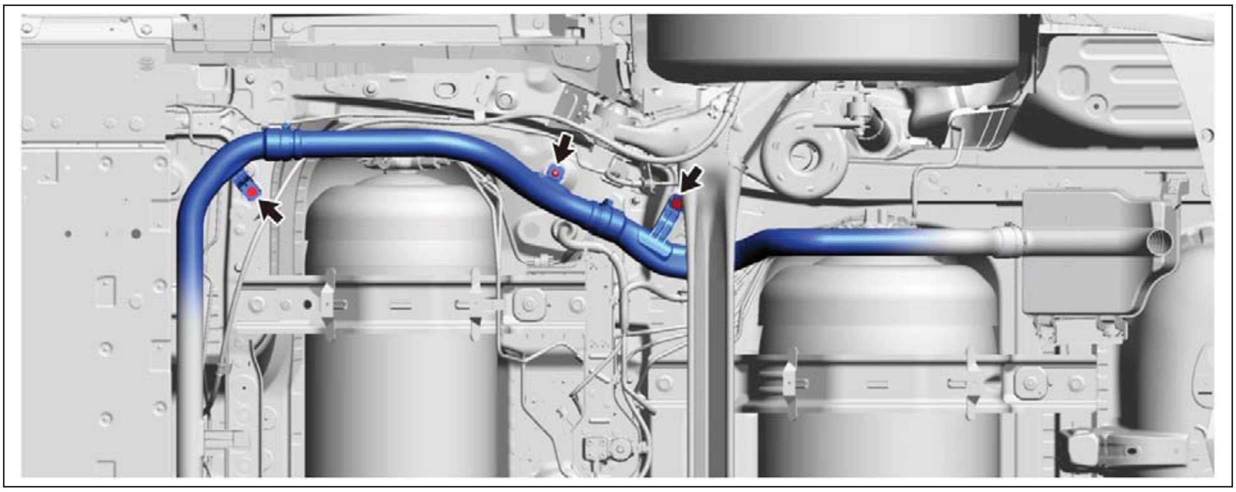


a	SST (Venting Stand)

SST

09404-62010 (09404-06010)

(2) Remove the 3 bolts and disconnect the FC exhaust pipe.



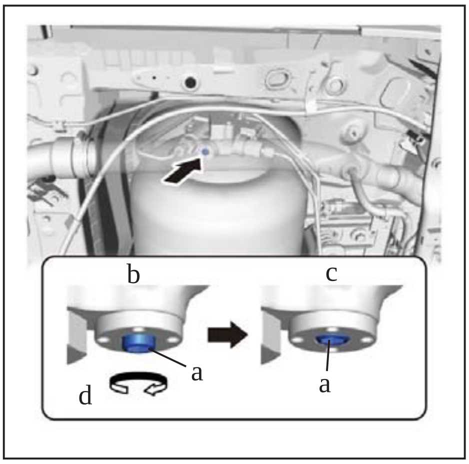
(3) Using an 8 mm socket hexagon wrench, rotate the adjustment bolt in the clockwise direction to close the manual valve of the No. 1 hydrogen tank assembly.

Torque:

20 N*m (204 kgf*cm, 15 ft.*lbf)

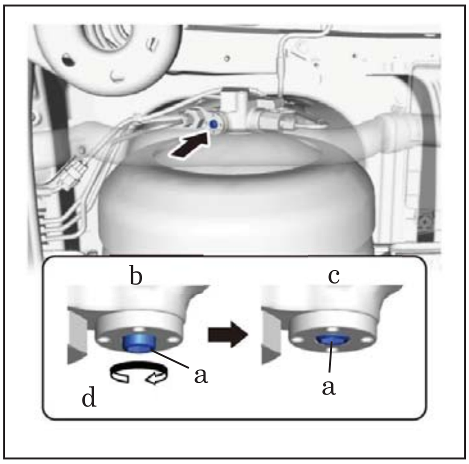
Notice:

- The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.



a	Adjustment Bolt
b	Manual Valve Open
c	Manual Valve Closed
d	Clockwise

(4) Using an 8 mm socket hexagon wrench, rotate the adjustment bolt in the clockwise direction to close the manual valve of the No. 2 hydrogen tank assembly.



a	Adjustment Bolt
b	Manual Valve Open
c	Manual Valve Closed
d	Clockwise

Torque:

20 N*m (204 kgf*cm, 15 ft.*lbf)

Notice:

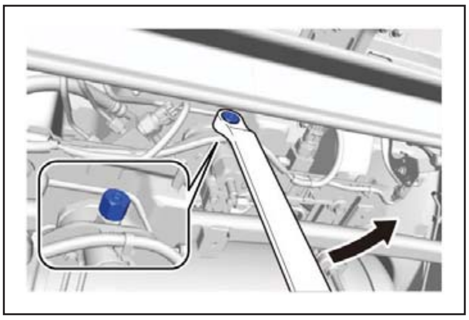
The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

(5) Before beginning depressurization procedures, if there are any contaminants such as mud near the medium pressure leak check port of the hydrogen supply regulator assembly, clean them away.

Hint:

Performing installation while any foreign matter is adhered to the nut of the medium pressure leak check port could cause a hydrogen gas leak.

(6) Perform depressurization.



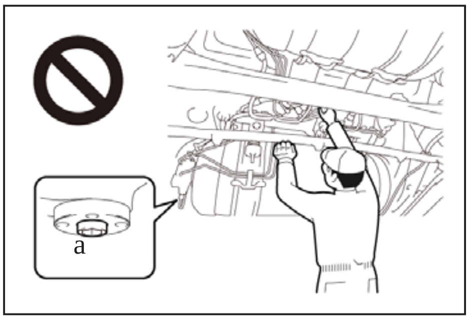
Notice:

When performing depressurization, only loosen the nut. Do not remove it.

i. Slowly loosen the nut until the hissing sound of gas escaping can be heard, then stop loosening the nut and wait for the sound to stop. Repeat this procedure multiple times until the sound stops occurring, in order to depressurize the compressed hydrogen gas from the medium pressure leak check port of the hydrogen supply regulator assembly.

Caption:

- Do not perform depressurization procedures when the manual valve of the hydrogen tank assembly is open.
- The highly pressurized hydrogen gas inside the hydrogen tank assembly could blow out, resulting in a serious accident.

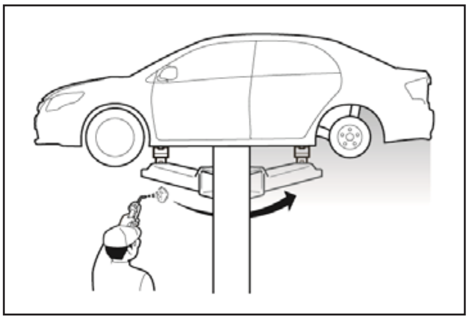


a	Manual Valve Open

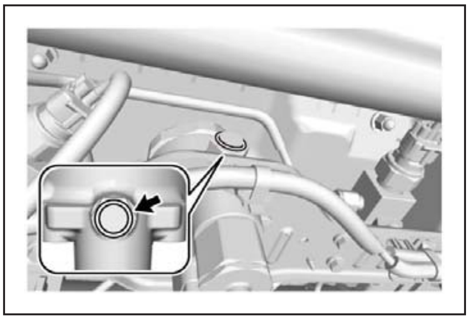
- When performing depressurization, do not perform procedures by hand without wearing protective glasses and gloves.
- The highly pressurized hydrogen gas inside the hydrogen tank assembly could blow out, resulting in a serious accident.

(7) Blow compressed air at the underside of the vehicle to disperse any accumulated hydrogen gas.

(8) Remove the nut from the medium-pressure leak check port of the hydrogen supply regulator assembly.

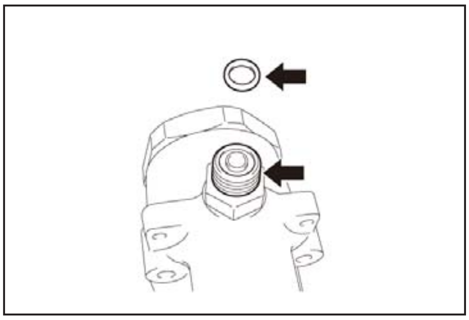


(9) Remove the O-ring from the hydrogen supply regulator assembly.



(10) Apply TOYOTA Genuine FC Grease to a new O-ring and to the threaded portion of the medium pressure leak check port.

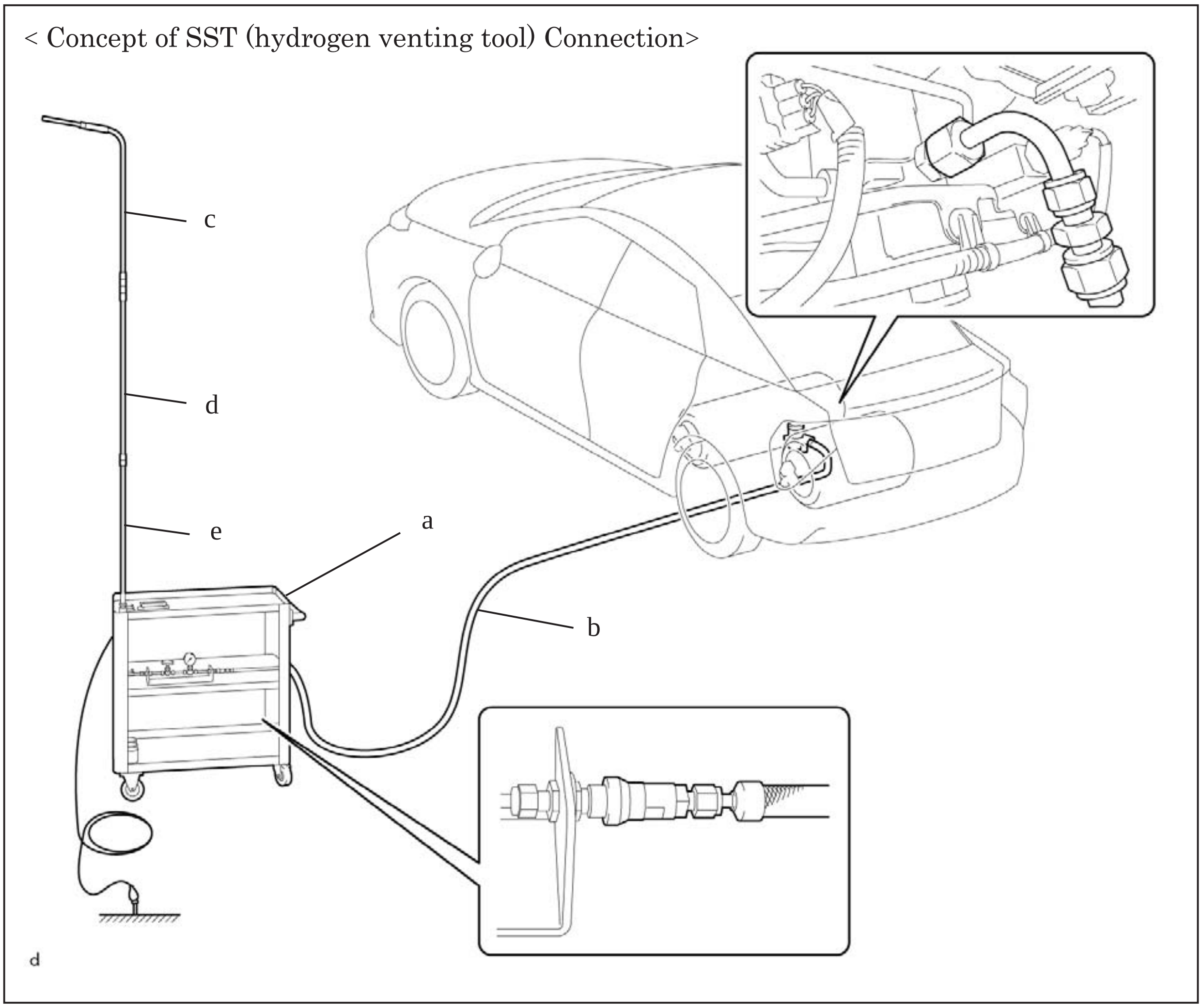
(11) Install the O-ring to the hydrogen supply regulator assembly.



Notice:

During installation, make sure not to damage the O-ring.

(12) Connect the SST (hydrogen venting tool).

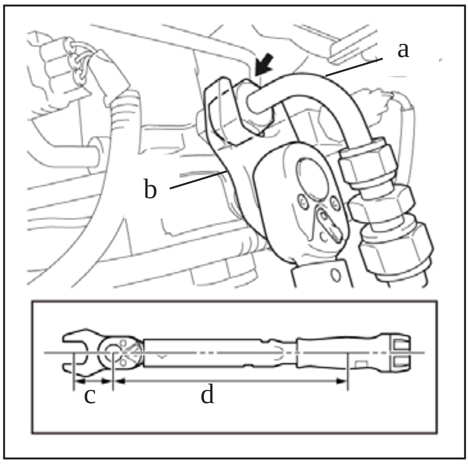


a	SST (Venting Stand)	b	SST (Flexible Hose)
c	SST (Upper Release Pipe)	d	SST (Middle Release Pipe)
e	SST (Lower Release Pipe)	-	-

SST

09404-62010 (09404-06010, 09404-06020, 09404-06030, 09404-06040, 09404-06050)

i. Using SST, install the flexible hose to the medium pressure leak check port of the hydrogen supply regulator assembly.



a	SST (Flexible Hose)
b	SST (Open End Wrench)
c	SST Fulcrum Length
d	Torque Wrench Fulcrum Length

SST

09922-10240

09404-62010 (09404-06020)

Torque:

Specified tightening torque

25 N*m (255 kgf*cm, 18 ft.*lbf)

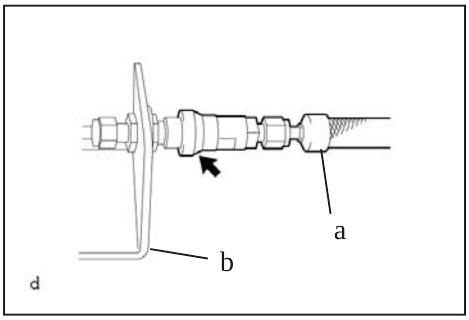
Notice:

- Make sure that the SST (flexible hose) does not interfere with any part of the vehicle.
- If the SST (flexible hose) interferes with any part of the vehicle, protect it with a piece of cloth, etc.

Hint:

- Calculate the torque wrench reading when changing the fulcrum length of the torque wrench.
- When using SST (fulcrum length of 40 mm (1.57 in.)) + torque wrench (fulcrum length of 255 mm (10.04 in.)): 21.6 N*m (220 kgf*cm, 16 ft.*lbf)

ii. Connect the SST (flexible hose) to the SST (Venting Stand).



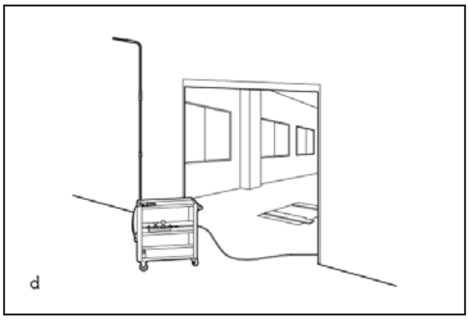
a	SST (Flexible Hose)
b	SST (Venting Stand)

SST

09404-62010 (09404-06010,09404-06020)

(13) Under basic conditions

i. Set the SST (hydrogen venting tool) in an outdoor location.

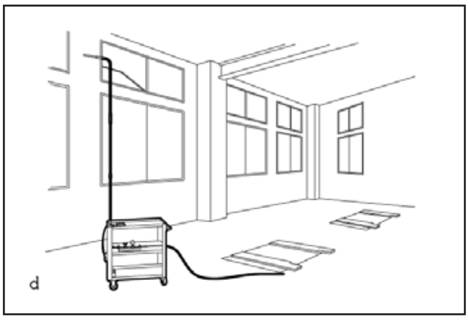


Notice:

Take care that the compressed hydrogen gas that is discharged during the discharging procedure does not enter any indoor location.

(14) Other than basic conditions (when outdoor setup is not possible)

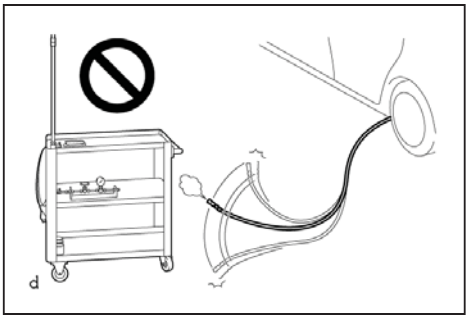
i. When the SST (hydrogen venting tool) will be set up indoors, locate it along a wall near a window, and with the tip of the SST (upper release pipe) outdoors.



Notice:

Open windows on two sides or more, and ensure that there is adequate ventilation to prevent the compressed hydrogen gas that is discharged from collecting inside.

(15) Open the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies, then immediately close them again.



Caution:

- **When opening the tank shut valve and applying pressure to the SST (hydrogen venting tool), stay away from the SST (flexible hose).**
- **If the SST (flexible hose) comes off, you could be struck by the loose end of the SST (flexible hose), causing a serious accident.**

(16) Perform preliminary leak check (using remaining piping pressure).

Hint:

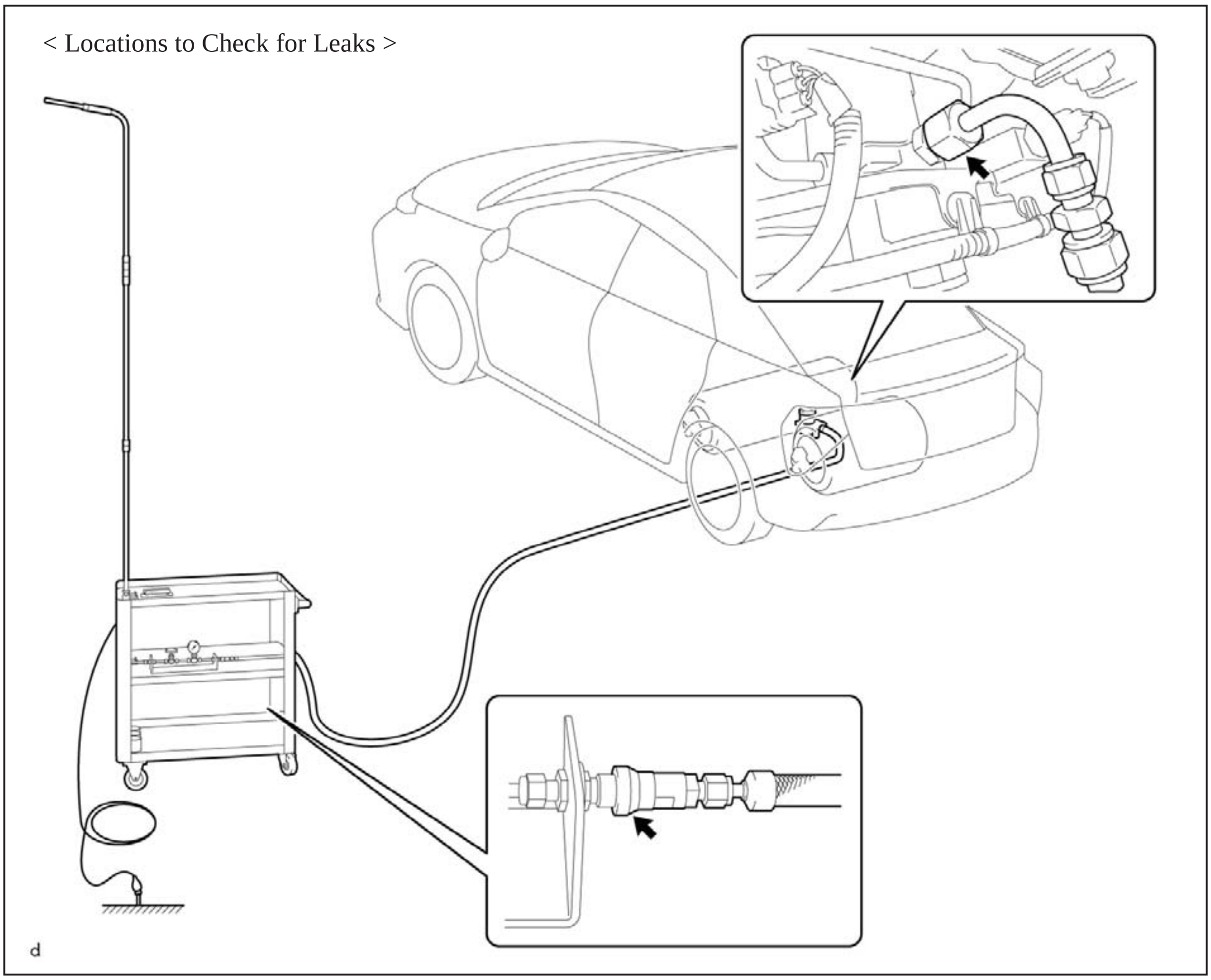
Perform leak check using the pressure remaining upstream of the tank shut valve.

i. If there are any water droplets, etc. adhering to the measurement locations, wipe them away before performing the procedure.

Notice:

Performing the measurement while any water droplets, etc. are adhering could damage the hydrogen gas detector.

ii. Using SST and a hydrogen gas detector, inspect for leaks in the locations shown in the illustration.



SST

09401-62010

Specified Value:

300 ppm or less

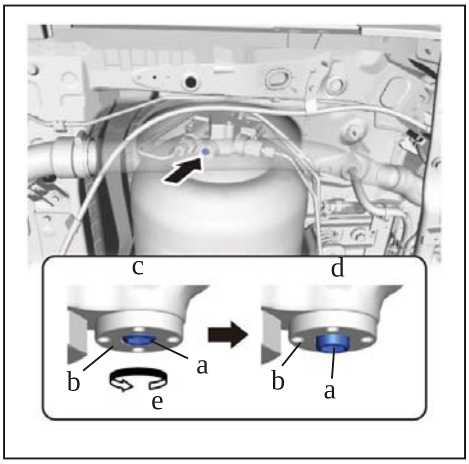
Notice:

If any values are outside the specified range, disconnect those locations that have leaks and assemble the parts again.

(17) Using an 8 mm socket hexagon wrench, rotate the adjustment bolt counterclockwise until it contacts the plug, and open the No. 1 hydrogen tank assembly manual valve.

Notice:

The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

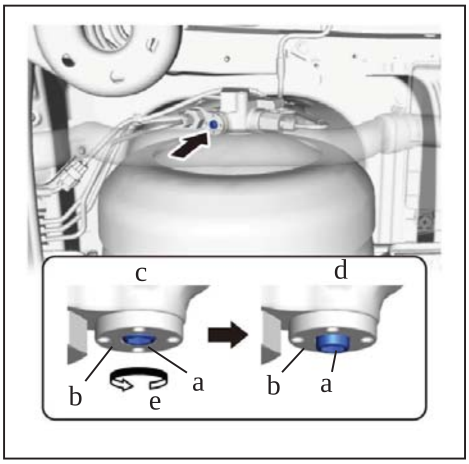


a	Adjustment Bolt
b	Plug
c	Manual Valve Closed
d	Manual Valve Open
e	Counterclockwise

(18) Using an 8 mm socket hexagon wrench, rotate the adjustment bolt counterclockwise until it contacts the plug, and open the No. 2 hydrogen tank assembly manual valve.

Notice:

The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

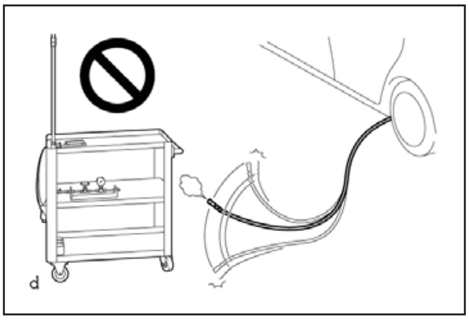


(19) Open the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies, then immediately close them again.

a	Adjustment Bolt
b	Plug
c	Manual Valve Closed
d	Manual Valve Open
e	Counterclockwise

Caution:

- **When opening the tank shut valve and applying pressure to the SST (hydrogen venting tool), stay away from the SST (flexible hose).**
- **If the SST (flexible hose) comes off, you could be struck by the loose end of the SST (flexible hose), causing a serious accident.**



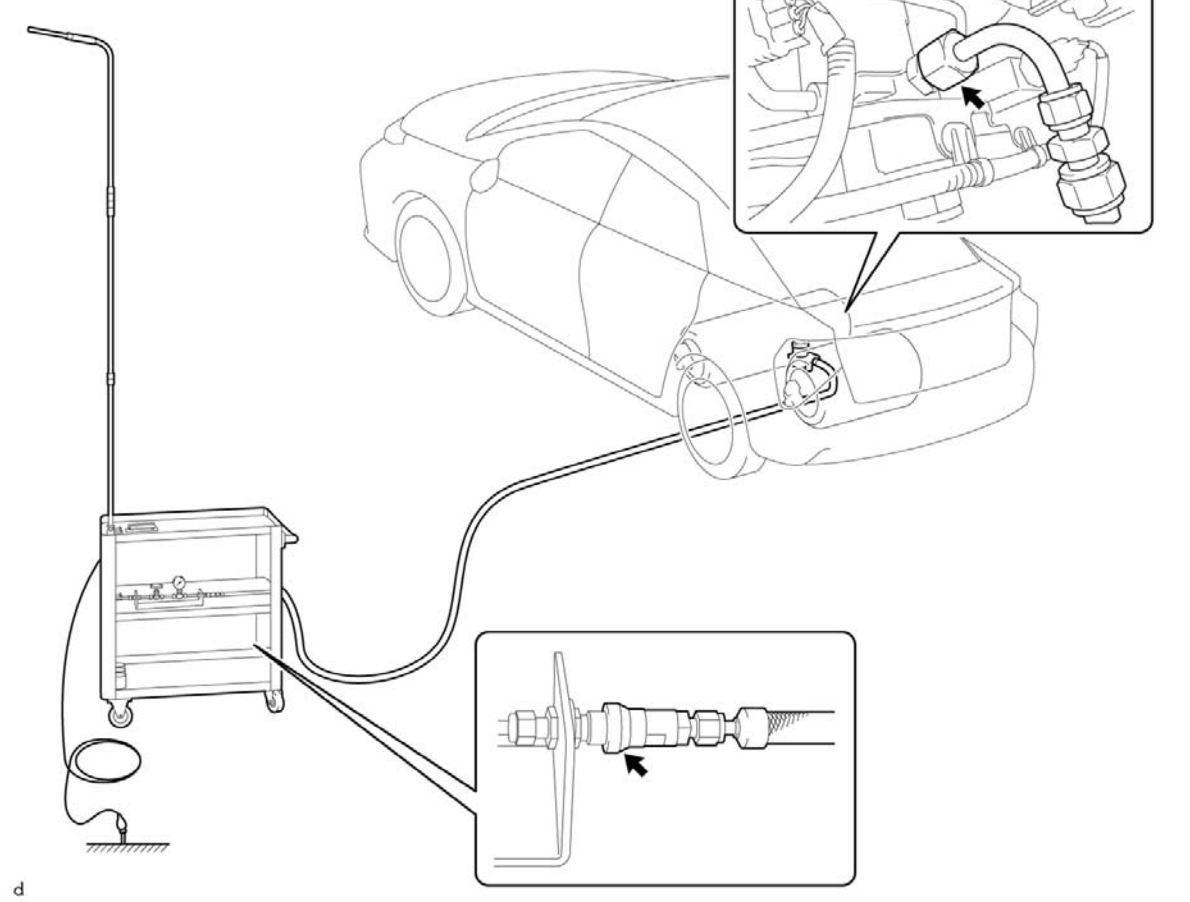
(20) Perform preliminary leak check (using tank pressure)

Hint:

Perform leak check while applying hydrogen tank pressure.

i. Using SST and a hydrogen gas detector, inspect for leaks in the locations shown in the illustration.

< Locations to Check for Leaks >



Specified Value:

300 ppm or less

Notice:

- If any values are outside the specified range, disconnect those locations that have leaks and assemble the parts again.
- After reassembling the locations that were leaking, perform the leak check again.

4. SELECT APPROPRIATE DISCHARGE PROCEDURE

Notice:

Except in a case where the tank shut valve for either the No. 1 or No. 2 hydrogen tank assembly cannot be opened, always perform the discharging procedure for both hydrogen tanks.

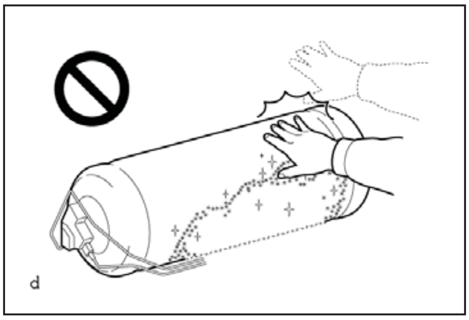
Using on-vehicle inspection of the hydrogen tanks or DTC-based troubleshooting, confirm the number of tanks for which compressed hydrogen gas will be discharged, and perform the appropriate discharging procedures.

Compressed Hydrogen Gas Discharging Conditions

Number of Compressed Hydrogen Gas Tanks Possible to Discharge	Proceed To
2 Tanks (Both No. 1 and No. 2 hydrogen tank assembly tank shut valves can be opened)	DRAIN COMPRESSED HYDROGEN GAS (2 Tanks Being Discharged)
1 Tank (Either No. 1 or No. 2 hydrogen tank assembly tank shut valve cannot be opened)	DRAIN COMPRESSED HYDROGEN GAS (1 Tank Being Discharged)

5. DRAIN COMPRESSED HYDROGEN GAS (2 Tanks Being Discharged)

Caution:



- **While discharging pressurized hydrogen gas, the temperature inside the tank decreases and frost may form on the outside. Do not touch tanks, piping, or SST (hydrogen venting tool) when frost has formed on them.**
- **Touching tanks, piping, or SST (hydrogen venting tool) on which frost has formed could result in burn-like injuries due to frostbite.**

Notice:

- Starting the discharging of compressed hydrogen gas will cause the temperature inside the hydrogen gas lines to decrease.
- To protect the hydrogen tank and related components, when the hydrogen gas temperature becomes -30 °C (-86 °F) or less, the discharging of compressed hydrogen gas must be stopped temporarily.
- Monitor the Data List items "Smoothed Value of Hydrogen Tank 1 Temperature" and "Smoothed Value of Hydrogen Tank 2 Temperature" while performing compressed hydrogen gas discharging.
- While performing compressed hydrogen gas discharging, periodically conduct leak checks of each connecting part of the SST (hydrogen venting tool).
- If a leak is found, stop the discharging procedure.

Hint:

<Approximate Discharging Times for Compressed Hydrogen Gas>

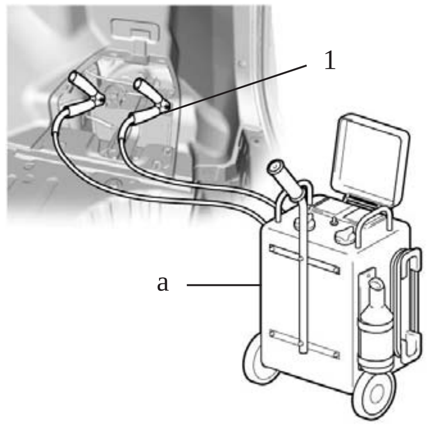
Hydrogen Gas Pressure	Discharging Time (approximate)
70 MPa	180 minutes
55 MPa	150 minutes
35 MPa	110 minutes

- The times listed above are only approximations, and times will vary depending on the actual work environment (ambient temperature, hydrogen tank gas temperature, etc,)
- The (approximate) times listed above do not include time spent while the procedure is halted due to hydrogen gas temperature becoming too low.

(1) Lower the vehicle on the lift.

(2) Connect a charger to the auxiliary battery and put the auxiliary battery into a charging state.

(3) Using the Tech stream, enter the following menus: Body Electrical / Power Source Control / Utility / Auto Power OFF Cancel



1	Auxiliary Battery
a	Battery Charger

Body Electrical > Power Source Control >Utility

Tester Display
Auto Power OFF Cancel

Execute

(4) Using the Tech stream, enter the following menus: Powertrain / FC / Data List / Medium-range Hydrogen Pressure, High-range Hydrogen Pressure, Smoothed Value of Hydrogen Tank 1 Temperature, Smoothed Value of Hydrogen Tank 2 Temperature, Tank Side Hydrogen Detector Density

Powertrain > FC > Data List

Tester Display
Medium-range Hydrogen Pressure
High-range Hydrogen Pressure
Smoothed Value of Hydrogen Tank 1 Temperature
Smoothed Value of Hydrogen Tank 2 Temperature
Tank Side Hydrogen Detector Density

Execute

Hint:

If the Tech stream unit setting is absolute pressure (abs), change it to gauge pressure (gauge).

(5) Open the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies.

(6) Open the open/close valve of the SST (venting stand), and discharge compressed hydrogen gas.

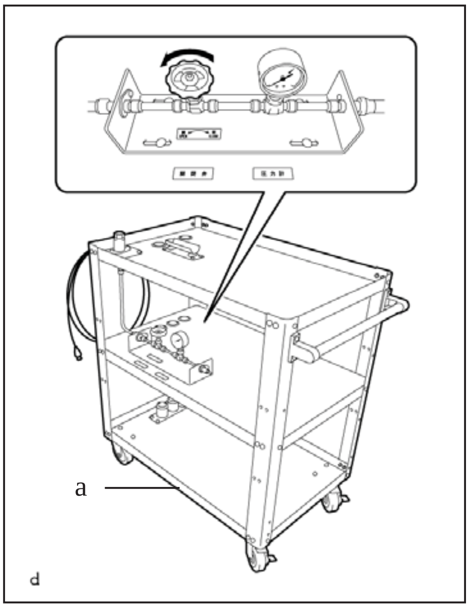
SST

09404-62010 (09404-06010)

(7) Read the Data List and check that "Smoothed Value of Hydrogen Tank 1 Temperature" and "Smoothed Value of Hydrogen Tank 2Temperature" begin to decrease together.

Hint:

- By checking that the hydrogen tank temperatures are decreasing, it can be determined that the compressed hydrogen gas is discharging.
- If either one of "Smoothed Value of Hydrogen Tank 1 Temperature" or "Smoothed Value of Hydrogen Tank 2Temperature" does not decrease, perform the following procedure.



a	SST (Venting Stand)

(a) Close the open/close valve of the SST (venting stand).

Notice:

To protect the tank shut valve, make sure to first close the open/close valve of the SST (venting stand).

(b) Close the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies.

(c) For the side where the hydrogen gas temperature does not decrease, check that the manual valve is open, and if it is closed, open the manual valve.

(d) Open the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies.

(e) Open the open/close valve of the SST (venting stand) again, and discharge the compressed hydrogen gas.

(8) Read the Data List, and if either of the items "Smoothed Value of Hydrogen Tank 1 Temperature" or "Smoothed Value of Hydrogen Tank 2 Temperature" have become -30°C or less:

i. Close the open/close valve of the hydrogen discharging device. [*1]

Notice:

To protect the tank shut valve, make sure to first close the open/close valve of the SST (venting stand).

ii. Close the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies. [*2]

Wait until both values "Smoothed Value of Hydrogen Tank 1 Temperature" and "Smoothed Value of Hydrogen Tank 2 Temperature" have increased to -20 °C (-68 °F) or more. [*3]

iii. Open the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies. [*4]

iv. Open the open/close valve of the SST (venting stand) and discharge compressed hydrogen gas again. [*5]

Notice:

During the compressed hydrogen gas discharging procedure, if it appears that either "Smoothed Value of Hydrogen Tank 1 Temperature" or "Smoothed Value of Hydrogen Tank 2 Temperature" are about to decrease to -30 °C (-86 °F) or less, repeat steps [*1] through [*5].

(9) Continue to monitor the Data List, and when the value of "Medium-range Hydrogen Pressure (gauge)" becomes 0.8 MPa, close the open/close valve of the SST (venting stand).

Notice:

To protect the tank shut valve, make sure to first close the open/close valve of the SST (venting stand).

(10) Check that the Data List item "Medium-range Hydrogen Pressure (gauge)" and the pressure on the pressure indicator of the SST (venting stand) are less than 0.8 MPa.

Notice:

- The pressure immediately after closing the open/close valve of the SST (venting stand) should be less than 0.8 MPa for both the Data List item "Medium-range Hydrogen Pressure (gauge)" and on the pressure indicator of the SST (venting stand).
- If either the Data List item "Medium-range Hydrogen Pressure (gauge)" or the pressure on the pressure indicator of the SST (venting stand) are 0.8 MPa or greater, open the open/close valve of the SST (venting stand) and adjust the pressure.
- After the pressure discharging, when the gas temperature inside the hydrogen tank increases, the pressure will also increase, so make sure to continue discharging until the pressure is less than 0.8 MPa.

Hint:

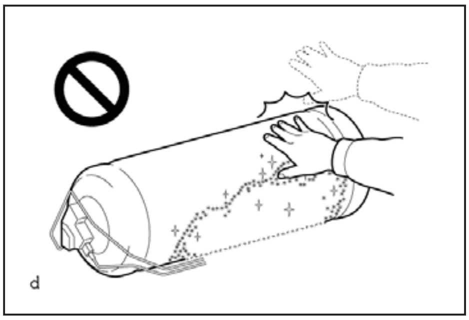
If the pressure immediately after closing the open/close valve of the SST (venting stand) is less than 0.8 MPa for both the Data List item "Medium-range Hydrogen Pressure (gauge)" and on the pressure indicator of the SST (venting stand), then the pressurized hydrogen gas discharging procedure is complete.

(11) Close the tank shut valves of both the No. 1 and No. 2 hydrogen tank assemblies.

(12) Disconnect the hydrogen discharging device (medium pressure).

6. DRAIN COMPRESSED HYDROGEN GAS (1 Tank Being Discharged)

Caution:



- **While discharging pressurized hydrogen gas, the temperature inside the tank decreases and frost may form on the outside. Do not touch tanks, piping, or SST (hydrogen venting tool) when frost has formed on them.**
- **Touching tanks, piping, or SST (hydrogen venting tool) on which frost has formed could result in burn-like injuries due to frostbite.**

Notice:

- Starting the discharging of compressed hydrogen gas will cause the temperature inside the hydrogen gas lines to decrease.
- To protect the hydrogen tank and related components, when the hydrogen gas temperature becomes -30 °C (-86 °F) or less, the discharging of compressed hydrogen gas must be stopped temporarily.
- When discharging compressed hydrogen gas from only a single hydrogen tank, the decrease of hydrogen gas temperature is more rapid than when discharging only one tank, so the discharging procedure will need to be stopped a greater number of times.
- Because the temperature decrease in the hydrogen gas lines is more rapid, the following steps [*1] through [*5] must be repeated more often.
- Monitor the Data List items "Smoothed Value of Hydrogen Tank 1 Temperature" and "Smoothed Value of Hydrogen Tank 2 Temperature" while performing compressed hydrogen gas discharging.
- While performing compressed hydrogen gas discharging, periodically conduct leak checks of each connecting part of the SST (hydrogen venting tool).
- If a leak is found, stop the discharging procedure.

Hint:

<Approximate Discharging Times for Compressed Hydrogen Gas>

Hydrogen Gas Pressure	Discharging Time (approximate)
70 MPa	90 minutes
55 MPa	75 minutes
35 MPa	55 minutes

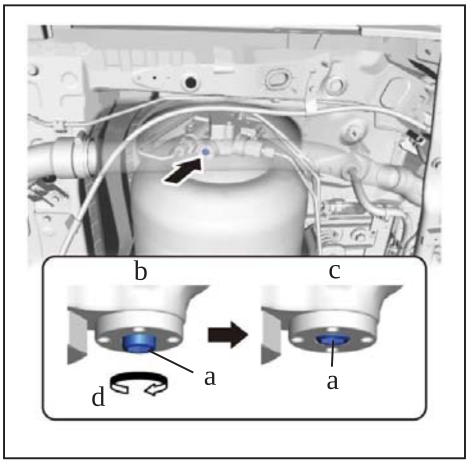
- The times listed above are only approximations, and times will vary depending on the actual work environment (ambient temperature, hydrogen tank gas temperature, etc,)
- The (approximate) times listed above do not include time spent while the procedure is halted due to hydrogen gas temperature becoming too low.

(1) If the tank shut valve of the No. 1 hydrogen tank assembly can not be opened:

i. Using an 8 mm socket hexagon wrench, rotate the adjustment bolt in the clockwise direction to close the manual valve of the No. 1 hydrogen tank assembly.

Torque:

20 N*m (204 kgf*cm, 15 ft.*lbf)



a	Adjustment Bolt
b	Manual Valve Closed
c	Manual Valve Open
d	Counterclockwise

Notice:

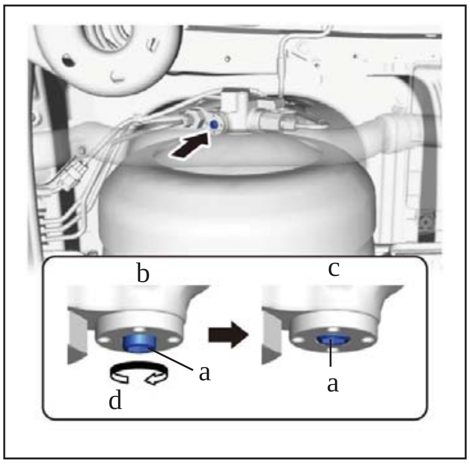
The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

(2) If the tank shut valve of the No. 2 hydrogen tank assembly can not be opened:

i. Using an 8 mm socket hexagon wrench, rotate the adjustment bolt in the clockwise direction to close the manual valve of the No. 2 hydrogen tank assembly.

Torque:

20 N*m (204 kgf*cm, 15 ft.*lbf)



a	Adjustment Bolt
b	Manual Valve Closed
c	Manual Valve Open
d	Counterclockwise

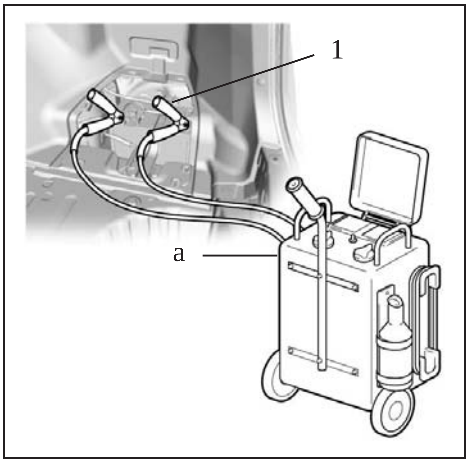
Notice:

The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

(3) Lower the vehicle on the lift.

(4) Connect a charger to the auxiliary battery and put the auxiliary battery into a charging state.

(5) Using the Techstream, enter the following menus: Body Electrical / Power Source Control / Utility / Auto Power OFF Cancel



1	Auxiliary Battery
a	Battery Charger

Body Electrical > Power Source Control >Utility

Tester Display
Auto Power OFF Cancel

Execute

(6) Using the Techstream, enter the following menus: Powertrain / FC / Data List / Medium-range Hydrogen Pressure, High-range Hydrogen Pressure, Smoothed Value of Hydrogen Tank 1 Temperature, Smoothed Value of Hydrogen Tank 2 Temperature, Tank Side Hydrogen Detector Density

Powertrain > FC > Data List

Tester Display
Medium-range Hydrogen Pressure
High-range Hydrogen Pressure
Smoothed Value of Hydrogen Tank 1 Temperature
Smoothed Value of Hydrogen Tank 2 Temperature
Tank Side Hydrogen Detector Density

Execute

Hint:

If the Tech stream unit setting is absolute pressure (abs), change it to gauge pressure (gauge).

(7) Open the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies.

(8) Open the open/close valve of the SST (venting stand), and discharge compressed hydrogen gas.

SST

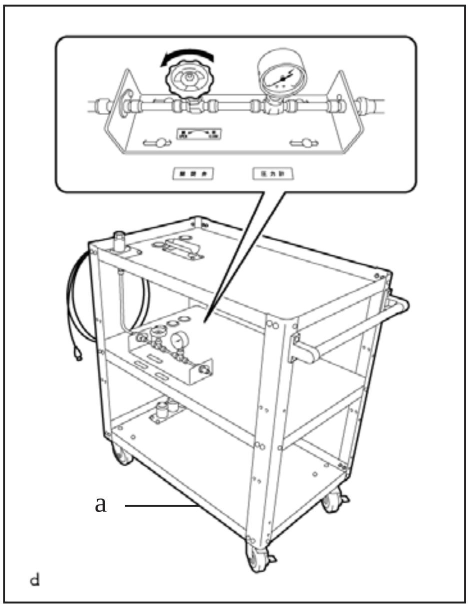
09404-62010 (09404-06010)

(9) Read the Data List, and if either of the items "Smoothed Value of Hydrogen Tank 1Temperature" or "Smoothed Value of Hydrogen Tank 2 Temperature" have become -30 °C (-86 °F)or less:

i. Close the open/close valve of the SST (venting stand) [*1]

Notice:

To protect the tank shut valve, make sure to first close the open/close valve of the SST (venting stand).



a	SST (Venting Stand)

ii. Close the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies. [*2]

iii. Wait until both values "Smoothed Value of Hydrogen Tank 1 Temperature" and "Smoothed Value of Hydrogen Tank 2 Temperature" have increased to -20 °C (-68°F) or more. [*3]

iv. Open the tank shut valves of the No. 1 and No. 2 hydrogen tank assemblies. [*4]

v. Open the open/close valve of the SST (venting stand) and discharge compressed hydrogen gas again. [*5]

Notice:

During the compressed hydrogen gas discharging procedure, if it appears that either "Smoothed Value of Hydrogen Tank 1 Temperature" or "Smoothed Value of Hydrogen Tank 2 Temperature" are about to decrease to -30 °C (-86 °F) or less, repeat steps [*1] through [*5].

(10) Continue to monitor the Data List, and when the value of "Medium-range Hydrogen Pressure (gauge)" becomes 0.8 MPa, close the open/close valve of the SST (venting stand).

Notice:

To protect the tank shut valve, make sure to first close the open/close valve of the SST (venting stand).

(11) Check that the Data List item "Medium-range Hydrogen Pressure (gauge)" and the pressure on the pressure indicator of the SST (venting stand) are less than 0.8 MPa.

Notice:

- The pressure immediately after closing the open/close valve of the SST (venting stand) should be less than 0.8 MPa for both the Data List item "Medium-range Hydrogen Pressure (gauge)" and on the pressure indicator of the SST (venting stand).
- If either the Data List item "Medium-range Hydrogen Pressure (gauge)" or the pressure on the pressure indicator of the SST (venting stand) are 0.8 MPa or greater, open the open/close valve of the SST (venting stand) and adjust the pressure.

- After the pressure discharging, when the gas temperature inside the hydrogen tank increases, the pressure will also increase, so make sure to continue discharging until the pressure is less than 0.8 MPa.

Hint:

If the pressure immediately after closing the open/close valve of the SST (venting stand) is less than 0.8 MPa for both the Data List item "Medium-range Hydrogen Pressure (gauge)" and on the pressure indicator of the SST (venting stand), then the pressurized hydrogen gas discharging procedure is complete.

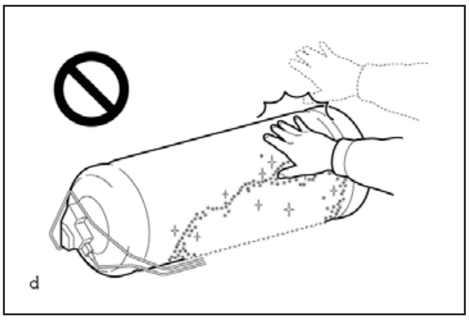
(12) Close the tank shut valves of both the No. 1 and No. 2 hydrogen tank assemblies.

(13) Disconnect the hydrogen discharging device (medium pressure).

7. DISCONNECT SST (HYDROGEN VENTING TOOL)

Caution:

- **While discharging pressurized hydrogen gas, the temperature inside the tank decreases and frost may form on the outside. Do not touch tanks, piping, or SST (hydrogen venting tool) when frost has formed on them.**
- **Touching tanks, piping, or SST (hydrogen venting tool) on which frost has formed could result in burn-like injuries due to frostbite.**



(1) Using an 8 mm socket hexagon wrench, rotate the adjustment bolt in the clockwise direction to closethe manual valve of the No. 1 hydrogen tank assembly.

Torque:

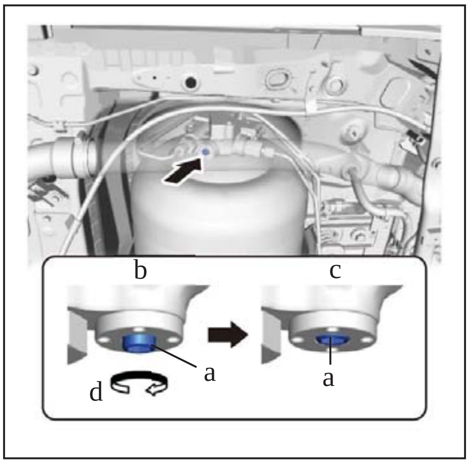
20 N*m (204 kgf*cm, 15 ft.*lbf)

Notice:

The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

Hint:

If the manual valve is closed at the time of discharging compressed hydrogen gas, this procedure is unnecessary.



a	Adjustment Bolt
b	Manual Valve Open
c	Manual Valve Closed
d	Clockwise

(2) Using an 8 mm socket hexagon wrench, rotate the adjustment bolt in the clockwise direction to close the manual valve of the No. 2 hydrogen tank assembly.

Torque:

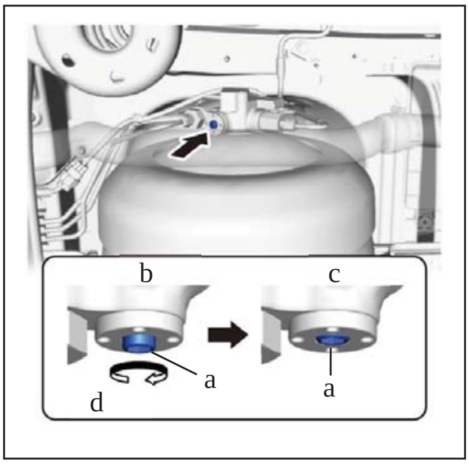
20 N*m (204 kgf*cm, 15 ft.*lbf)

NOTICE:

The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

Hint:

If the manual valve is closed at the time of discharging compressed hydrogen gas, this procedure is unnecessary.



a	Adjustment Bolt
b	Manual Valve Open
c	Manual Valve Closed
d	Clockwise

(3) Open the open/close valve of the SST (venting stand) and discharge the compressed hydrogen gas remaining inside the SST (flexible hose).

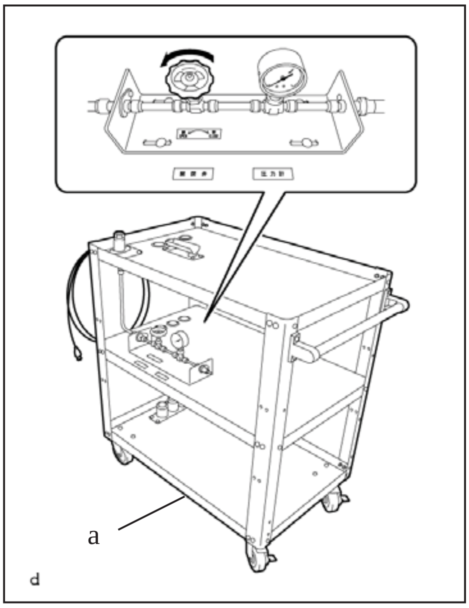
Notice:

- Do not disconnect the SST (flexible hose) while there is still pressure remaining inside it.
- Continue discharging until the pressure gauge of the SST (Venting Stand) becomes "0".

SST

09404-62010 (09404-06010)

(4) Before performing the disconnection procedure, if there are any contaminants such as water droplets adhering near the medium pressure leak check port of the hydrogen supply regulator assembly, wipe them away before performing the procedure.

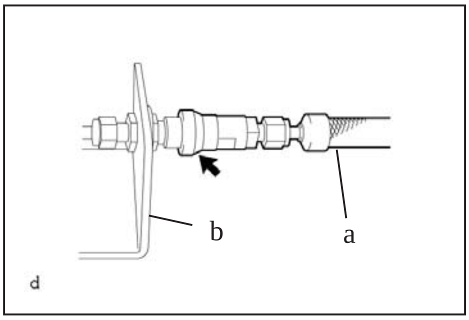


a	SST (Venting Stand)

(5) Disconnect the SST (flexible hose) from the SST (Venting Stand).

SST

09404-62010 (09404-06010, 09404-06020)



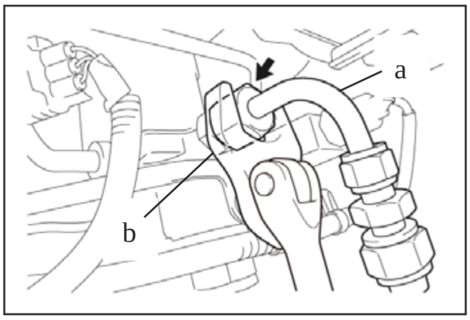
a	SST (Flexible Hose)
b	SST (Venting Stand)

(6) Using SST (open end wrench), remove the SST (flexible hose) from the medium pressure leak check port of the hydrogen supply regulator assembly.

SST

09922-10240

09404-62010 (09404-06020)



a	SST (Flexible Hose)
b	SST (Open End Wrench)

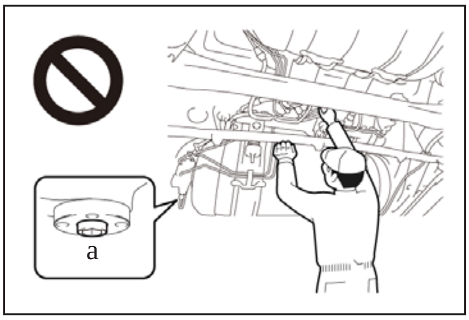
Dismantling the vehicle (Continued)

Removal of Hydrogen Tank

The following 2 pages contain general instructions for use when working on an MIRAI. Read these instructions before proceeding to the hydrogen tank removal instructions on page 54.

Caution:

- **Do not perform depressurization procedures when the manual valve of the hydrogen tank assembly is open.**
- **The highly pressurized hydrogen gas inside the hydrogen tank assembly could blow out, resulting in a serious accident.**

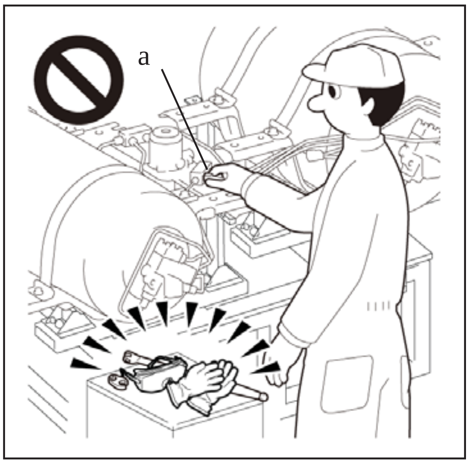


a	Manual Valve Open

- **When performing depressurization, do not perform procedures by hand without wearing protective glasses and gloves.**
- **High pressure nitrogen gas could cause a serious accident.**

- **After performing depressurization procedures, when first loosening the union nut of the high pressure hydrogen piping, do not loosen the union nut by hand without wearing protective glasses and gloves.**

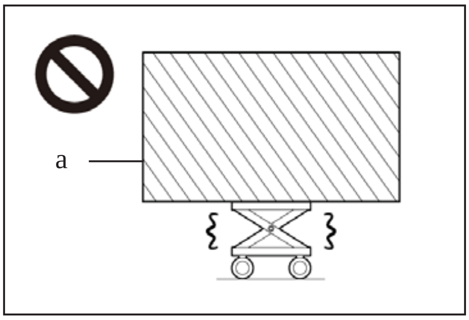
- **Even when depressurization procedures are performed, the pressurized hydrogen gas inside the high pressure hydrogen piping cannot be completely depressurized, so the highly pressurized hydrogen gas remaining in the high pressure hydrogen piping could blow out, resulting in a serious accident.**



a	After depressurization procedures, the high pressure piping union nut that is loosened first

- **Because the hydrogen tank unit is extremely heavy, make sure to follow the work procedures described in the repair manual.**

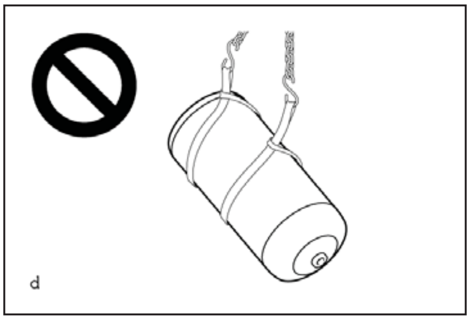
- **If work is not performed according to the procedures described in the repair manual, there is a danger that the engine lifter could drop and components could fall down.**



a	Heavy load exceeding the weight limits or size limits of the engine lifter

- **When hoisting up the hydrogen tank assembly, do not hoist it when not properly balanced.**

- **The hydrogen tank assembly could fall, resulting in a serious accident.**

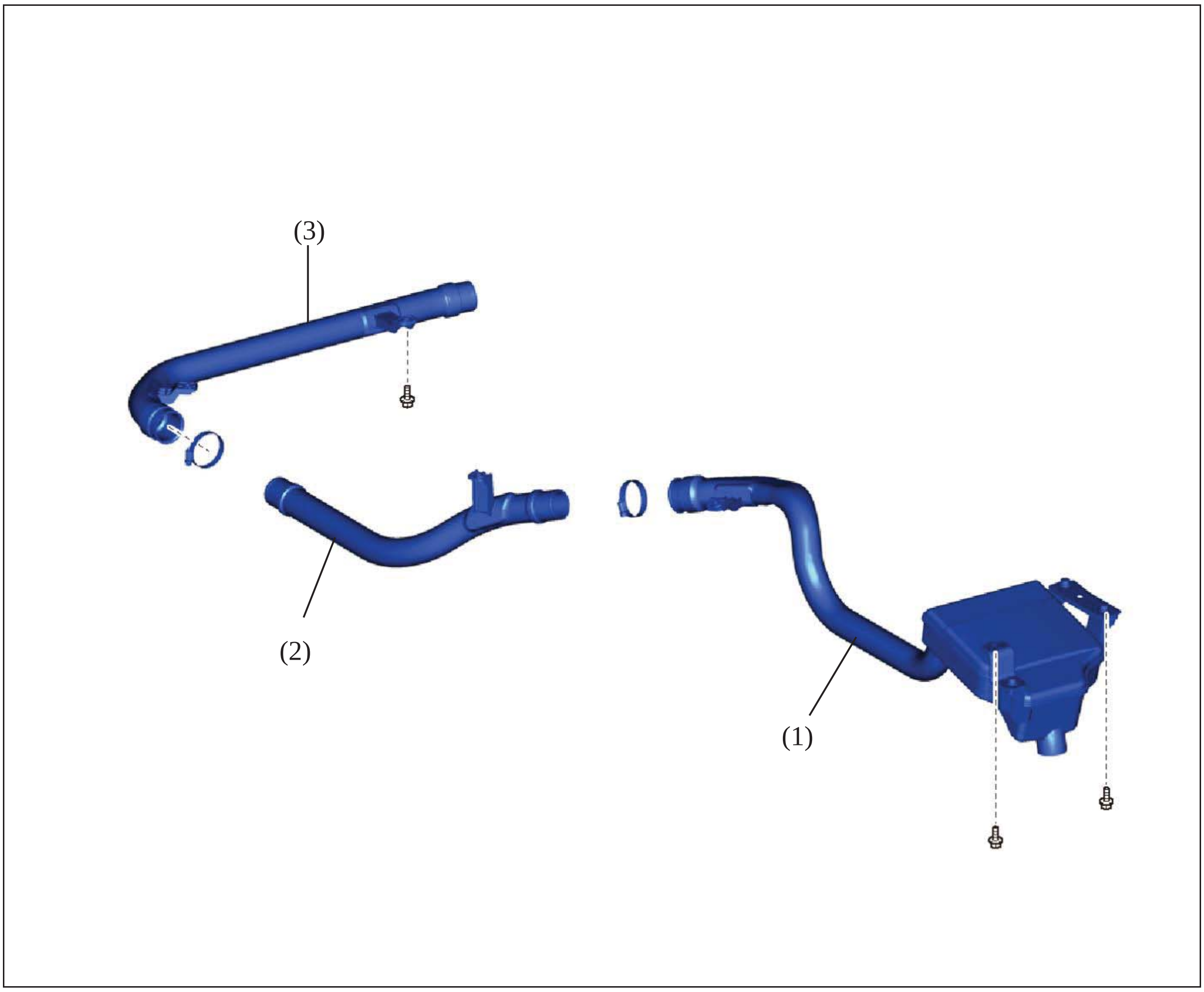


1. Remove No. 2 FC exhaust pipe.

(1) Remove the FC exhaust tail pipe assembly.

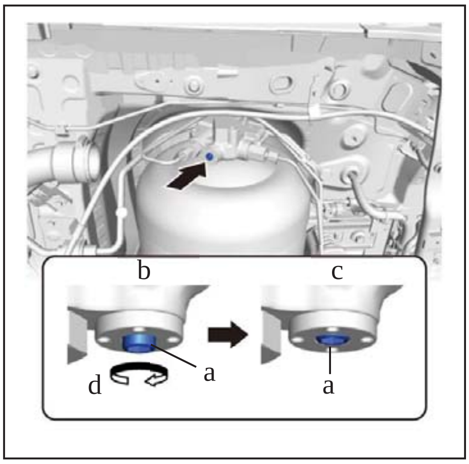
(2) Remove the No. 3 FC exhaust pipe.

(3) Remove the No. 2 FC exhaust pipe.



2. PRESSURE RELEASE OPERATION

(1) Using an 8 mm hexagon socket wrench, rotate the adjustment bolt clockwise to close the manual valve of the No. 1 hydrogen tank assembly.



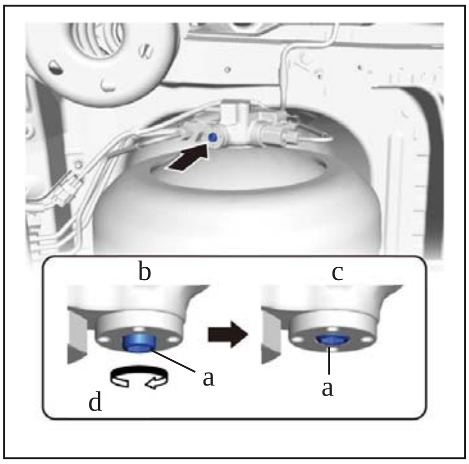
Torque: 20 N*m (204 kgf*cm, 15 ft.*lbf)

a	Adjustment Bolt
b	Manual Valve Open
c	Manual Valve Closed
d	Clockwise

Notice:

The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

(2) Using an 8 mm hexagon socket wrench, rotate the adjustment bolt clockwise to close the manual valve of the No. 2 hydrogen tank assembly.



Torque: 20 N*m (204 kgf*cm, 15 ft.*lbf)

a	Adjustment Bolt
b	Manual Valve Open
c	Manual Valve Closed
d	Clockwise

Notice:

The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.

(3) Open the tank shut valve of the No. 1 hydrogen tank assembly and No. 2 hydrogen tank assembly.

(4) Before starting the depressurization procedure, first check that there is no mud or other contaminant around the medium pressure leak check port of the hydrogen supply regulator assembly, and clean it as necessary.

Hint:

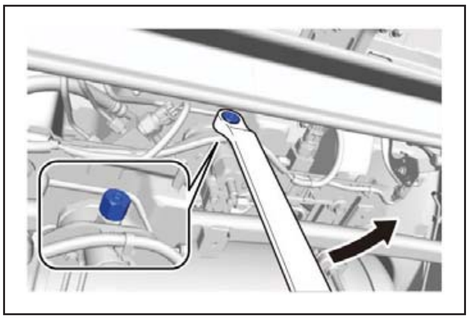
Installing the nut of the medium pressure leak check port while any foreign matter adheres to it can cause a hydrogen gas leak.

(5) Perform the depressurization procedure.

Notice:

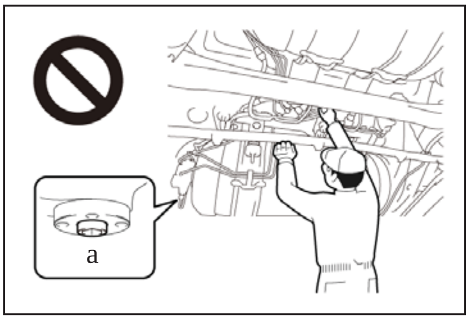
When performing depressurization, only loosen the nut. Do not remove it.

i. Slowly loosen the nut until the hissing sound of gas escaping can be heard, then stop loosening the nut and wait for the sound to stop. Repeat this procedure multiple times until the sound stops occurring, in order to depressurize the compressed hydrogen gas from the medium pressure leak check port of the hydrogen supply regulator assembly.



Caution:

- **Do not perform depressurization procedures when the manual valve of the hydrogen tank assembly is open.**
- **The highly pressurized hydrogen gas inside the hydrogen tank assembly could blow out, resulting in a serious accident.**

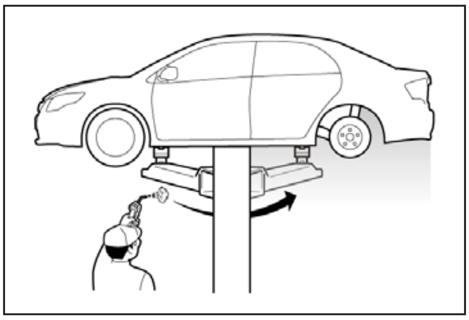


a	Manual Valve Open

- **When performing depressurization, do not perform procedures by hand without wearing protective glasses and gloves.**
- **High pressure nitrogen gas could cause a serious accident.**

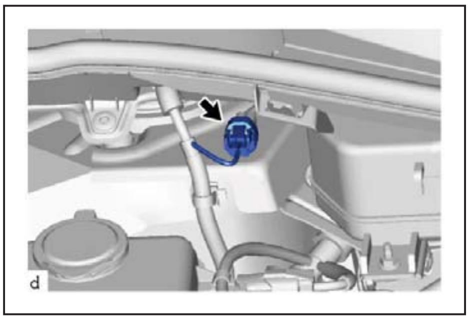
(6) Blow compressed air around the underside of the vehicle.

(7) Remove the nut from the medium-pressure leak check port of the hydrogen supply regulator assembly.



3. DISABLE BRAKE CONTROL

(1) Wait for at least 2 minutes after turning the power switch off.



Notice:

When the brake pedal is depressed or the door courtesy switch is turned on even if the power switch is off, the brake control system activates. Therefore, do not depress the brake pedal or open/close the doors until the reservoir level switch connector is disconnected.

(2) Disconnect the reservoir level switch connector with the parking brake applied.

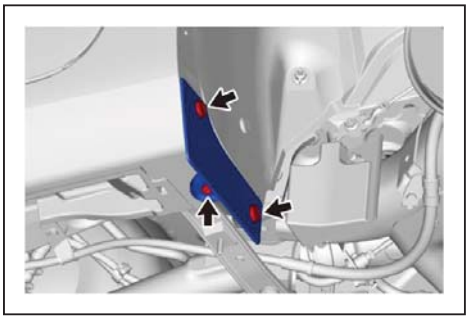
(3) Depress the brake pedal 40 times or more to return all the fluid in the accumulator back to the reservoir.

(4) Check that the brake pedal cannot be further depressed.

(5) Release the parking brake.

4. REMOVE REAR WHEEL HOUSE FRONT PLATE LH

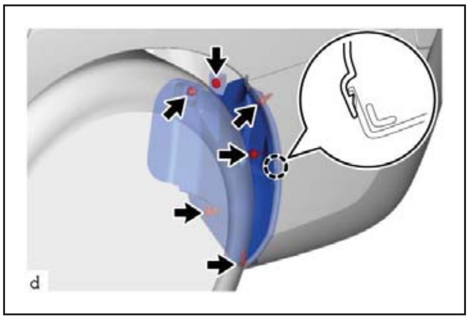
Remove the screw and 2 clips and the rear wheel house front plate LH from the vehicle.



5. REMOVE REAR BUMPER SIDE SEAL LH

(1) Remove the 6 clips.

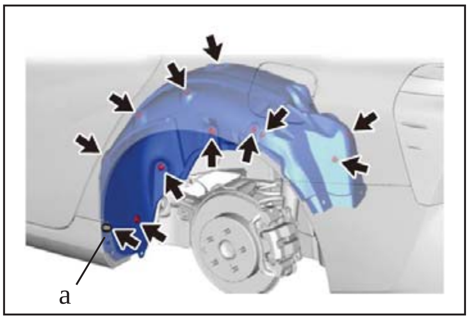
(2) Disengage the claw to remove the rear bumper side seal LH.



6. REMOVE REAR WHEEL HOUSE LINER LH

(1) Using a 4 mm socket hexagon wrench, remove the hexagon screw.

(2) Remove the 12 clips and rear wheel house liner LH from the vehicle.



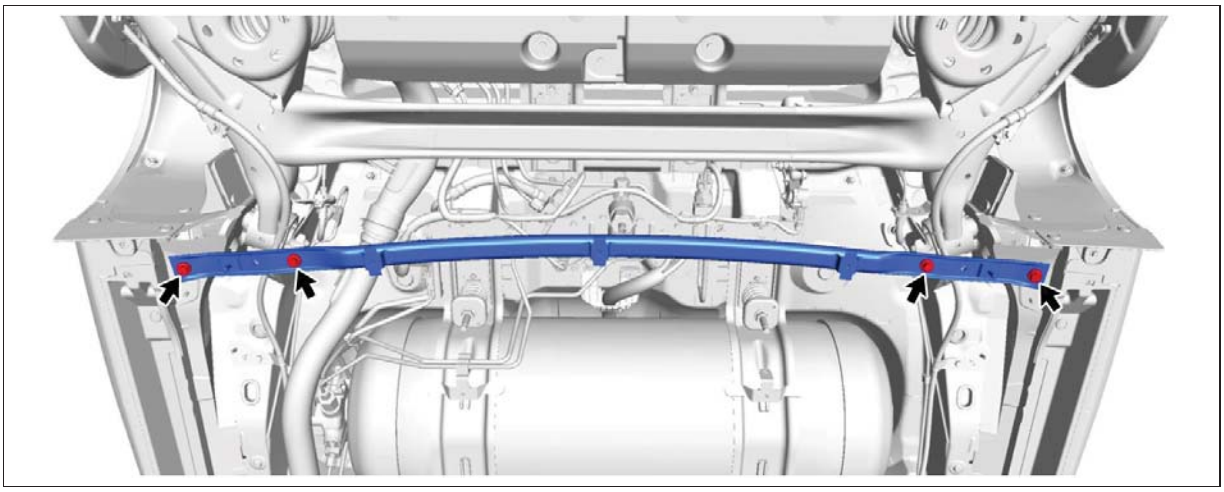
a	Hexagon Screw

7. REMOVE REAR WHEEL

8. DRAIN BRAKE FLUID

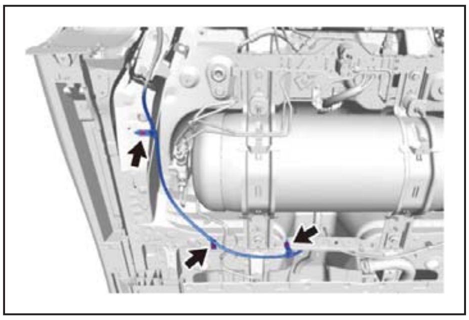
9. REMOVE REAR SUSPENSION BRACE SUB-ASSEMBLY

Remove the 4 bolts and rear suspension brace sub-assembly from the vehicle.



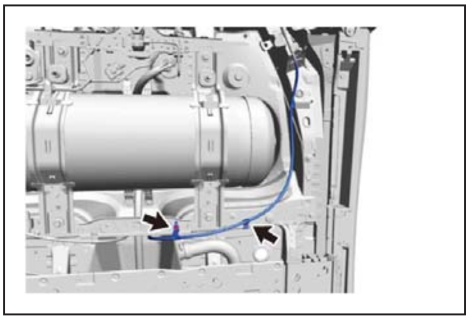
10. SEPARATE NO. 2 PARKING BRAKE CABLE ASSEMBLY

Remove the 3 bolts and separate the No. 2 parking brake cable assembly from the vehicle.



11. SEPARATE NO. 3 PARKING BRAKE CABLE ASSEMBLY

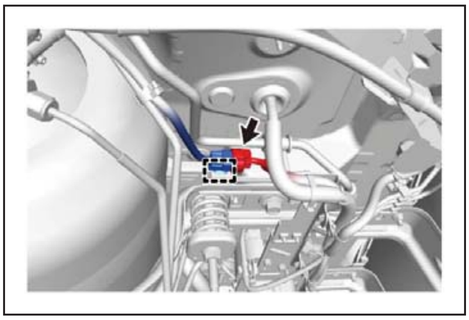
Remove the 2 bolts and separate the No. 3 parking brake cable assembly from the vehicle.



12. SEPARATE NO. 3 FLOOR WIRE

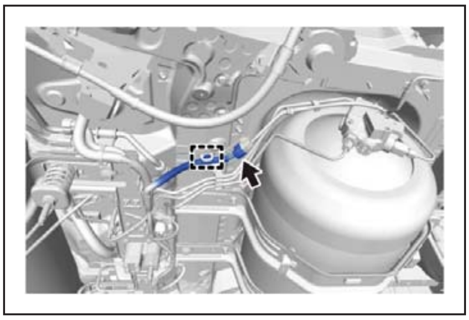
(1) Disconnect the No. 1 hydrogen tank assembly connector.

(2) Disengage the clamp and separate the No. 1 hydrogen tank assembly connector from the wire harness clamp bracket.

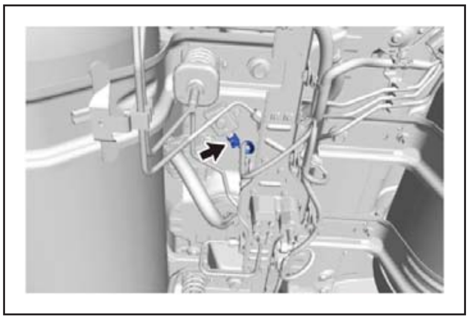


(3) Disconnect the No. 2 hydrogen tank assembly connector.

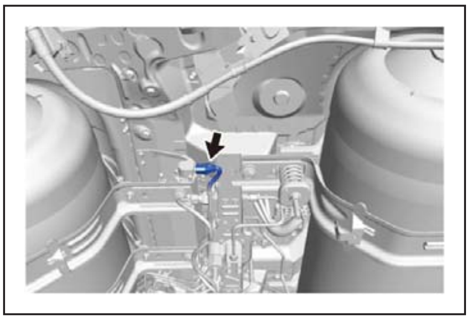
(4) Disengage the clamp and separate the No. 3 floor wire from the hydrogen tank tube clamp bracket.



(5) Disconnect the hydrogen detector connector.

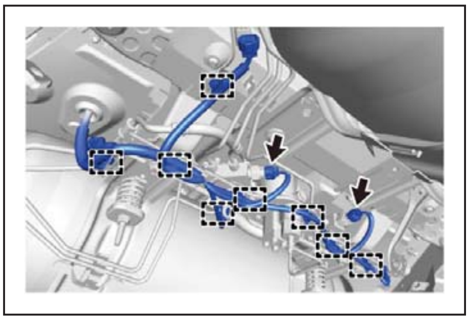


(6) Disconnect the rear height control sensor sub-assembly connector.



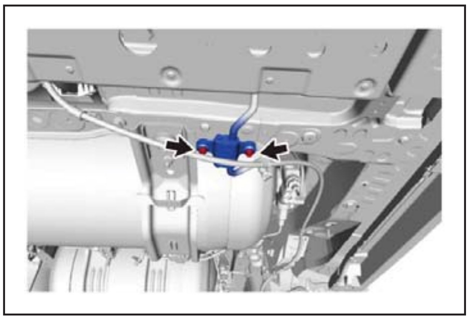
(7) Disconnect the 2 hydrogen tank pressure sensor connectors.

(8) Disengage the 8 clamps and separate the No. 3 floor wire from the front center hydrogen tank frame and wire harness clamp bracket.



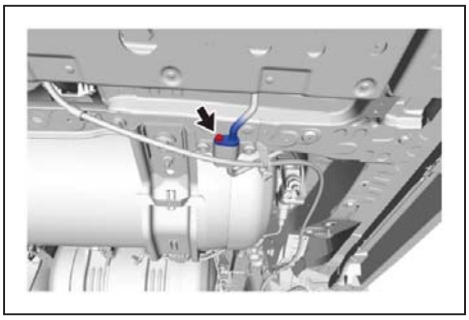
13. SEPARATE NO. 2 HYDROGEN SUPPLY TUBE SUB-ASSEMBLY

Remove the 2 bolts and separate the No. 2 hydrogen supply tube sub-assembly from the vehicle.

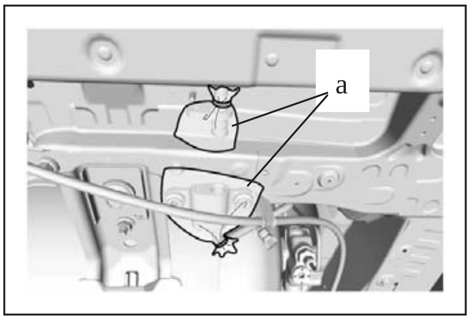


14. DISCONNECT NO. 1 HYDROGEN SUPPLY TUBE SUB-ASSEMBLY

(1) Remove the bolt and disconnect the No. 1 hydrogen supply tube sub-assembly from the No. 2 hydrogen supply tube sub-assembly.



(2) To prevent contamination by foreign matter, cover the openings of the No. 1 hydrogen supply tube sub-assembly and No. 2 hydrogen supply tube sub-assembly with plastic bags.

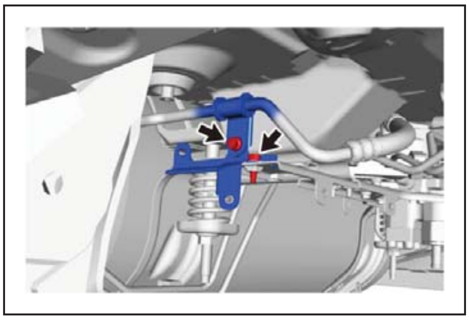


a	Plastic Bag

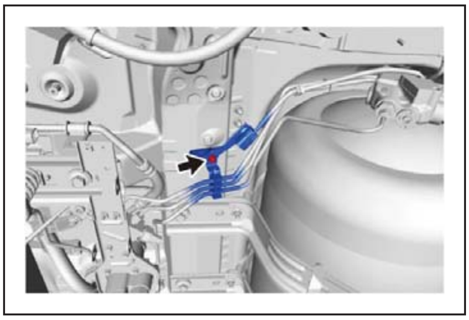
15. REMOVE WIRING HARNESS CLAMP BRACKET

(1) Remove the bolt and separate the No. 2 hydrogen supply tube sub-assembly from the wire harness clamp bracket.

(2) Remove the bolt and wire harness clamp bracket from the front hydrogen tank frame sub-assembly LH.



16. SEPARATE HYDROGEN TANK TUBE CLAMP BRACKET



Remove the bolt and separate the hydrogen tank tube clamp bracket from the vehicle.

Notice:

When loosening the bolt, to prevent the high pressure hydrogen piping from rotating together and being strained, hold the hydrogen tube clamp bracket in place by hand while performing the procedure.

17. DISCONNECT HYDROGEN TANK TUBE ASSEMBLY

Caution:

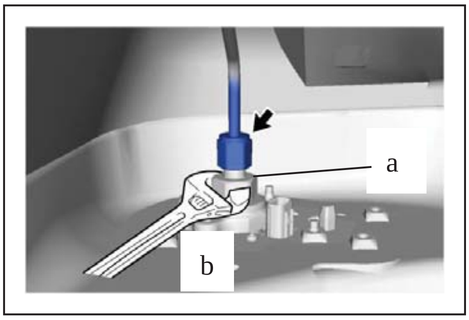
- **After performing depressurization procedures, when first loosening the union nut of the high pressure hydrogen piping, do not loosen the union nut by hand without wearing protective glasses and gloves.**
- **Even when depressurization procedures are performed, the pressurized hydrogen gas inside the high pressure hydrogen piping cannot be completely depressurized, so the highly pressurized hydrogen gas remaining in the high pressure hydrogen piping could blow out, resulting in a serious accident.**

a	After depressurization procedures, the high pressure piping union nut that is loosened first.

(1) Using a 17 mm union nut wrench, loosen the union nut and disconnect the hydrogen tank tube assembly from the hydrogen inlet receptacle assembly.

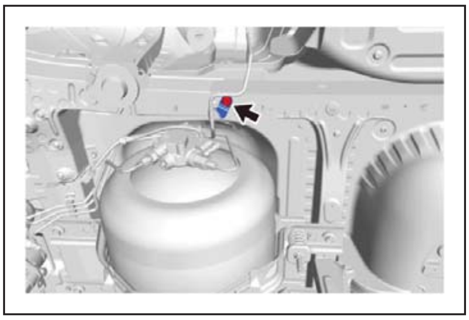
Notice:

While using an adjustable wrench to hold the adaptor portion of the hydrogen inlet receptacle assembly in place, loosen the union nut.



a	Adaptor Portion
b	Hold

(2) Remove the bolt and separate the bracket of the hydrogen tank tube assembly from the vehicle.



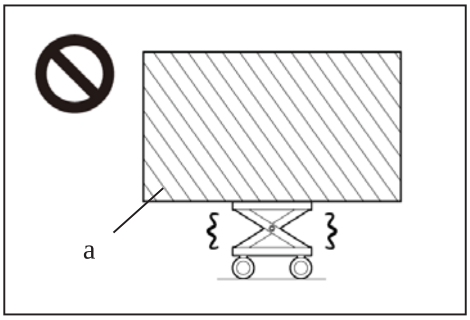
Notice:

When loosening the bolt, to prevent the high pressure hydrogen piping from rotating together and being strained, hold the bracket portion in place by hand while performing the procedure.

18. REMOVE HYDROGEN TANK UNIT

Caution:

- **Because the hydrogen tank unit is extremely heavy, make sure to follow the work procedures described in the repair manual.**
- **If work is not performed according to the procedures described in the repair manual, there is a danger that the engine lifter could drop and components could fall down.**



a	Heavy load exceeding the weight limits or size limits of the engine lifter

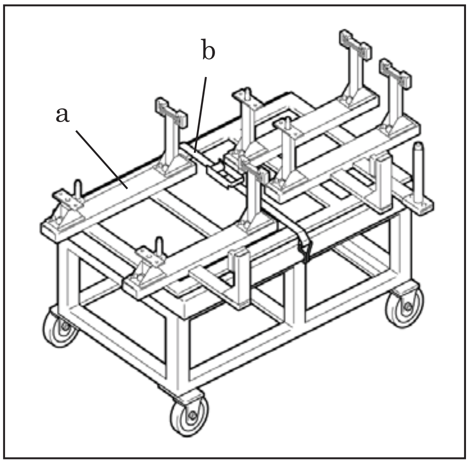
(1) Set the SST (hydrogen tank stand) on the engine lifter and secure it with the belt.

SST

09403-62010 (09403-06010, 09403-06020, 09403-06030, 09403-06040, 09403-06050, 09403-06060, 09403-06070, 09403-06080, 09403-06090, 09403-06100, 09403-06110)

Notice:

Set the SST (hydrogen tank stand) in the middle of the engine lifter and secure the center portion with the belt.

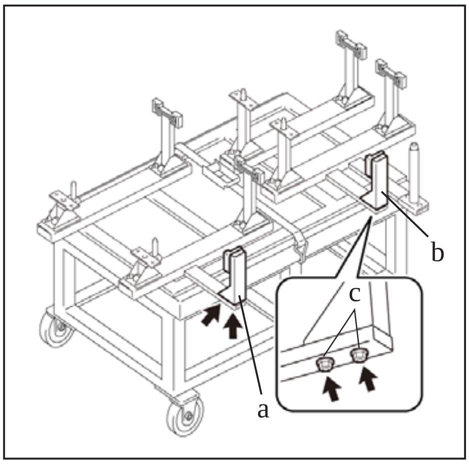


a	SST (Hydrogen Tank Stand)
b	Belt

(2) Remove the SST (nuts) and each tank support type SST.

SST

09403-62010 (09403-06050, 09403-06060, 09403-06090)

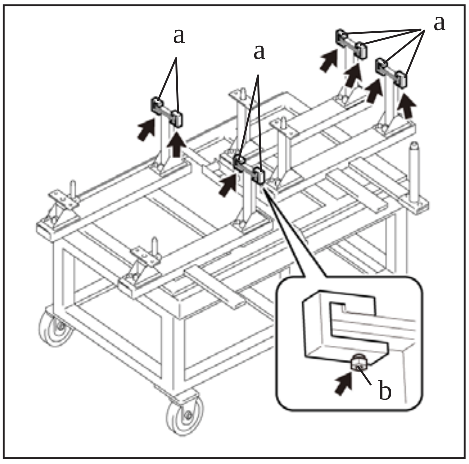


a	SST (Support No. 5)
b	SST (Support No. 6)
c	SST (Nut)

(3) Remove the SST (bolts) and each SST (tank belt fixture).

SST

09403-62010 (09403-06100, 09403-06110)



a	SST (Tank Belt Fixture)
b	SST (Bolt)

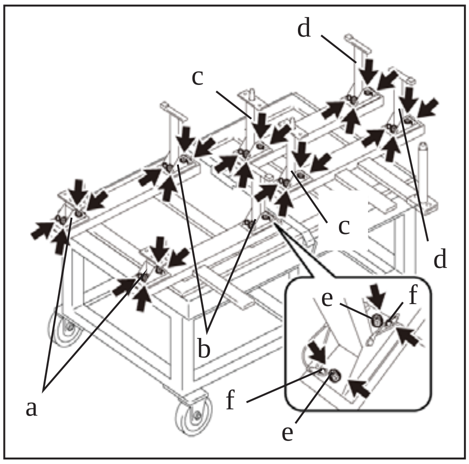
(4) For each tank support type SST, disengage the 2pins and loosen the 2 SST (bolts).

SST

09403-62010 (09403-06010, 09403-06020,09403-06030, 09403-06040, 09403-06080)

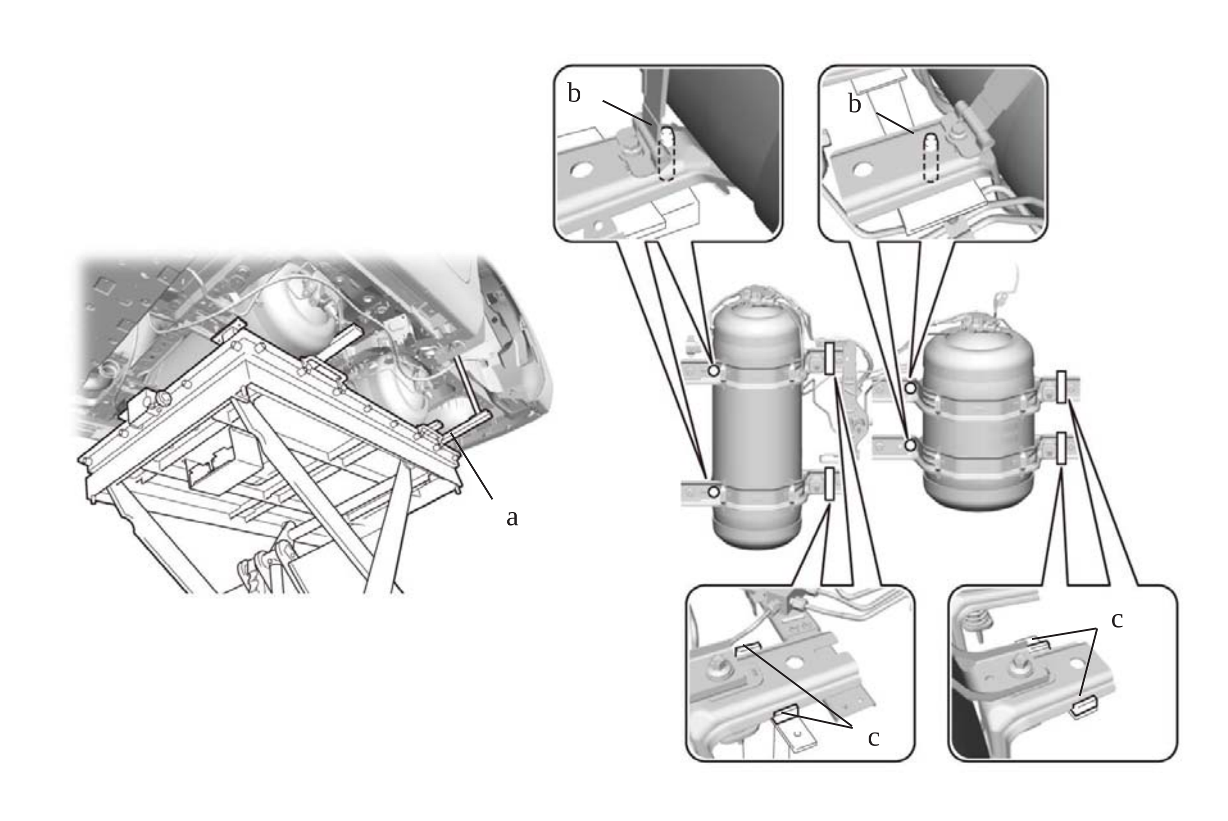
Hint:

This is done to align the SST (hydrogen tankstand) with the installation condition of the hydrogen tank unit on the vehicle.



a	SST (Support No. 1)
b	SST (Support No. 2)
c	SST (Support No. 3)
d	SST (Support No. 4)
e	SST (Bolt)
f	Pin

(5) Operate the engine lifter, and set the SST (hydrogen tank stand) against the hydrogen tank frame.

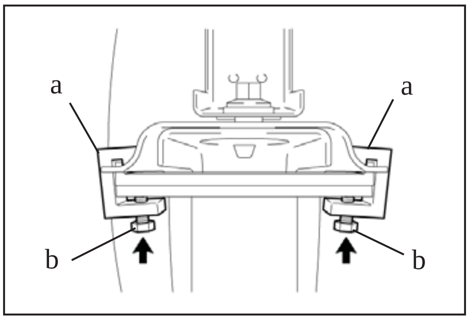


a	SST (Hydrogen Tank Stand)	b	Pin
c	Groove	-	-

Notice:

- Align the pins of the each tank support type SST with the pin holes of the hydrogen tank frame.
- Align the grooves of the each tank support type SST with the tank frame.

(6) Using the SST (bolts), install each SST (tank belt fixture), and support the hydrogen tank frame.



a	SST (Tank Belt Fixture)
b	SST (Bolt)

SST

09403-62010 (09403-06100, 09403-06110)

Notice:

- If the hydrogen tank unit is removed from the vehicle without attaching each SST (tank belt fixture), the hydrogen tank frame will spring back because of the spring force and the installation positions of parts will be misaligned.
- Do not remove any of the tank frame installation bolts until each SST (tank belt fixture) are installed.

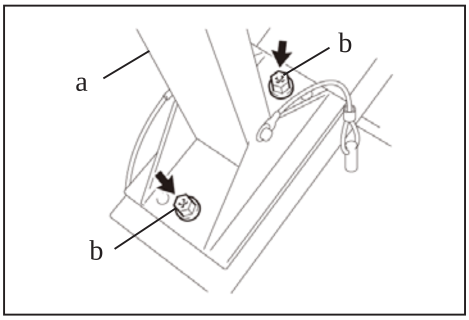
Hint:

If it is difficult to install each SST (tank belt fixture), loosen the tank frame installation bolts to a position where the tank frame support attachments can be installed.

(7) Tighten the SST (bolts) of each tank support type SST.

SST

09403-62010 (09403-06010, 09403-06020, 09403-06030, 09403-06040, 09403-06080)



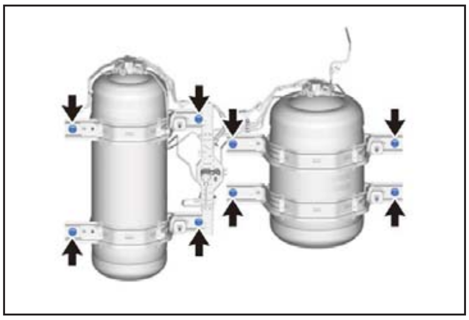
a	SST (Support No. 1, Support No. 2, Support No. 3 and Support No. 4)
b	SST (Bolt)

(8) Remove the 8 bolts.

(9) Operate the engine lifter and slowly remove the hydrogen tank unit from the vehicle.

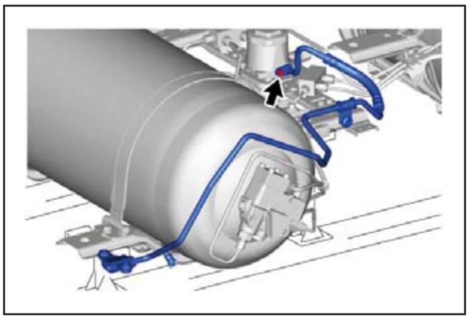
Notice:

Make sure the hydrogen tank assembly and high pressure hydrogen piping do not interfere with the vehicle body or surrounding components.



19. REMOVE NO. 2 HYDROGEN SUPPLY TUBE SUB-ASSEMBLY

(1) Remove the bolt and No. 2 hydrogen supply tube sub-assembly from the hydrogen supply regulator assembly.



20. REMOVE WIRE HARNESS CLAMP

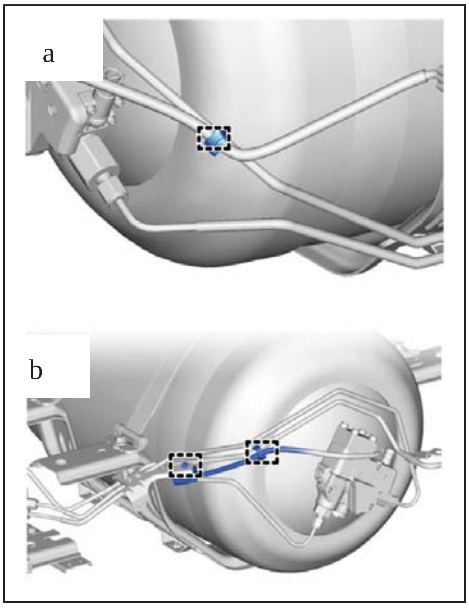
(1) No. 1 Hydrogen Tank Assembly Side:

i. Disengage the clamp and remove the wire harness clamp from the wire harness of the No. 1 hydrogen tank assembly and No. 4 hydrogen tube sub-assembly.

(2) No. 2 Hydrogen Tank Assembly Side:

i. Disengage the clamp and separate the No. 2 hydrogen tank assembly connector to the hydrogen tank tube clamp bracket.

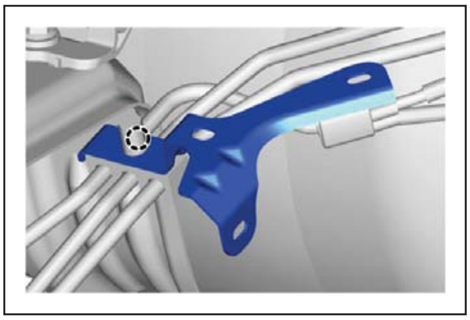
ii. Disengage the clamp and remove the wire harness clamp from the wire harness of the No. 2 hydrogen tank assembly and hydrogen tube sub-assembly.



a	No. 1 Hydrogen Tank Assembly Side
b	No. 2 Hydrogen Tank Assembly Side

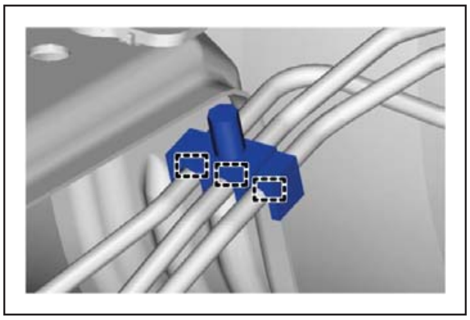
21. REMOVE HYDROGEN TANK TUBE CLAMP BRACKET

Disengage the claw and remove the hydrogen tank tube clamp bracket to the No. 1 fuel tube clamp.



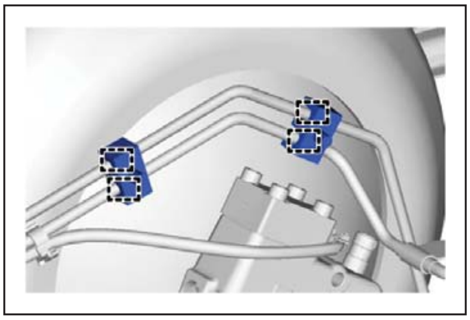
22. REMOVE NO. 1 FUEL TUBE CLAMP

Disengage the 3 clamps and remove the No. 1 fuel tube clamp from the hydrogen tank tube assembly, No. 3 hydrogen tank tube and No. 5 hydrogen tank tube.



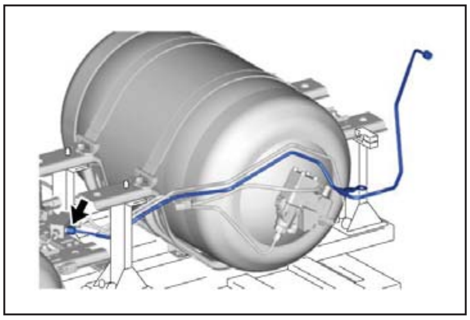
23. REMOVE FUEL TUBE GROMMET

Disengage the 2 clamps and remove the 2 fuel tube grommets from the hydrogen tank tube assembly and No. 3 hydrogen tank tube.



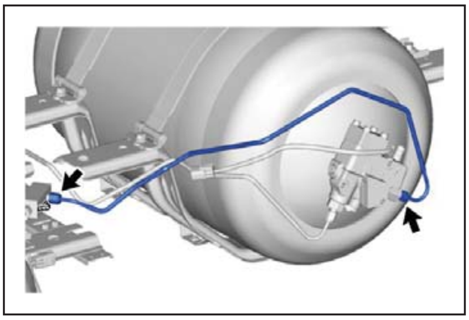
24. REMOVE HYDROGEN TANK TUBE ASSEMBLY

(1) Using a 17 mm union nut wrench, loosen the union nut and remove the hydrogen tank tube assembly from the hydrogen tank tube joint.



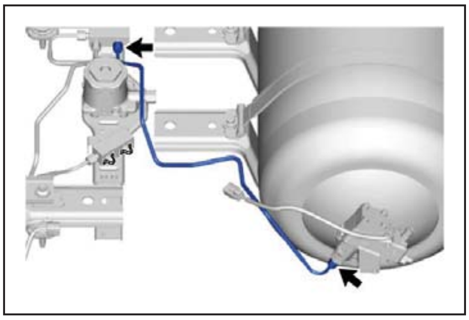
25. REMOVE NO. 3 HYDROGEN TANK TUBE

(1) Using a 17 mm union nut wrench, loosen the 2 union nuts and remove the No. 3 hydrogen tank tube from the No. 2 hydrogen tank assembly and hydrogen tank tube joint.



26. REMOVE NO. 5 HYDROGEN TANK TUBE

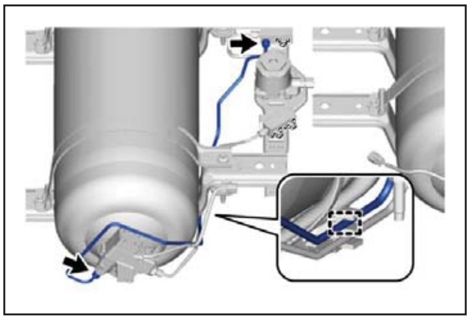
(1) Using a 17 mm union nut wrench, loosen the 2 union nuts and remove the No. 5 hydrogen tank tube from the No. 2 hydrogen tank assembly and hydrogen tank tube joint.



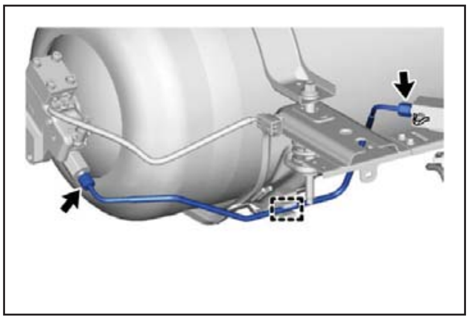
27. REMOVE NO. 4 HYDROGEN TANK TUBE

(1) Using a 17 mm union nut wrench, loosen the 2 union nuts and disconnect the No. 4 hydrogen tank tube from the No. 1 hydrogen tank assembly and hydrogen tank tube joint.

(2) Disengage the clamp and remove the No. 4 hydrogen tank tube from the fuel tube grommet.



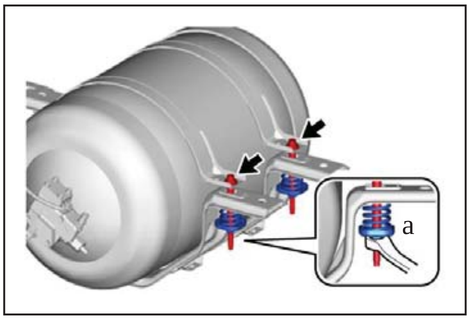
28. REMOVE NO. 2 HYDROGEN TANK TUBE



(1) Using a 17 mm union nut wrench, loosen the 2 union nuts and disconnect the No. 2 hydrogen tank tube from the No. 1 hydrogen tank assembly and hydrogen tank tube joint.

(2) Disengage the clamp and remove the No. 2 hydrogen tank tube from the fuel tube grommet.

29. REMOVE NO. 2 HYDROGEN TANK ASSEMBLY

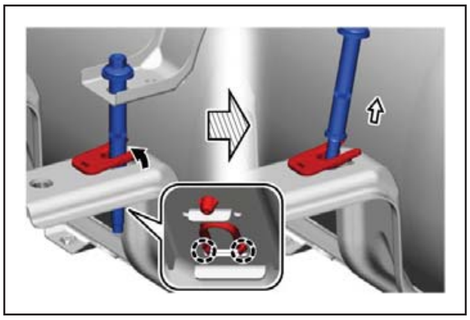


a	Hold

(1) Loosen the 2 bolts and remove the 2 rear hydrogen tank spring bolt cups and 2 compression springs.

Notice:

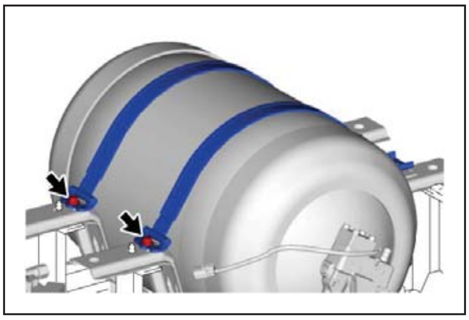
While holding the rear hydrogen tank spring bolt cup, loosen the bolt.



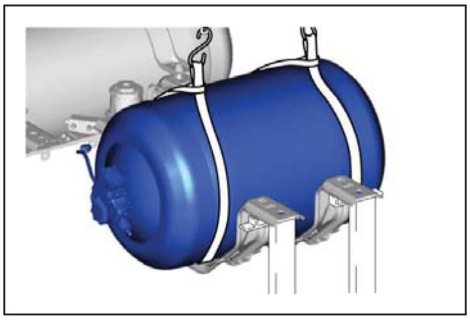
(2) Disengage the 2 claws, raise up the rear hydrogen tank frame spring bolt cushion, and remove the bolt.

Hint:

Use the same procedure to remove the other bolt.



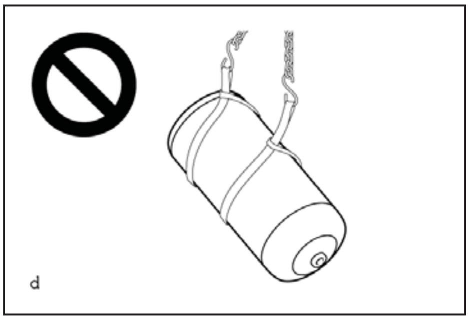
(3) Remove the 2 bolts and 2 rear hydrogen tank band sub-assemblies from the 2 rear hydrogen tank frame sub-assemblies.



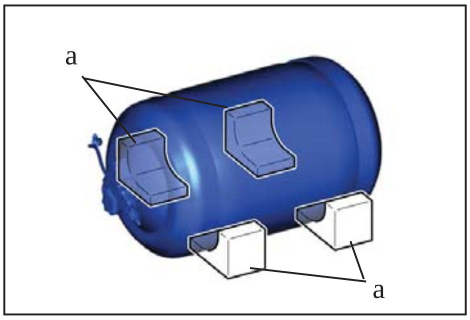
(4) Using an engine sling device and belts, remove the No. 2 hydrogen tank assembly to the rear hydrogen tank frame sub-assembly.

Caption:

- **When hoisting up the hydrogen tank assembly, do not hoist it when not properly balanced.**
- **The hydrogen tank assembly could fall, resulting in a serious accident.**



(5) Place the No. 2 hydrogen tank assembly on wheel chocks or similar.



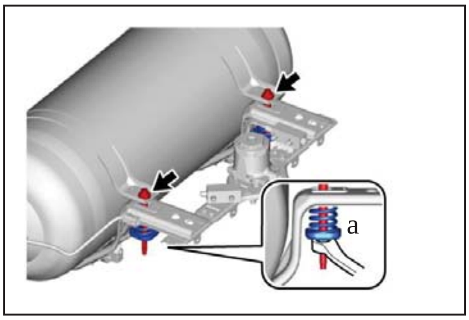
a	Wheel Chocks

30. REMOVE NO. 1 HYDROGEN TANK ASSEMBLY

(1) Loosen the 2 bolts and remove the 2 front hydrogen tank spring bolt cups and 2 compression springs.

Notice:

While holding the front hydrogen tank spring bolt cup, loosen the bolt.

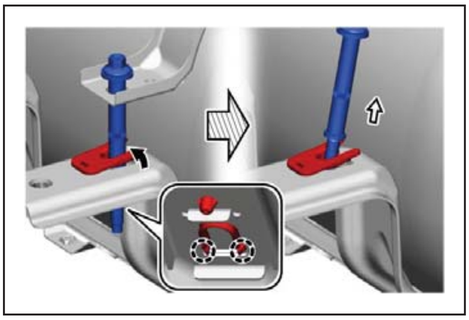


a	Hold

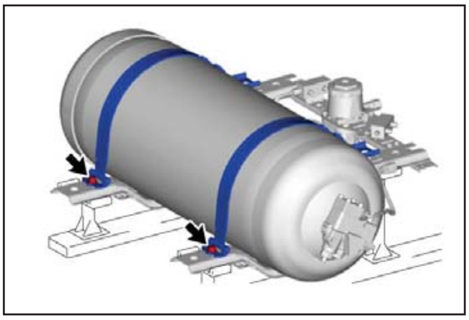
(2) Disengage the 2 claws, raise up the rear hydrogen tank frame spring bolt cushion, and remove the bolt.

Hint:

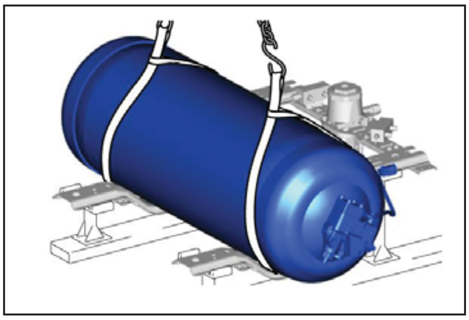
Use the same procedure to remove the other bolt.



(3) Remove the 2 bolts and 2 front hydrogen tank band sub-assemblies from the front hydrogen tank frame sub-assembly LH and front hydrogen tank frame sub-assembly RH.

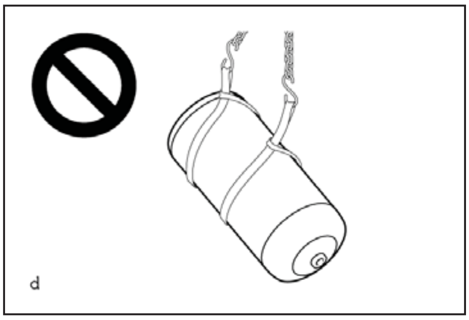


(4) Using an engine sling device and belts, remove the No. 1 hydrogen tank assembly to the front hydrogen tank frame sub-assembly LH and front hydrogen tank frame sub-assembly RH.

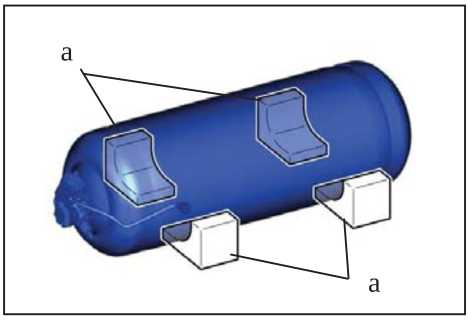


Caution:

- **When hoisting up the hydrogen tank assembly, do not hoist it when not properly balanced.**
- **The hydrogen tank assembly could fall, resulting in a serious accident.**



(5) Place the No. 1 hydrogen tank assembly on wheel chocks or similar.



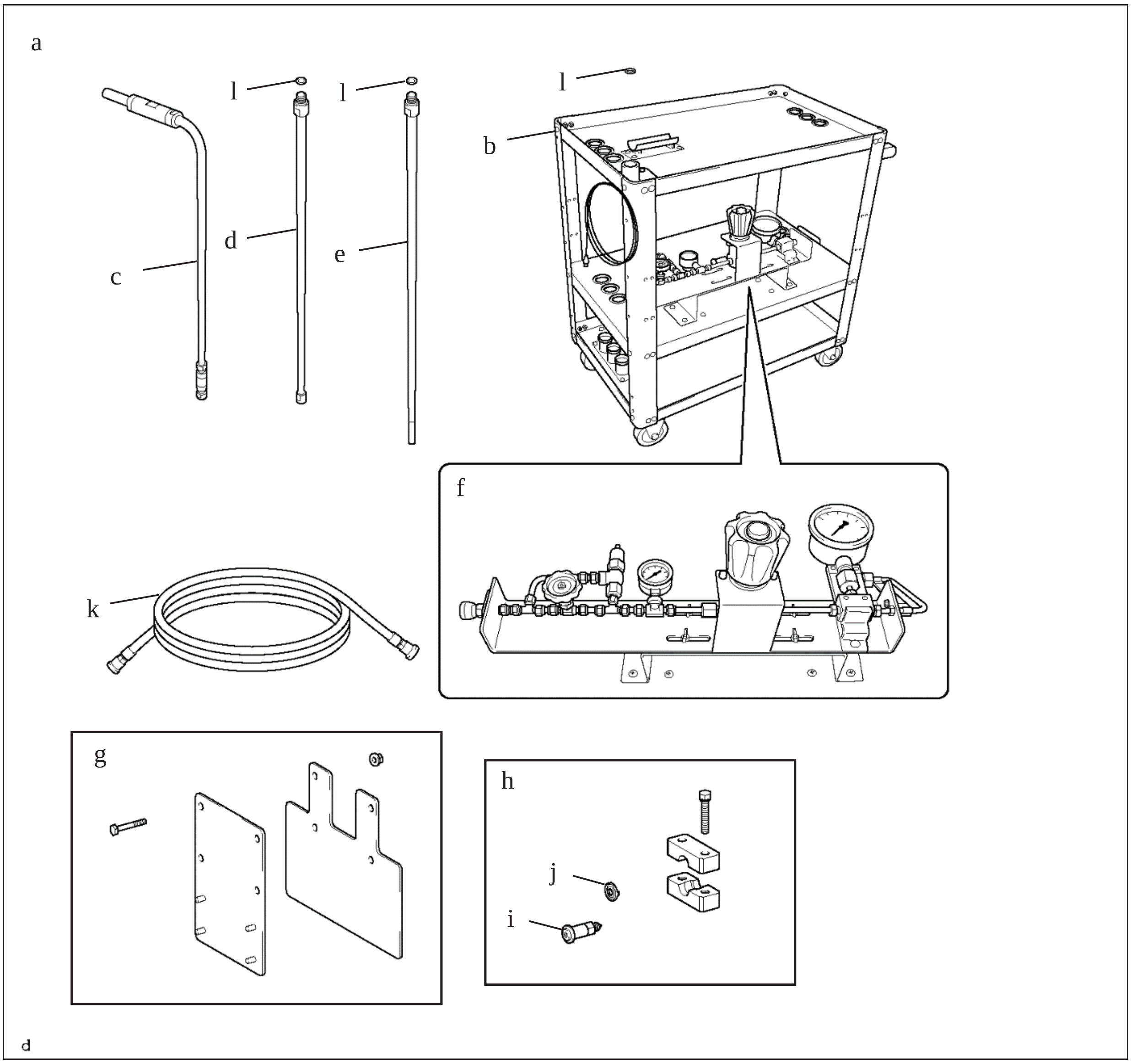
a	Wheel Chocks

Dismantling the vehicle (Continued)

Discharge Hydrogen Gas from High Pressure Port

1. PREPARE SST (HYDROGEN TANK VENTING TOOL (HIGH PRESSURE))

(1) Check the configuration of SST (hydrogen tank venting tool (high pressure)).



a	Hydrogen Tank Venting Tool (High Pressure)	b	Venting Stand
c	Upper Release Pipe	d	Middle Release Pipe
e	Lower Release Pipe	f	Regulator
g	Tank Holder	h	Clamp
i	Plug	j	Gasket
k	Extension Hose	l	O-Ring (Replace before using SST (Hydrogen Tank Venting Tool (High Pressure)))

(2) Make sure to replace the SST (3 O-rings) of the SST (hydrogen tank venting tool (high pressure)) with new ones.

i. Remove the SST (O-ring) from the SST (middle release pipe).

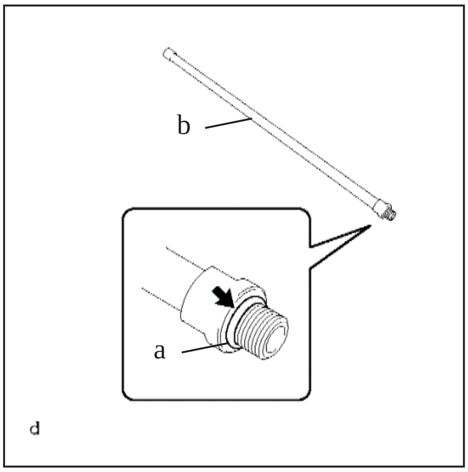
SST

09404-62030 (09404-06120, 09404-06220)

ii. Install a new SST (O-ring) to the SST (middle release pipe).

SST

09404-62030 (09404-06120, 09404-06220)



a	SST (O-ring)
b	SST (Middle Release Pipe)

iii. Remove the SST (O-ring) from the SST (lower release pipe).

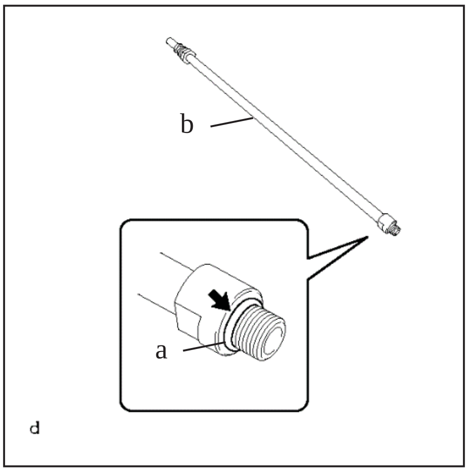
SST

09404-62030 (09404-06130, 09404-06220)

iv. Install a new SST (O-ring) to the SST (lower release pipe).

SST

09404-62030 (09404-06130, 09404-06220)

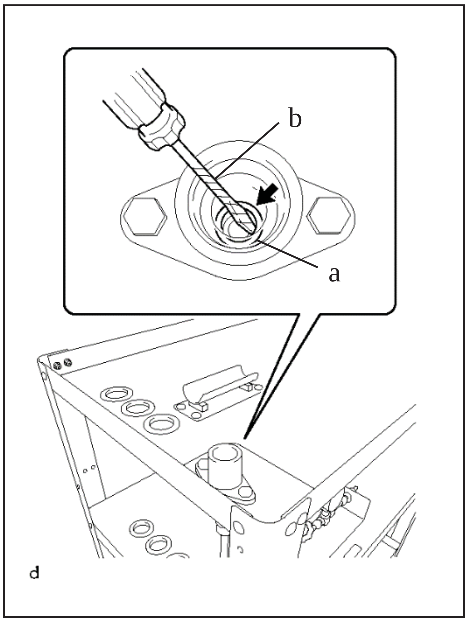


a	SST (O-ring)
b	SST (Lower Release Pipe)

v. Using a thin-bladed screwdriver with its tip wrapped in protective tape, remove the SST (O-ring) from the SST (venting stand).

SST

09404-62030 (09404-06100, 09404-06220)

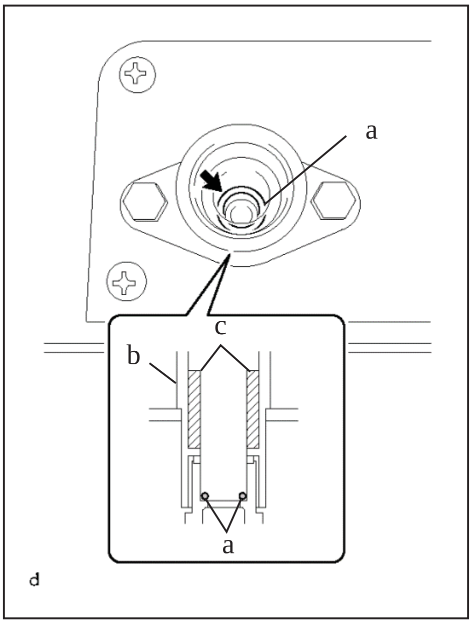


a	SST (O-ring)
b	Protective Tape

vi. As shown in the illustration, install a new SST (O-ring) to the SST (venting stand).

SST

09404-62030 (09404-06100, 09404-06220)



a	SST (O-ring)
b	SST (Venting Stand)
c	Collar

(3) Connect each part of the SST (hydrogen tank venting tool (high pressure)) and prepare it for use.

i. Connect the SST (upper release pipe) and SST (middle release pipe), and using a thickness gauge, measure the clearance in the location shown in the illustration.

SST

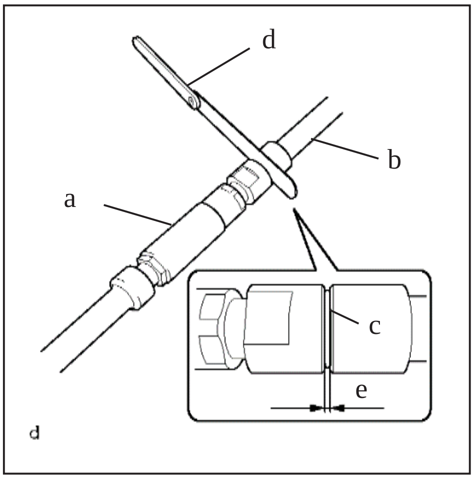
09404-62030 (09404-06110, 09404-06120)

Release pipe connection clearance:

1.7 mm (0.0669 in.)

Notice:

Perform the procedure by hand. Do not use any tools.



a	SST (Upper Release Pipe)
b	SST (Middle Release Pipe)
c	SST (O-ring)
d	Thickness Gauge
e	1.7 mm (0.0669 in.)

ii. Connect the SST (middle release pipe) and SST (lower release pipe), and using a thickness gauge, measure the clearance in the location shown in the illustration.

SST

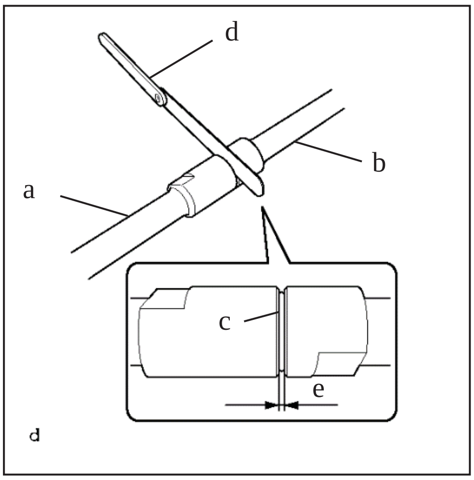
09404-62030 (09404-06120, 09404-06130)

Release pipe connection clearance:

1.7 mm (0.0669 in.)

Notice:

Perform the procedure by hand. Do not use any tools.



a	SST (Middle Release Pipe)
b	SST (Lower Release Pipe)
c	SST (O-ring)
d	Thickness Gauge
e	1.7 mm (0.0669 in.)

iii. Connect the SST (lower release pipe) to the SST (venting stand), and using SST (variable open wrench), tighten the nut.

SST

09922-10010

Torque:

Specified tightening torque

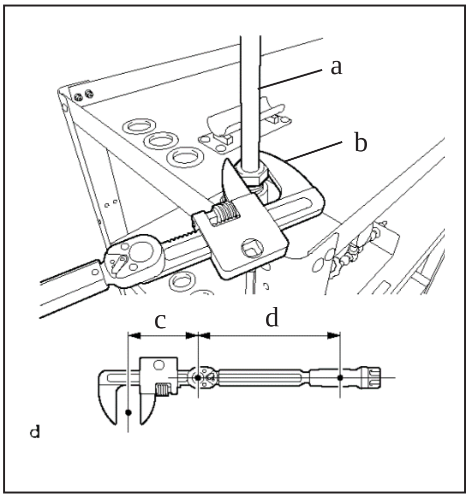
20 N*m (204 kgf*cm, 15 ft.*lbf)

Notice:

Securely insert the SST (lower release pipe).

Hint:

- Calculate the torque wrench reading when changing the fulcrum length of the torque wrench.
- When using SST (fulcrum length of 136 mm (5.35 in.)) + torque wrench (fulcrum length of 180 mm (7.09 in.)): 11.4 N*m (116 kgf*cm, 8 ft.*lbf)

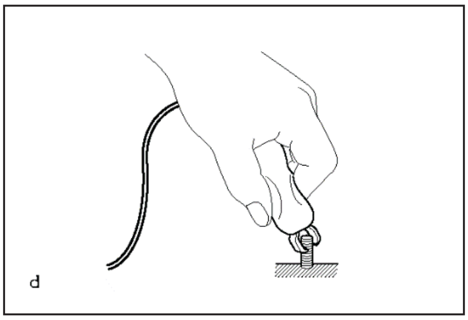


a	SST (Lower Release Pipe)
b	SST (Variable Open Wrench)
c	SST Fulcrum Length
d	Torque Wrench Fulcrum Length

iv. Connect the ground wire.

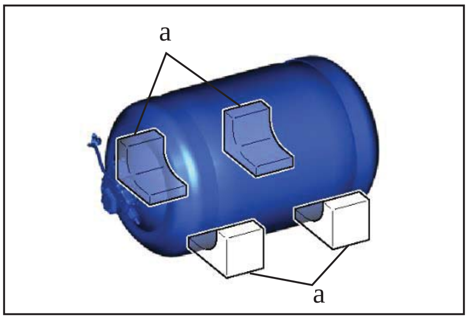
Notice:

Connect the ground wire to somewhere that will enable secure electrical grounding.



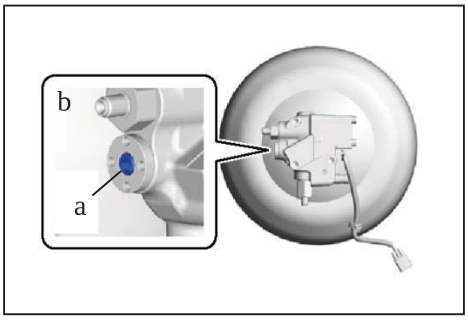
2. RELEASE COMPRESSED HYDROGEN GAS

(1) To prevent the hydrogen tank assembly from rolling, secure it with wheel chocks or similar.



a	Wheel Chocks

(2) Using an 8 mm socket hexagon wrench, apply the specified tightening torque to the adjustment bolt and check that the manual valve of the hydrogen tank assembly is closed.



a	Adjustment Bolt
b	Manual Valve Closed

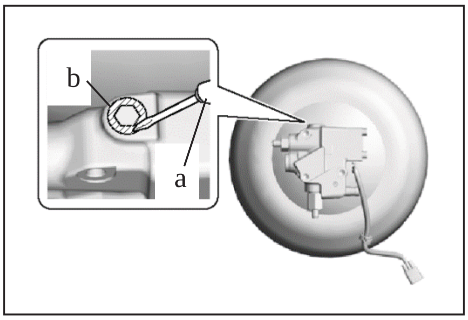
Torque:

20 N*m (204 kgf*cm, 15 ft.*lbf)

Notice:

- The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.
- If the hexagonal portion has been damaged, releasing compressed hydrogen gas from the hydrogen tank assembly will not be possible.

(3) Using a flat-bladed screwdriver, remove the resin from around the release valve of the hydrogen tank valve assembly.

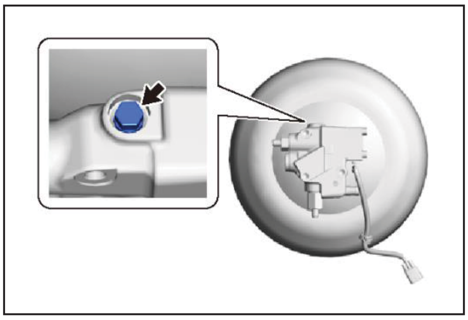


a	Flat-bladed Screwdriver
b	Resin

Notice:

If any resin enters the venting tool it could cause damage or gas leakage, so be sure to completely remove the resin.

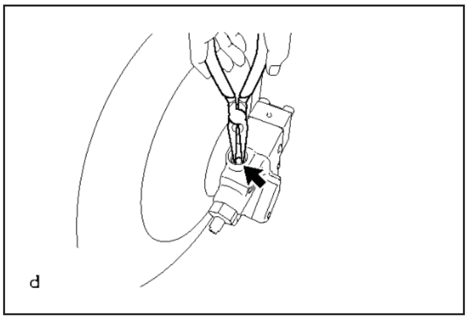
(4) Slowly loosen the release valve of the hydrogen tank valve assembly and release the compressed hydrogen gas.



Notice:

- The compressed hydrogen gas remaining inside the hydrogen tank valve assembly will come out, so continue to slowly loosen the plug until compressed hydrogen gas stops coming out.
- If compressed hydrogen gas continues to come out without stopping, close the release valve of the hydrogen tank valve assembly and recheck that the manual valve of the hydrogen tank valve assembly is closed.

(5) Remove the release valve of the hydrogen tank valve assembly.



Hint:

After removing the release valve of the hydrogen tank valve assembly, part of the release valve may remain on the hydrogen tank valve assembly side. When part of the release valve remains on the hydrogen tank valve assembly, the SST (plug) cannot be installed securely, so remove any part of the release valve that remains on the hydrogen tank valve assembly.

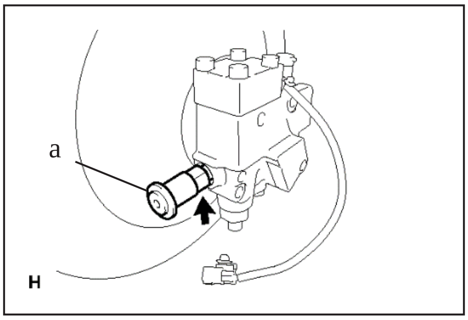
(6) Install the SST (plug) to the hydrogen tank valve assembly.

SST

09404-62030 (09404-06180, 09404-06190)

Torque:

21 N*m (214 kgf*cm, 15 ft.*lbf)



a	SST (Plug)

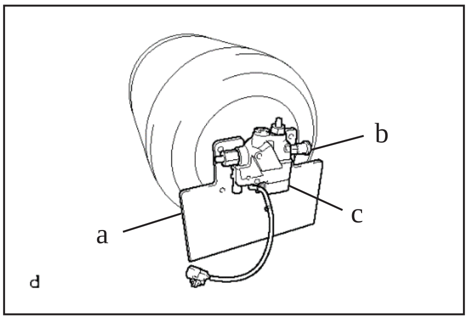
(7) Set the SST (tank holder) on the hydrogen tank assembly as shown in the illustration.

SST

09404-62030 (09404-06150)

Hint:

Make sure that the hydrogen tank valve assembly and SST (plug) are facing in the directions shown in the illustration.



a	SST (Tank Holder)
b	SST (Plug)
c	Hydrogen Tank Valve Assembly

(8) Align and set the pins of the SST (tank holder) into the holes of the hydrogen tank valve assembly, and temporarily install the SST (tank holder) with the 4 bolts and 4 nuts.

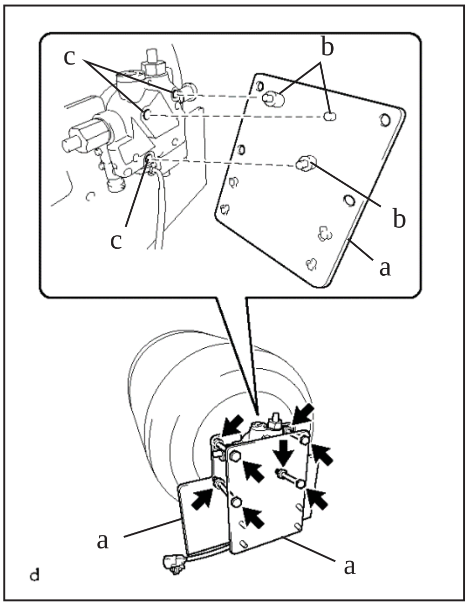
SST

09404-62030 (09404-06150, 09404-06160)

(9) Using several steps, gradually tighten the 4 bolts equally, and then fully tighten them to the specified torque to install the SST (tank holder).

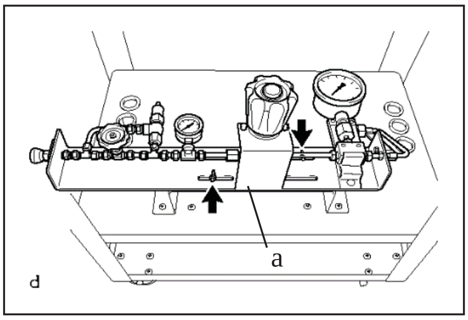
Torque:

12 N*m (122 kgf*cm, 9 ft.*lbf)



a	SST (Tank Holder)
b	Pin
c	Hole

(10) Remove the 2 nuts, and remove the SST (regulator) from the SST (venting stand).



a	SST (Regulator)

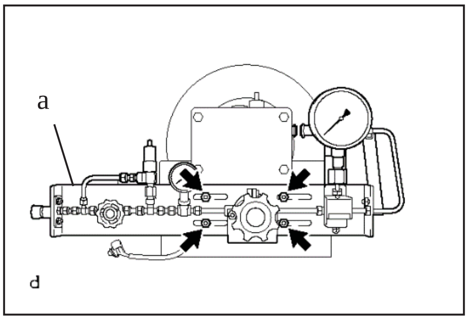
(11) Temporarily install the SST (regulator) to the SST (tank holder) with the 4 nuts.

SST

09404-62030 (09404-06150, 09404-06170)

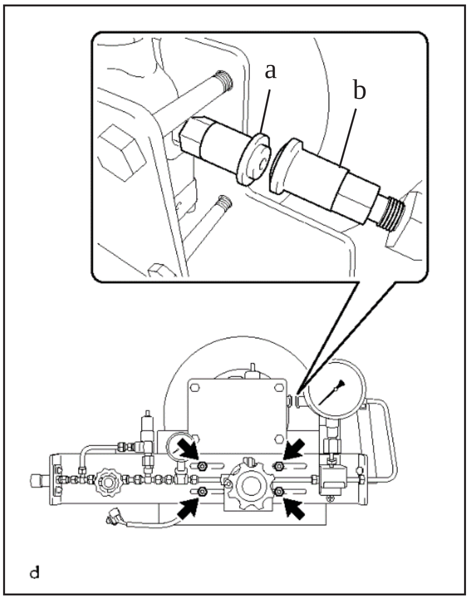
Hint:

Temporarily tighten the nuts with your fingers only, do not use any tools.



a	SST (Regulator)

(12) Set the SST (plug) and SST (regulator) in a position where they can be secured with the SST (clamp) as shown in the illustration.



a	SST (Plug)
b	SST (Regulator)

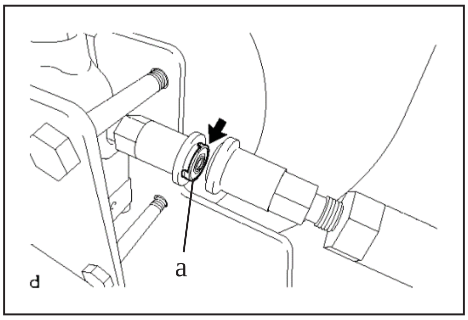
(13) Install a new SST (gasket) to the SST (plug) facing in the direction shown in the illustration.

SST

09404-62030 (09404-06180, 09404-06210)

Notice:

Do not reuse the SST (gasket).



a	SST (Gasket)

(14) Temporarily install the SST (plug) and SST (regulator) with the SST (clamp).

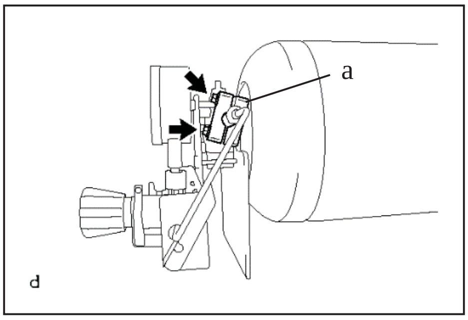
SST

09404-62030 (09404-06180, 09404-06200)

(15) Using several steps, gradually tighten the 2 bolts equally, and then fully tighten them to the specified torque.

Torque:

20 N*m (204 kgf*cm, 15 ft.*lbf)

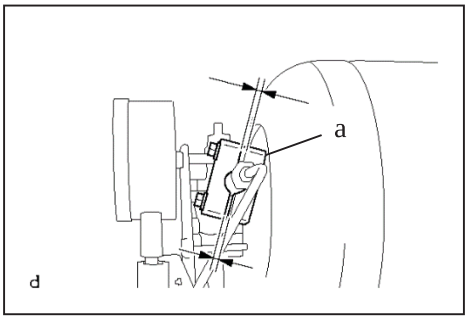


a	SST (Clamp)

(16) Make sure there is not an excessive difference in the size of the gap on the left and right sides of the SST (clamp).

Notice:

If there is an excessive difference in the size of the gap, remove the SST (clamp), replace the SST (gasket) with a new one, and assemble the parts again.

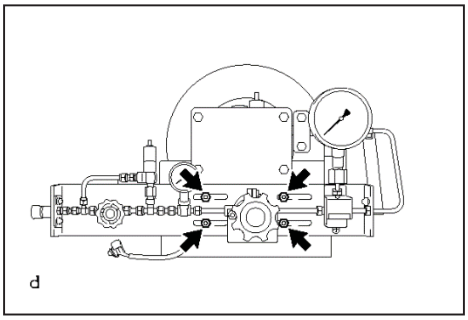


a	SST (Clamp)

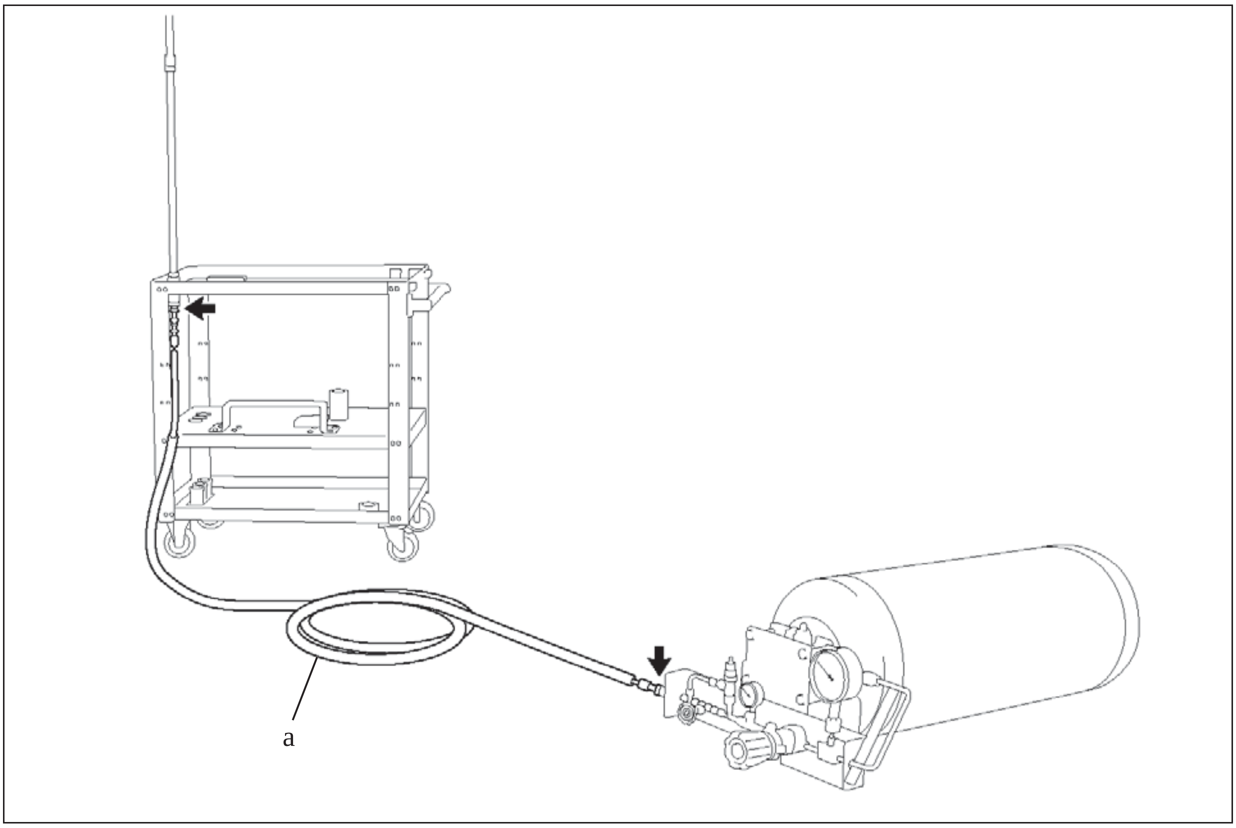
(17) Fully tighten the 4 nuts.

Torque:

5.0 N*m (51 kgf*cm, 44 in.*lbf)



(18) Install the SST (extension hose) to the SST (venting stand) and SST (regulator).



a	SST (Extension Hose)	-	-

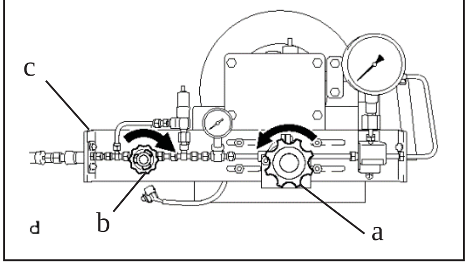
SST

09404-62020

(19) Check that the primary-side pressure regulator valve and secondary-side pressure regulator valve of the SST (regulator) are closed.

SST

09404-62030 (09404-06140)



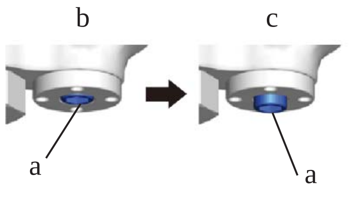
a	Primary-side Pressure Regulator Valve
b	Secondary-side Pressure Regulator Valve
c	SST (Regulator)
➡	Primary-side Pressure Regulator Valve and Secondary-side Pressure Regulator Valve Closing Direction

(20) Open and close the manual valve of the hydrogen tank assembly.

i. Using an 8 mm socket hexagon wrench, turn the adjustment bolt 4 turns counterclockwise to open the manual valve of the hydrogen tank assembly.

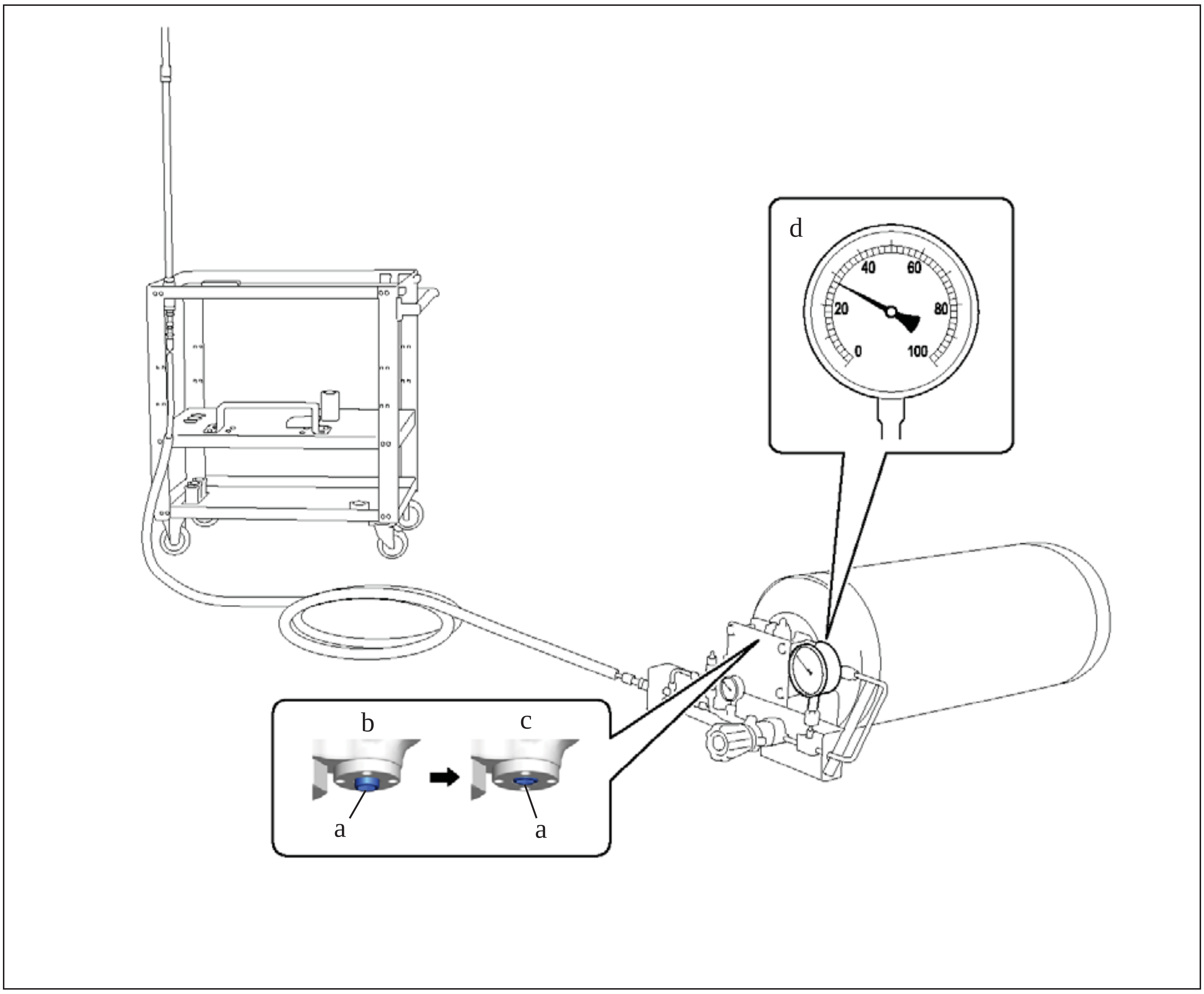
Notice:

- The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.
- If the hexagonal portion has been damaged, releasing compressed hydrogen gas from the hydrogen tank assembly will not be possible.



a	Adjustment Bolt
b	Manual Valve Closed
c	Manual Valve Open

ii. Once pressure at the primary-side pressure gauge has increased, then using an 8 mm socket hexagon wrench, turn the adjustment bolt clockwise to close the manual valve of the hydrogen tank assembly.



a	Adjustment Bolt	b	Manual Valve Open
c	Manual Valve Closed	d	Primary-side Pressure Gauge

Torque:

20 N*m (204 kgf*cm, 15 ft.*lbf)

Notice:

- The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.
- If the hexagonal portion has been damaged, releasing compressed hydrogen gas from the hydrogen tank assembly will not be possible.

Hint:

Because a leak will cause gas to leak out continuously, once the pressure has risen, close the manual valve of the hydrogen tank assembly for now.

(21) Using SST (hydrogen gas detector adapter) and a hydrogen gas detector, check for leaks between the primary-side pressure regulator valve of the SST (regulator) and SST (plug).

SST

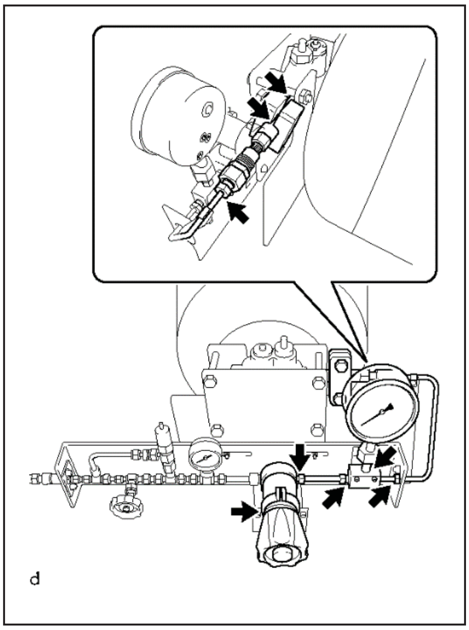
09401-62010

Specified value:

300 ppm or less

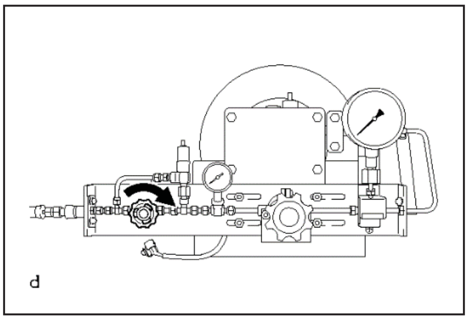
Notice:

If the values are not as specified, replace the SST (hydrogen tank venting tool (high pressure)) with a new one, or disconnect and reassemble the components at the location where the leak occurs.



➡	Leak Check Location

(22) Check that the secondary-side pressure regulator valve of the SST (regulator) is closed.

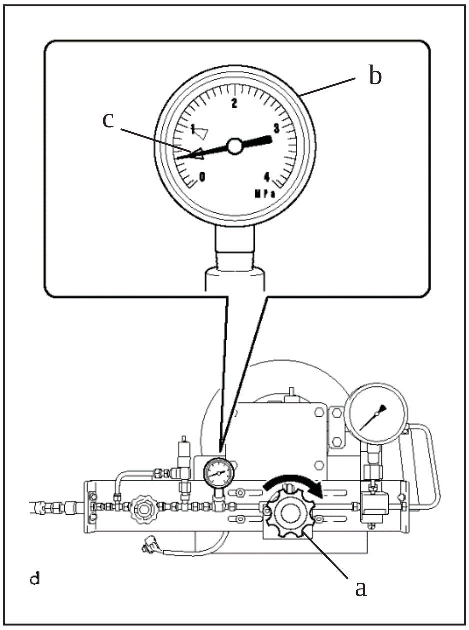


➡	Secondary-side Pressure Regulator Valve Closing Direction

(23) Slowly open the primary-side pressure regulator valve of the SST (regulator) so that the secondary-side pressure gauge becomes 0.5 MPa (5.1 kgf/cm2, 72.5 psi).

Hint:

The green triangle mark of the secondary-side pressure gauge indicates 0.5 MPa (5.1 kgf/cm2, 72.5 psi).



a	Primary-side Pressure Regulator Valve
b	Secondary-side Pressure Gauge
c	Green Triangle Mark
➡	Open Primary-side Pressure Regulator Valve

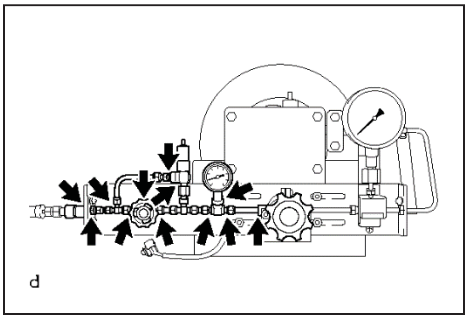
(24) Using SST (hydrogen gas detector adapter) and a hydrogen gas detector, check for leaks between the primary-side pressure regulator valve and secondary-side pressure regulator valve of the SST (regulator).

SST

09401-62010

Specified value:

300 ppm or less



➡	Leak Check Location

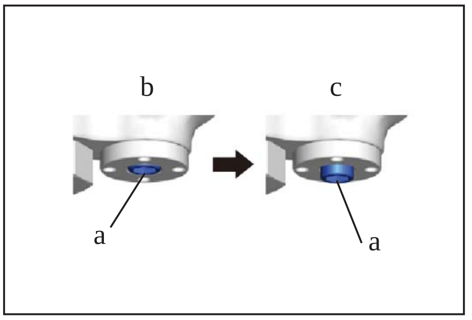
Notice:

If the value is not as specified, replace the SST (hydrogen tank venting tool (high pressure)) with a new one.

(25) Using an 8 mm socket hexagon wrench, turn the adjustment bolt 4 turns counterclockwise to open the manual valve of the hydrogen tank assembly.

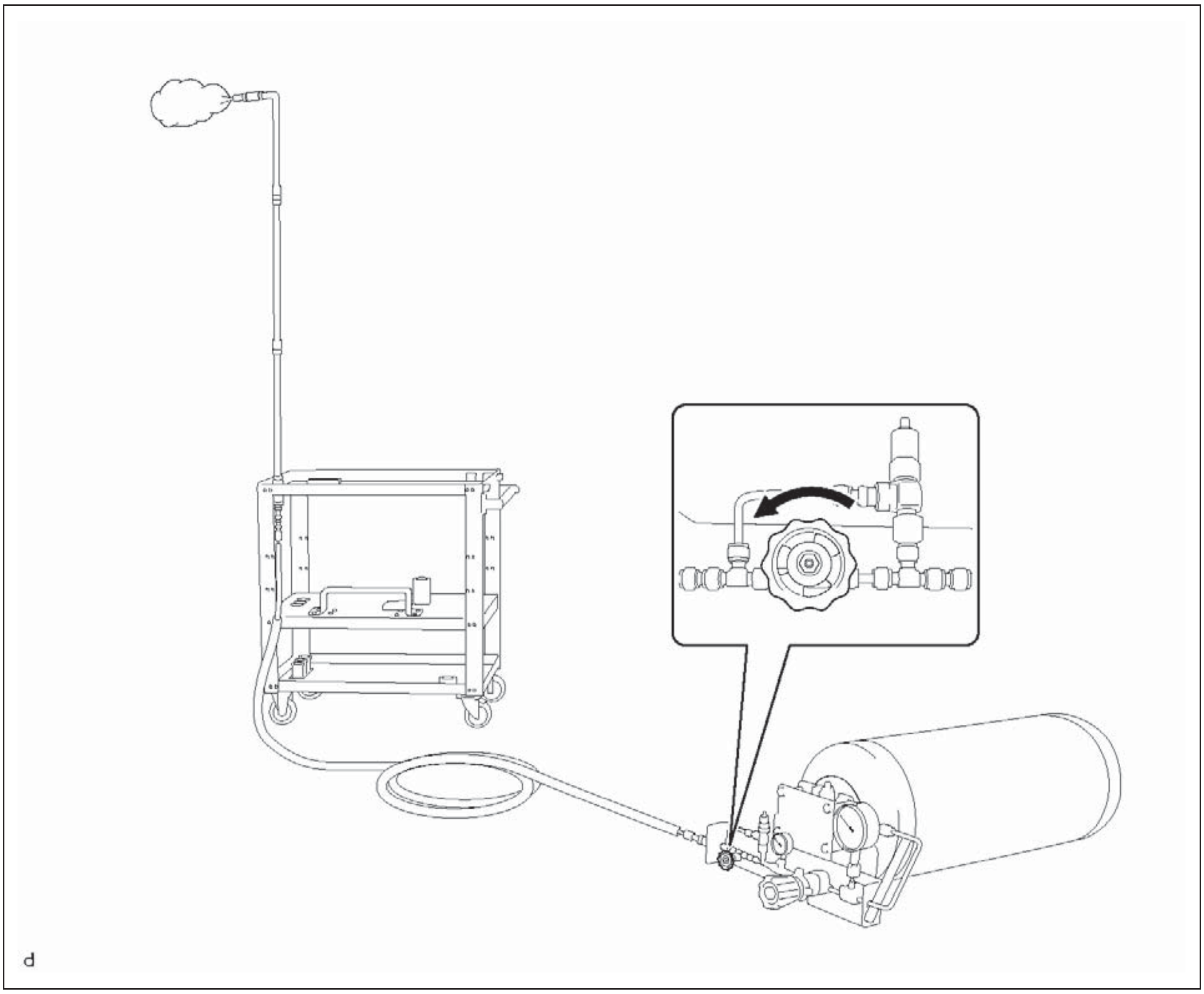
Notice:

- The manual valve shuts off the pressure from the hydrogen tank assembly, so be careful not to damage the hexagonal portion.
- If the hexagonal portion has been damaged, releasing compressed hydrogen gas from the hydrogen tank assembly will not be possible.



a	Adjustment Bolt
b	Manual Valve Closed
c	Manual Valve Open

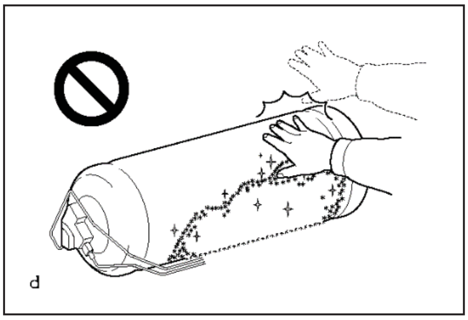
(26) Slowly open the secondary-side pressure regulator valve of the SST (regulator) and release the compressed hydrogen gas.



➡	Open Secondary-side Pressure Regulator Valve	-	-

Caution:

- **While releasing compressed hydrogen gas, the temperature inside the tank decreases and frost may form on the outside. Do not touch tanks or SST (hydrogen tank venting tool (high pressure)) when frost has formed on them.**
- **Touching tanks or SST (hydrogen tank venting tool (high pressure)) on which frost has formed could result in burn-like injuries due to frostbite.**

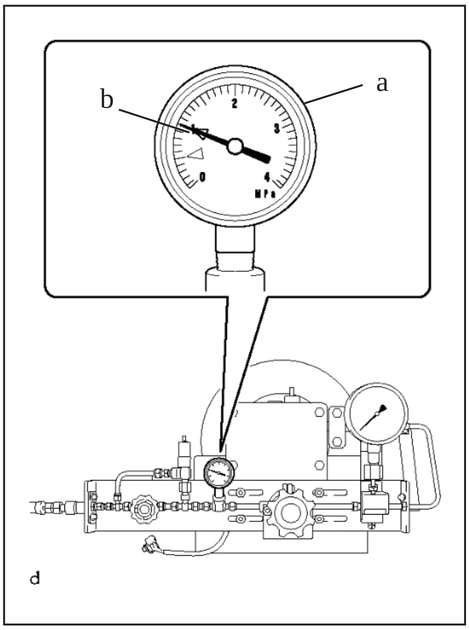


Notice:

- If the reading of the secondary-side pressure gauge of the SST (regulator) is higher than 1.0 MPa (10.2 kgf/cm2, 145 psi), close the primary-side pressure regulator valve and secondary-side pressure regulator valve of the SST (regulator) and adjust the pressure again.
- While releasing compressed hydrogen gas, if a loud, high-frequency sound is heard from the SST (regulator), stop using that SST (regulator).

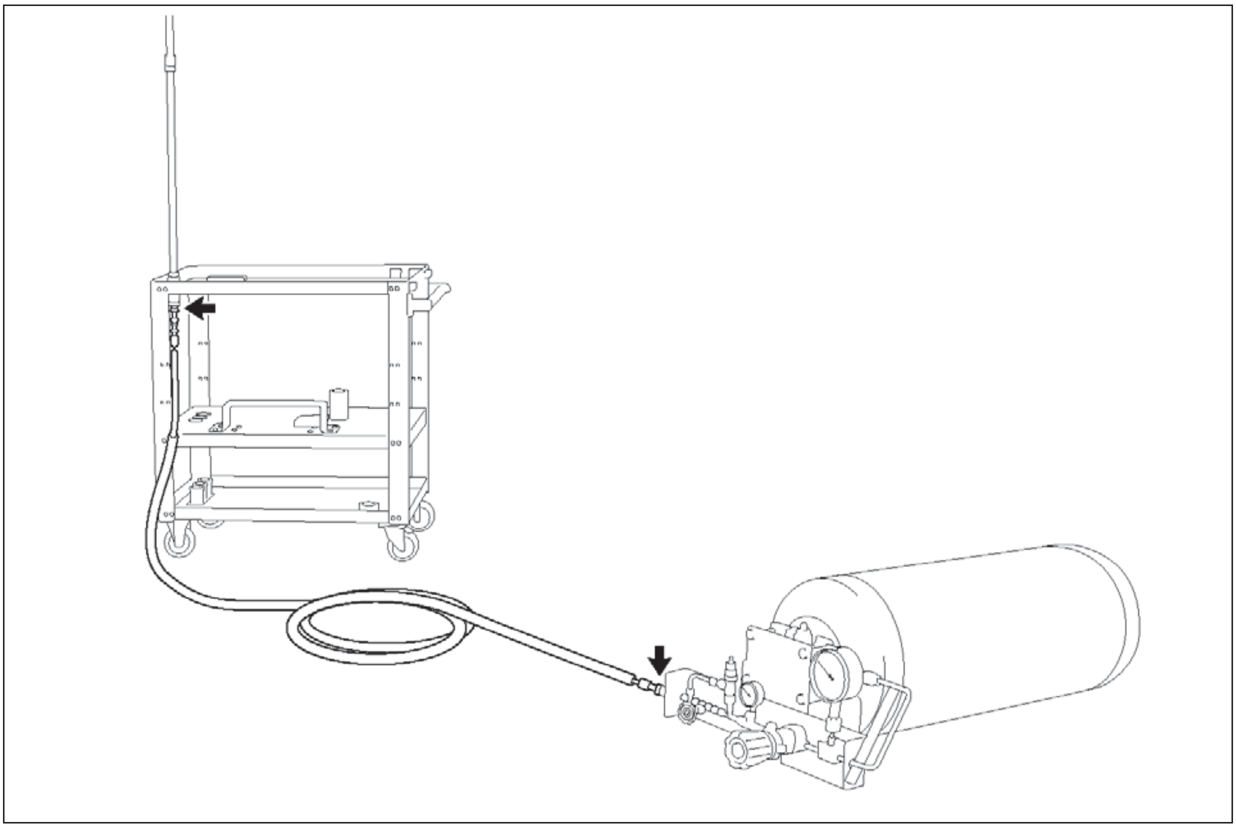
Hint:

The red triangle mark of the secondary-side pressure gauge indicates 1.0 MPa (10.2 kgf/cm 2, 145 psi).



a	Secondary-side Pressure Gauge
b	Red Triangle Mark

i. Using SST (hydrogen gas detector adapter) and a hydrogen gas detector, check for leaks at the 2 connectors of the SST (extension hose) while compressed hydrogen gas is being released.



➡	Leak Check Location	-	-

SST
09401-62010

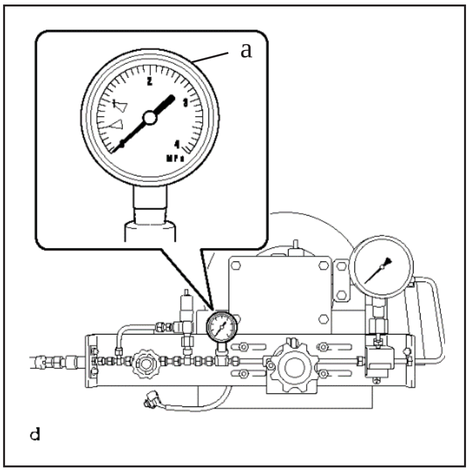
Specified value:
300 ppm or less

Notice:

If the values are not as specified, replace the SST (extension hose) with a new one, or remove and reconnect the SST (extension hose)

(27) Check that the secondary-side pressure gauge of the SST (regulator) has become 0 MPa (0 kgf/cm2, 0 psi).

(28) After confirming that the hissing sound of compressed hydrogen gas escaping from the SST (hydrogen tank venting tool (high pressure)) can no longer be heard, wait for 1 hour before continuing.

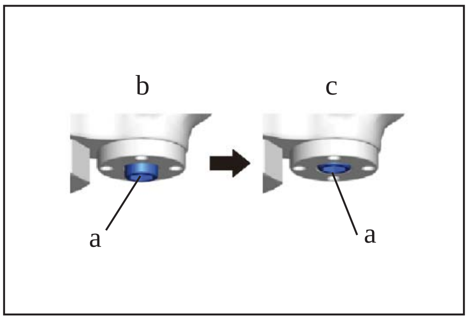


a	Secondary-side Pressure Gauge

(29) Using an 8 mm socket hexagon wrench, turn the adjustment bolt clockwise to close the manual valve of the hydrogen tank assembly.

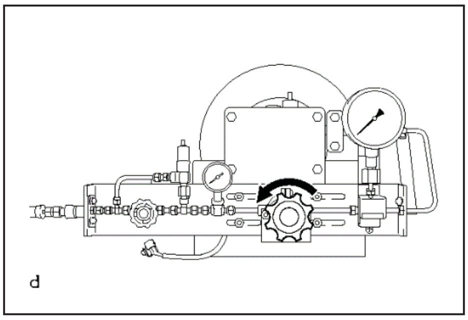
Torque:

20 N*m (204 kgf*cm, 15 ft.*lbf)



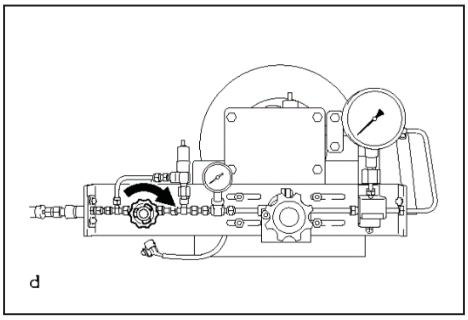
a	Adjustment Bolt
b	Manual Valve Open
c	Manual Valve Closed

(30) Close the primary-side pressure regulator valve of the SST (regulator).



➡	Close Primary-side Pressure Regulator Valve

(31) Close the secondary-side pressure regulator valve of the SST (regulator).

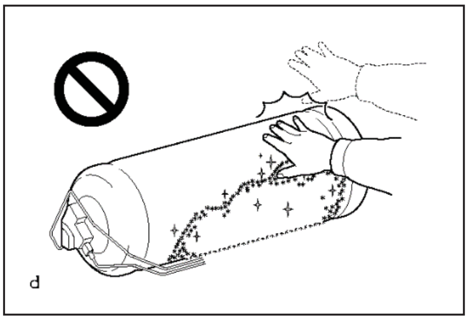


➡	Close Secondary-side Pressure Regulator Valve

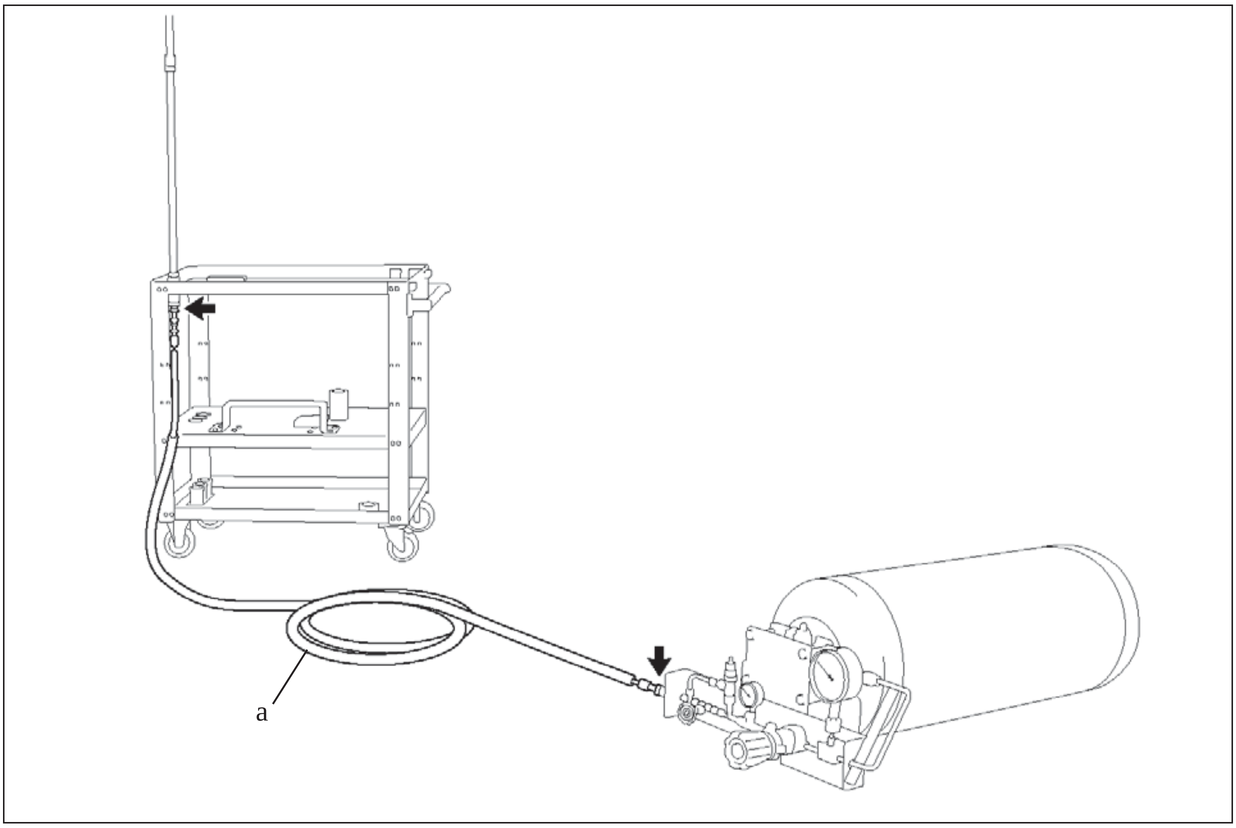
3. REMOVE SST (HYDROGEN TANK VENTING TOOL (HIGH PRESSURE))

Caution:

- **While releasing compressed hydrogen gas, the temperature inside the tank decreases and frost may form on the outside. Do not touch tanks or SST (hydrogen tank venting tool) when frost has formed on them.**
- **Touching tanks or SST (hydrogen tank venting tool) on which frost has formed could result in burn-like injuries due to frostbite.**

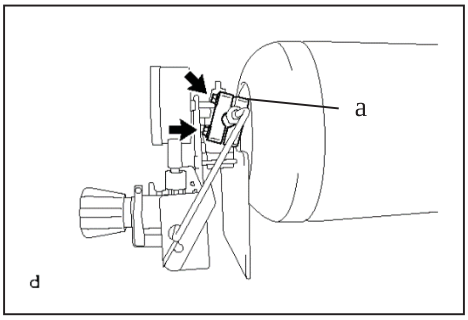


(1) Remove the SST (extension hose) from the SST (venting stand) and SST (regulator).



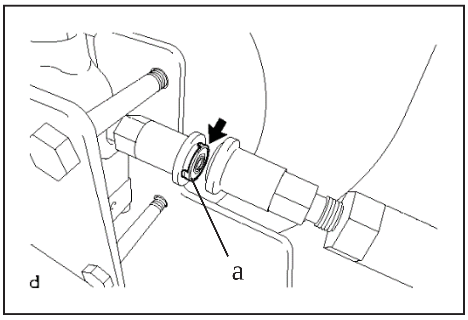
a	SST (Extension Hose)	-	-

(2) Using several steps, gradually loosen the 2 bolts equally, and remove the SST (clamp) from the SST (plug) and SST (regulator).



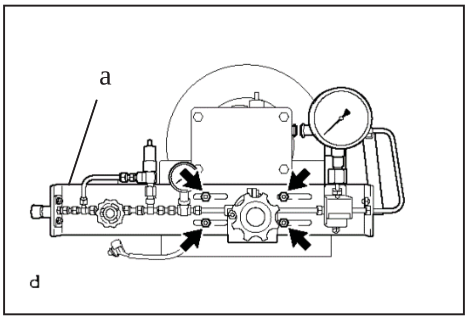
a	SST (Clamp)

(3) Remove the SST (gasket) from the SST (plug).



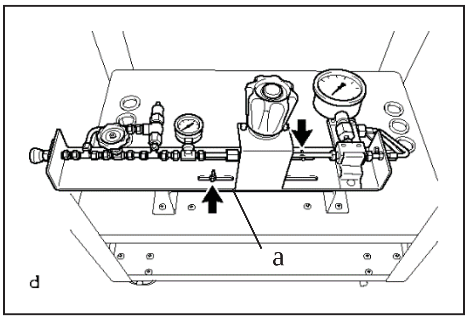
a	SST (Gasket)

(4) Remove the 4 nuts, and remove the SST (regulator) from the SST (tank holder).



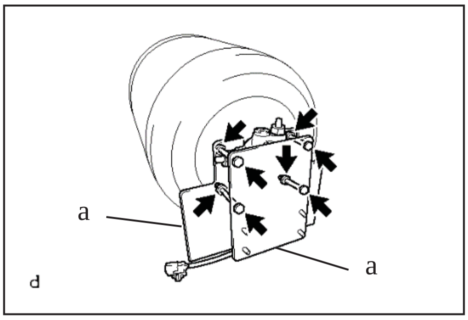
a	SST (Regulator)

(5) Install the SST (regulator) to the SST (venting stand) with the 2 nuts.



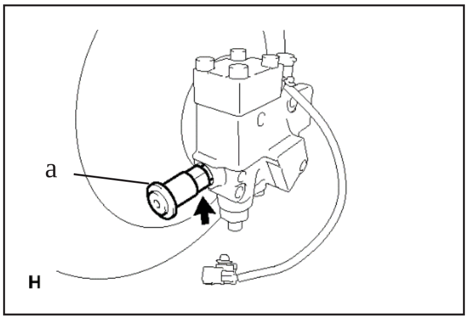
a	SST (Regulator)

(6) Using several steps, gradually loosen the 4 bolts and 4 nuts equally, and remove the SST (tank holder) from the hydrogen tank assembly.



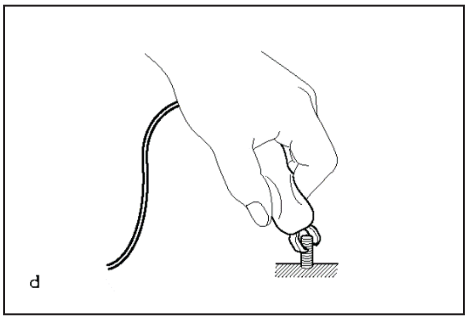
a	SST (Tank Holder)

(7) Remove the SST (plug) from the hydrogen tank valve assembly.

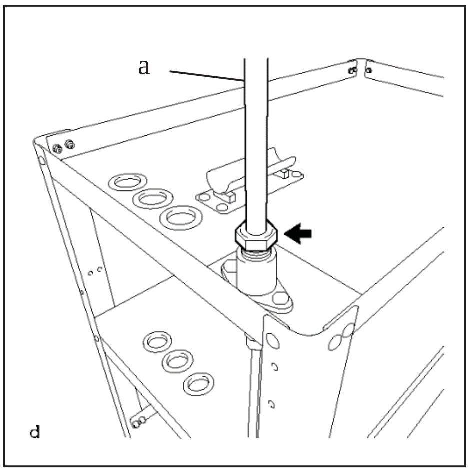


a	SST (Plug)

(8) Disconnect the ground wire.

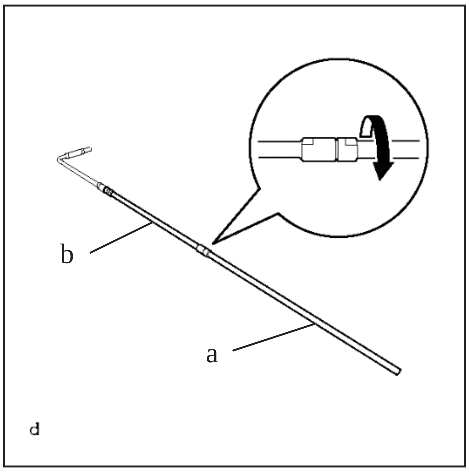


(9) Loosen the nut and disconnect the SST (lower release pipe) from the SST (venting stand).



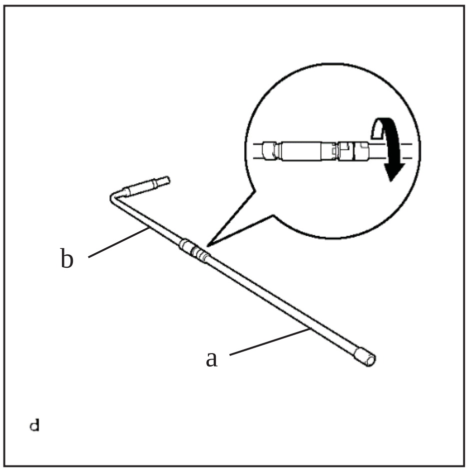
a	SST (Lower Release Pipe)

(10) Disconnect the SST (middle release pipe) and SST (lower release pipe).



a	SST (Lower Release Pipe)
b	SST (Middle Release Pipe)

(11) Disconnect the SST (upper release pipe) and SST (middle release pipe).



a	SST (Middle Release Pipe)
b	SST (Upper Release Pipe)

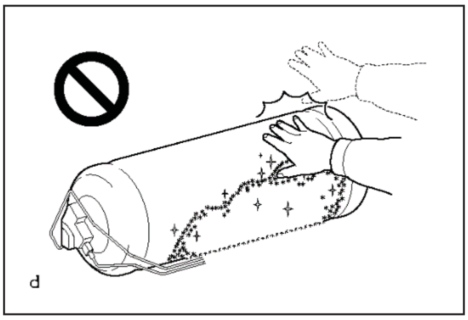
Dismantling the vehicle (Continued)

Prepare Hydrogen Tank for Disposal

1. DISPOSE OF HYDROGEN TANK ASSEMBLY

Caution:

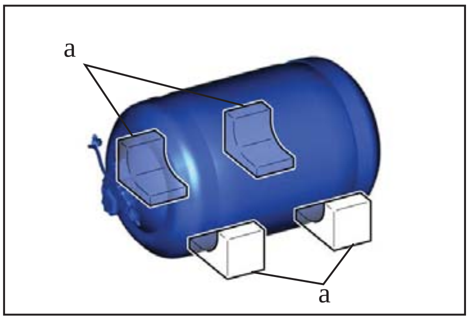
- **To prevent static electricity, spray water on the hydrogen tank and around the work area.**
- **Before performing work procedures, touch a metal object in contact with the ground in order to discharge any static electricity from your body.**
- **While releasing compressed hydrogen gas, the temperature inside the tank decreases and frost may form on the outside. Do not touch tanks or SST (hydrogen tank venting tool (high pressure)) when frost has formed on them.**
- **Touching tanks or SST (hydrogen tank venting tool (high pressure)) on which frost has formed could result in burn-like injuries due to frostbite.**



Hint:

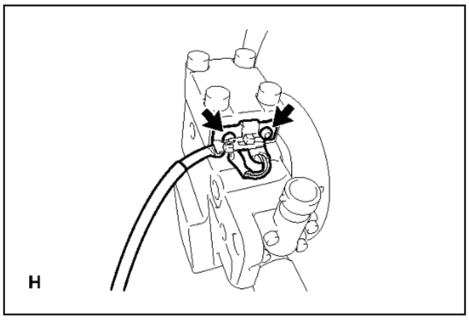
Before performing this procedure, make sure that the compressed hydrogen gas has been fully released from the hydrogen tank assembly.

(1) To prevent the hydrogen tank assembly from rolling, secure it with wheel chocks or similar.



a	Wheel Chocks

(2) Remove the 2 screws and disconnect the wire harness from the hydrogen tank valve assembly.



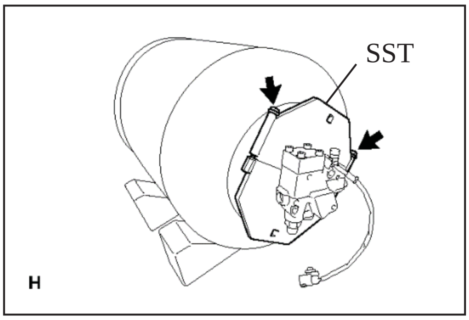
(3) Install SST (hydrogen tank holding tool) to the hydrogen tank valve assembly.

SST

09403-62020 (09403-00010)

Torque:

28 N*m (286 kgf*cm, 21 ft.*lbf)



(4) Remove the hydrogen tank valve assembly.

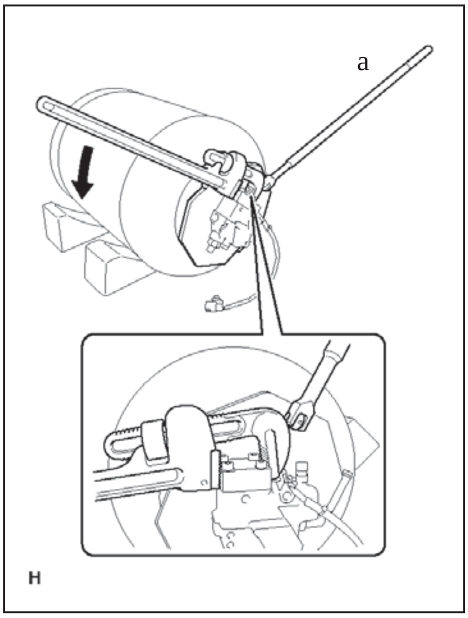
i. While holding SST (hydrogen tank holding tool), rotate the hydrogen tank valve assembly to loosen the valve.

Caution:

Because the tightening torque of the valve is extremely high, perform this operation with 2 people.

ii. Remove SST (hydrogen tank holding tool) from the hydrogen tank valve assembly.

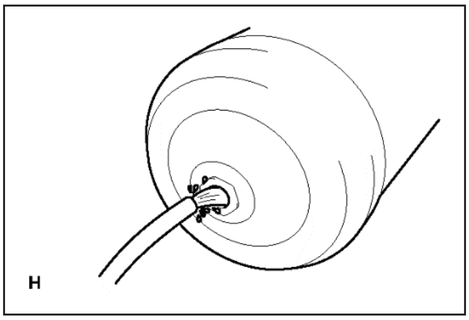
iii. Remove the hydrogen tank valve assembly.



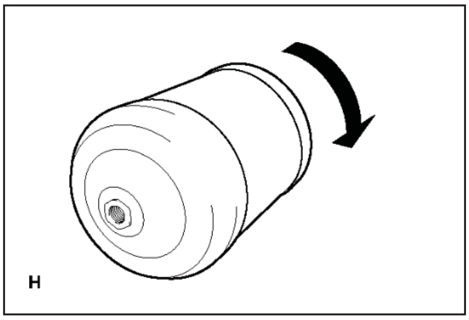
a	Hold
➡	Turn

(5) Soak the interior of the hydrogen tank assembly with water.

i. Spray water into the hydrogen tank assembly through the valve installation hole as shown in the illustration.



ii. After spraying water into the inside of the hydrogen tank assembly, roll the hydrogen tank assembly through at least 1 full rotation.



Notice:

To prevent static electricity from being generated when blowing compressed air into the hydrogen tank assembly through the valve installation hole, make sure to perform this procedure.

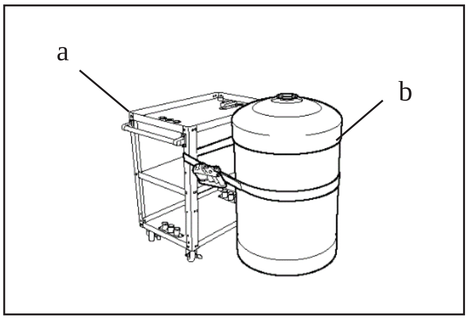
Hint:

To ensure the entire inside surface of the hydrogen tank assembly is soaked with water, roll the hydrogen tank assembly through at least 1 full rotation.

(6) Set the hydrogen tank assembly vertically.

SST

09404-62030



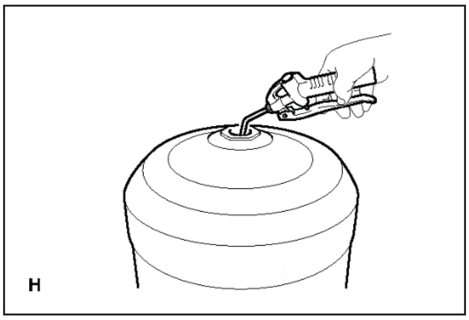
a	SST (Hydrogen Tank Venting Tool (High Pressure))
b	Belt

Notice:

To prevent the hydrogen tank assembly from falling over, use a belt to secure the hydrogen tank assembly to SST (hydrogen tank venting tool (high pressure)).

(7) Measure the hydrogen gas concentration.

i. Before measuring the hydrogen gas concentration, blow compressed air into the hydrogen tank assembly through the valve installation hole.



Hint:

This procedure is performed in order to force out hydrogen gas that may remain in the hydrogen tank assembly and release it into the atmosphere.

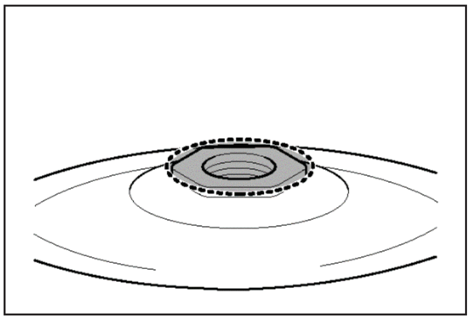
ii. If there are any water droplets, etc. adhering to the measurement locations, wipe them away before measuring the hydrogen gas concentration.

Notice:

Performing the measurement while any water droplets, etc. are adhering could damage the hydrogen gas detector.

iii. Measure the hydrogen gas concentration at the location shown in the illustration.

Specified value:
4% or less



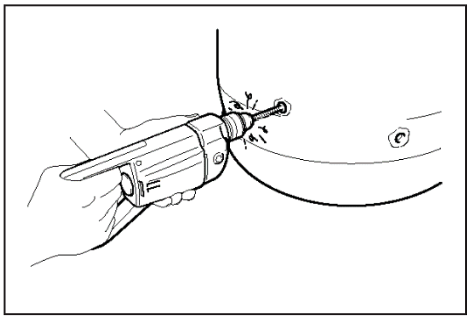
	Hydrogen Concentration Measurement Area

Hint:

- If the hydrogen tank assembly is left standing vertically for approximately 1 day, the hydrogen concentration becomes less than 4%. (Make sure to leave it in an area with good ventilation for at least 8 hours.)
- Immediately after the measurement starts, the measured value may be unstable.
- Measure the gas concentration for approximately 10 seconds continuously.

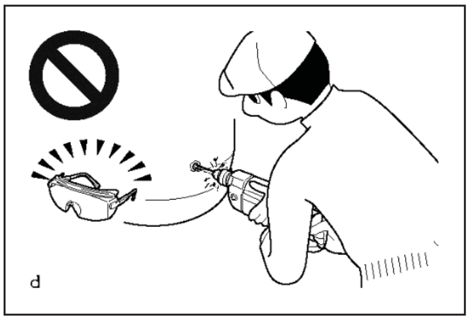
(8) Using a drill, drill holes in the hydrogen tank assembly in at least 2 locations.

Hole size:
12.5 mm (0.492 in.) diameter or larger



Caution:

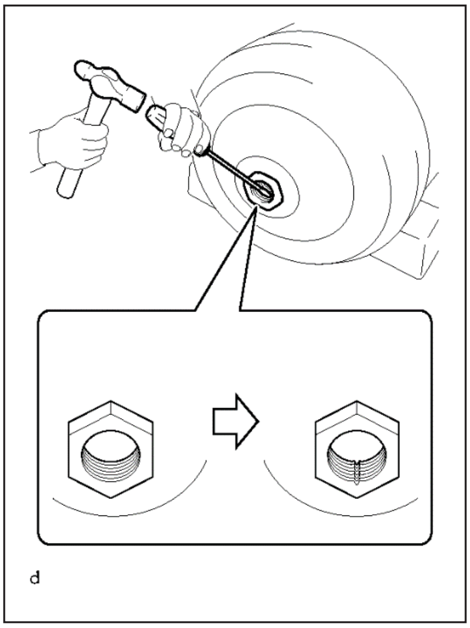
- **Make sure to wear protective glasses when drilling the holes.**
- **Drilling the holes without wearing protective glasses could result in a serious accident.**



Hint:

This is done to ensure that the hydrogen tank assembly will not be reused.

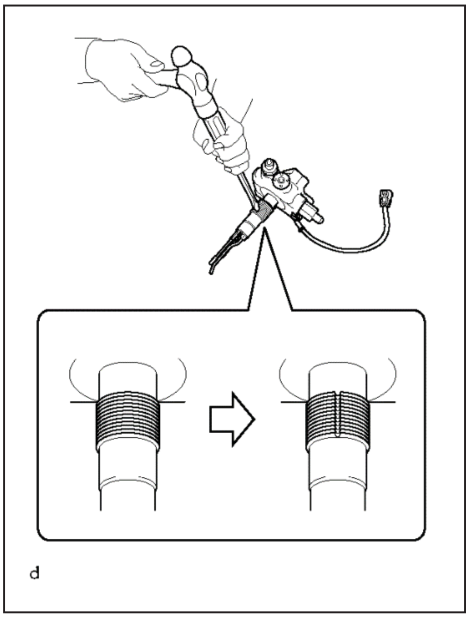
i. Destroy the threads of the valve installation hole of the hydrogen tank assembly as shown in the illustration.



Hint:

This is done to ensure that the hydrogen tank assembly will not be reused.

(9) Destroy the threads of the valve of the hydrogen tank assembly as shown in the illustration.



Hint:

This is done to ensure that the hydrogen tank valve assembly will not be reused.

DISCHARGING HYDROGEN TANKS

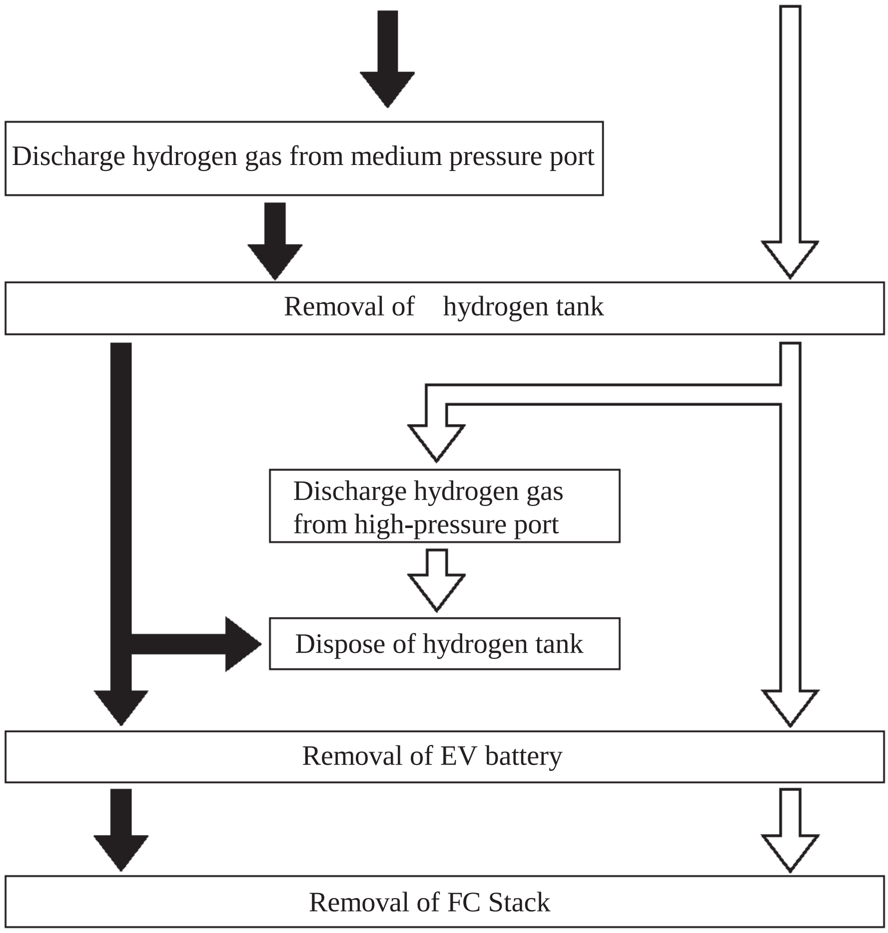
Introduction to Fuel Cell Vehicles
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

Reference Material

Conditions for Determining Whether Gas can be Discharged from Medium Pressure Port and How to Proceed with Work

Damaged area	・Only hydrogen tank damaged ・Tank shut valves stuck open ・Temperature sensor malfunctioning	・Hydrogen tank and hydrogen tank tube damage ・Tank shut valves stuck closed
Discharge hydrogen gas from medium pressure port	Possible	Impossible



Dismantling the vehicle (Continued)

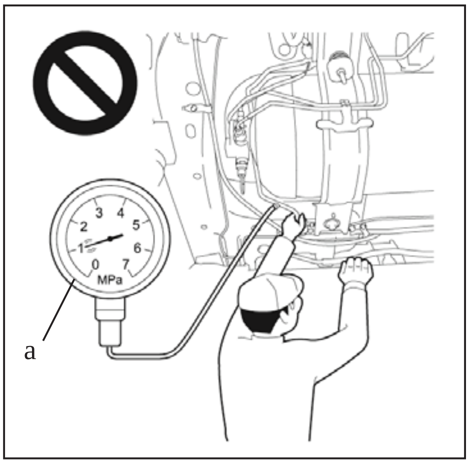
Discharge Hydrogen Gas from Medium Pressure Port

The following 5 pages contain general instructions for use when working on a MIRAI. Read these instructions before proceeding to the discharge hydrogen gas from medium pressure port instructions on page 23.

Caution:

- **Work procedures must be performed in an area with good ventilation (airflow) where hydrogen gas will not accumulate, and flames or other things that could act as ignition sources must not be present.**
- **Accumulated hydrogen gas could ignite, resulting in a serious accident.**

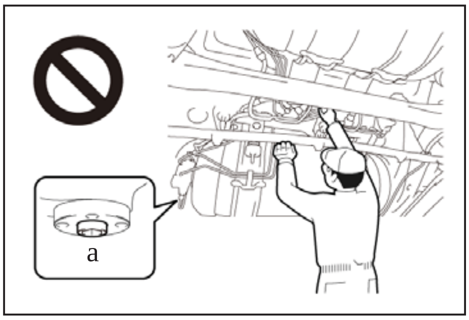
- **Do not remove any hydrogen system components without first performing depressurization procedures.**
- **The highly pressurized hydrogen gas inside the hydrogen tank assembly could blow out, resulting in a serious accident.**



a	When inside of piping is pressurized

- Do not perform depressurization procedures when the manual valve of the hydrogen tank assembly is open.

- The highly pressurized hydrogen gas inside the hydrogen tank assembly could blow out, resulting in a serious accident.



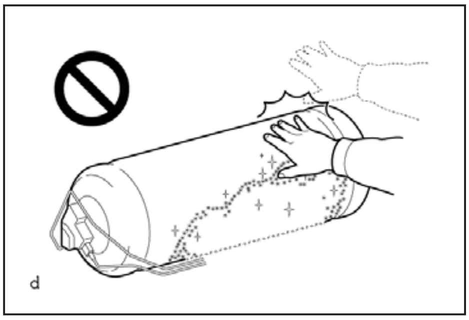
a	Manual Valve Open

- When performing depressurization, do not perform procedures by hand without wearing protective glasses and gloves.

- The highly pressurized hydrogen gas inside the hydrogen tank assembly could blow out, resulting in a serious accident.

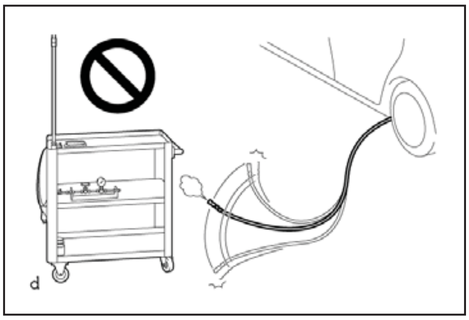
- While discharging pressurized hydrogen gas, the temperature inside the tank decreases and frost may form on the outside. Do not touch tanks, piping, or SST (hydrogen venting tool) when frost has formed on them.

- Touching tanks, piping, or SST (hydrogen venting tool) on which frost has formed could result in burn-like injuries due to frostbite.



- When opening the tank shut valve and applying pressure to the SST (hydrogen venting tool), stay away from the SST (flexible hose).

- If the SST (flexible hose) comes off, you could be struck by the loose end of the SST (flexible hose), causing a serious accident.



Notice:

- After turning the power switch off, waiting time may be required before disconnecting the cable from the negative (-) auxiliary battery terminal. Therefore, make sure to read the disconnecting the cable from the negative (-) auxiliary battery terminal notices before proceeding with work.
- When performing depressurization, do not open or close any parts of the hydrogen gas piping except for the following:
  - Adjustment bolt of the hydrogen tank assembly manual valve
  - Tank shut valve of the hydrogen tank assembly
  - Nut of the hydrogen supply regulator assembly medium pressure leak check port
- Place signs [HIGH PRESSURE GAS WORK IN PROGRESS - DO NOT TOUCH!], etc. to warn other technicians to be cautious. (An example sign is included, so make a copy and use it.)

Person in charge:

DO NOT TOUCH.
HIGH-PRESSURE GAS
CAUTION:

CAUTION:
HIGH-PRESSURE GAS
DO NOT TOUCH.

Person in charge: ____________________

Place signs [HIGH PRESSURE GAS WORK IN PROGRESS - DO NOT TOUCH!], etc. to warn other technicians to be cautious. (An example sign is included, so make a copy and use it.)

- When the vehicle is parked with the power switch off, if the FC control ECU judges that the FC stack temperature will go below 0° C (32° F), it activates the FC air compressor, hydrogen pump and FC cooling water pump for a maximum of 180 seconds and drains water from the FC stack assembly. When performing inspection or repairs with the power switch off (not on (IG) or on (READY)), disconnect the cable from the negative (-) auxiliary battery terminal before performing work.

FUEL CELL STACK REMOVAL PROCEDURES

Introduction to Fuel Cell Vehicles
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

Reference Material

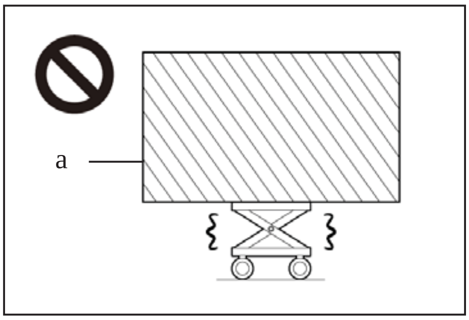
Dismantling the vehicle (Continued)

Removal of FC Stack

The following 1 pages contain general instructions for use when working on a MIRAI. Read these instructions before proceeding to the FC Stack removal instructions on page 114.

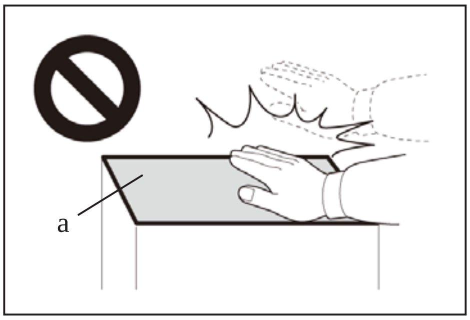
Caution:

- **Because the weight of the FC stack with FC converter assembly is extremely heavy, make sure to follow the work procedures described in the repair manual.**
- **If work is not performed according to the procedures described in the repair manual, there is a danger that the engine lifter could drop and components could fall down.**



a	Heavy load exceeding the weight limits or size limits of the engine lifter

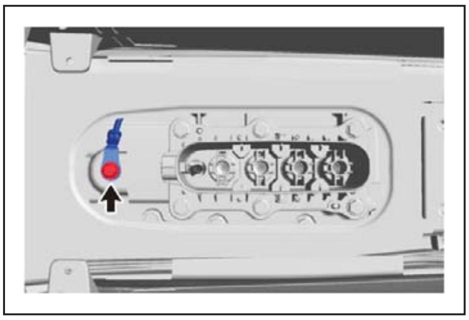
- **Do not touch the FC stack assembly or its surroundings when they are hot.**
- **Touching the FC stack service plug grip or surroundings when they are hot could result in burns.**



a	High temperature areas

1. SEPARATE WIRE HARNESS

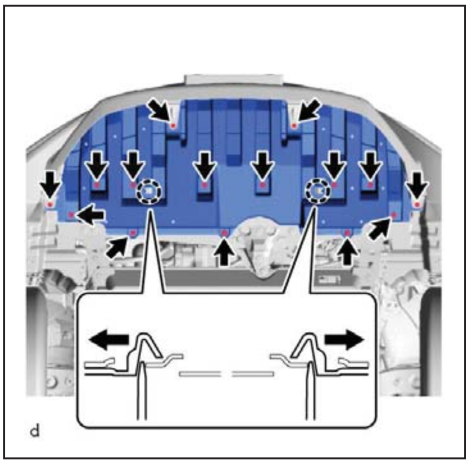
Remove the bolt to separate the wire harness from the vehicle.



2. REMOVE FRONT BUMPER LOWER ABSORBER

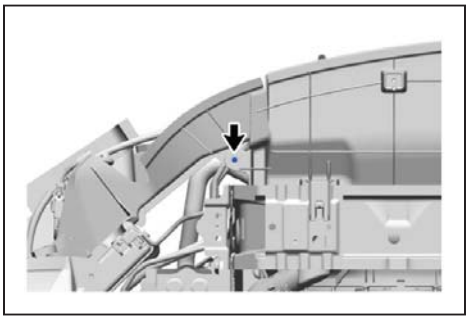
(1) Remove the 8 bolts, 4 screws and 3 clips.

(2) Using a screwdriver, disengage the 2 claws to remove the front bumper lower absorber as shown in the illustration.

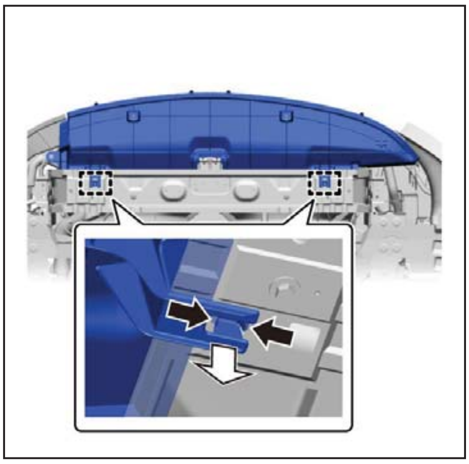


3. REMOVE NO. 3 RADIATOR AIR GUIDE

(1) Remove the clip.

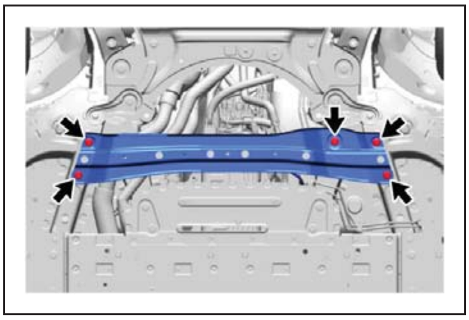


(2) While pinching the clamp portion of the No. 3 radiator air guide from both sides as shown in the illustration, pull it out towards the bottom of the vehicle, and remove the No. 3 radiator air guide from the radiator support LWR.



4. REMOVE SUSPENSION MEMBER TO FRONT CROSSMEMBER BRACE SUB-ASSEMBLY

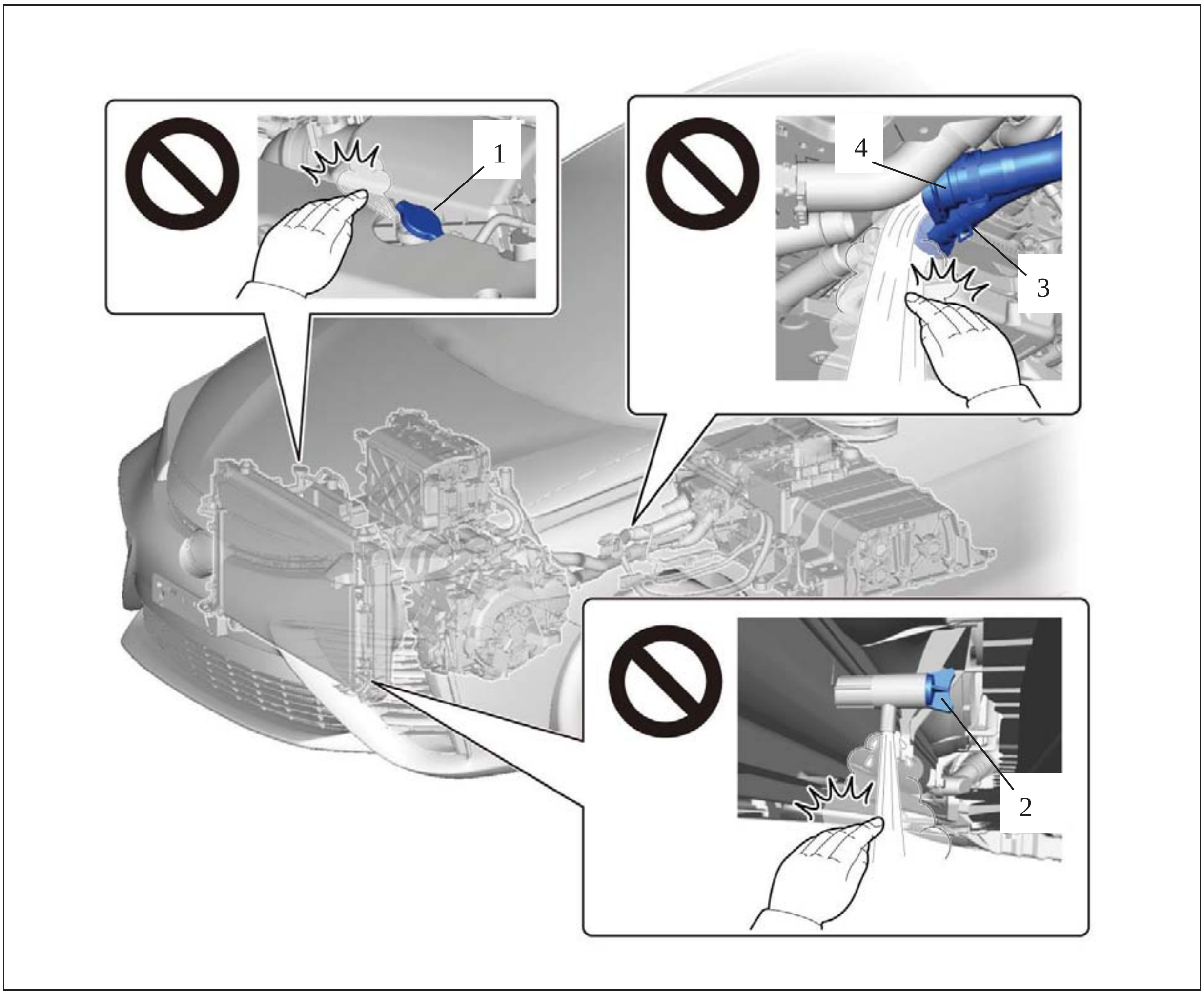
Remove the 5 bolts and suspension member to front crossmember brace sub-assembly from the vehicle.



5. DRAIN COOLANT (FC STACK COOLANT)

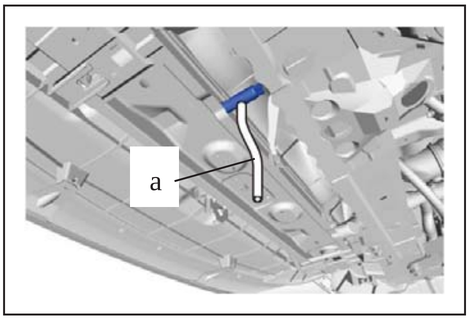
Caution:

- **When the coolant (Toyota genuine FC stack coolant) temperature is high, do not remove the radiator cap sub-assembly or the drain cock plug of the FC radiator, and do not disconnect the No. 2 FC cooling water pump outlet hose or No. 2 FC cooling water valve inlet hose.**
- **Fluid and steam may spray out due to high pressure, possibly resulting in burns.**



1	Radiator Cap Sub-assembly	2	FC Radiator Drain Cock Plug
3	No. 2 FC Cooling Water Pump Outlet Hose	4	No. 2 FC Cooling Water Valve Inlet Hose

(1) Connect a hose with an inside diameter of 9 mm (0.354 in.) to the FC radiator assembly drain cock as shown in the illustration.



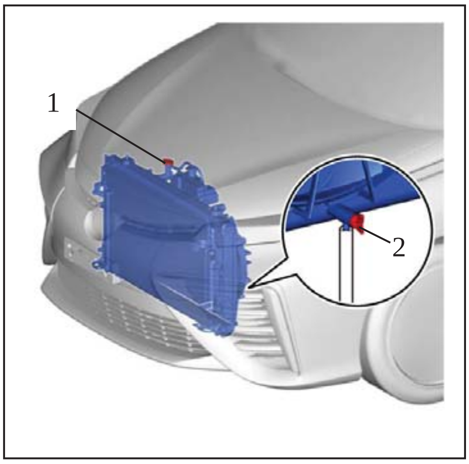
a	HOSE

(2) Loosen the FC radiator assembly drain cock plug.

(3) Remove the radiator cap sub-assembly, then drain the coolant (Toyota genuine FC stack coolant).

(4) Tighten the FC radiator drain cock plug by hand.

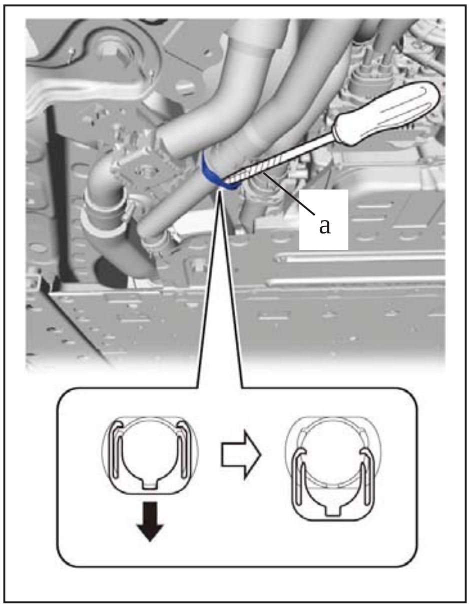
(5) Remove the hose from the FC radiator assembly drain cock.



1	Radiator Cap Sub-assembly
2	FC Radiator Drain Cock Plug

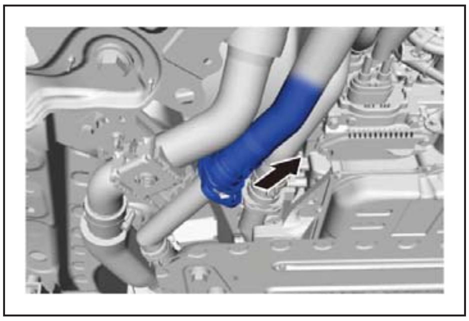
(6) Disconnect the No. 2 FC cooling water valve inlet hose (with FC water hose connector).

i. Using a screwdriver with its tip wrapped in protective tape, press down the retainer of the FC water hose connector to release the lock.



a	Protective Tape

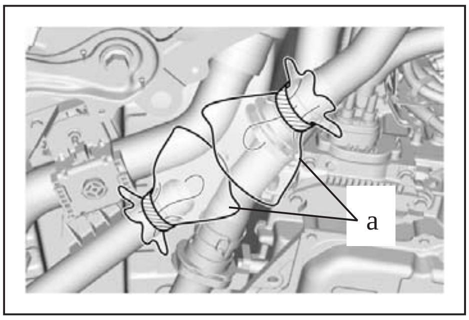
ii. Separate the No. 2 FC cooling water valve inlet hose (with FC water hose connector) from the FC stack cooling water outlet pipe, and drain the coolant (Toyota genuine FC stack coolant).



Notice:

- Disconnect the components slowly to prevent coolant (Toyota genuine FC stack coolant) from splattering.
- Perform the procedures by hand. Do not use any tools.
- Do not rotate or tilt the No. 2 FC cooling water pump outlet hose (with FC water hose connector) when pulling it out.

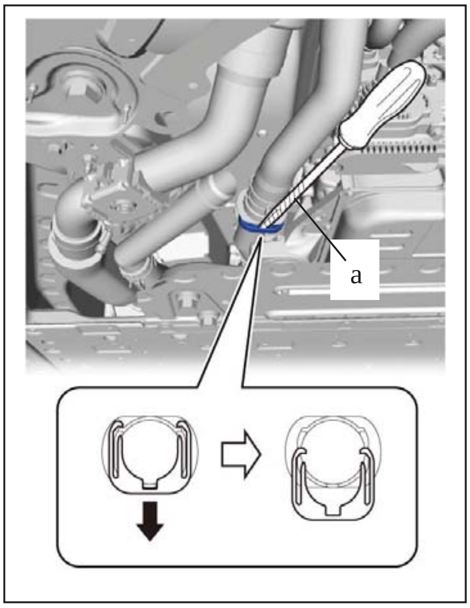
iii. When working with the No. 2 FC cooling water valve inlet hose (with FC water hose connector) disconnected, to prevent foreign matter from entering, protect the connecting portions of the No. 2 FC cooling water valve inlet hose (with FC water hose connector) and FC stack cooling water outlet pipe with plastic bags.



a	Plastic Bag

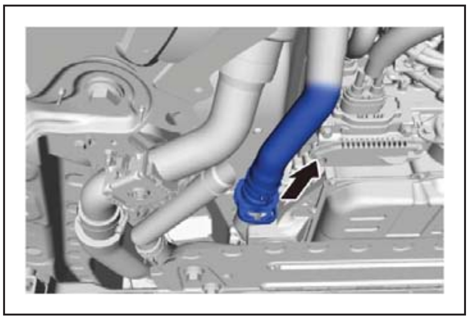
(7) Disconnect the No. 2 FC cooling water valve inlet hose (with FC water hose connector).

i. Using a screwdriver with its tip wrapped in protective tape, press down the retainer of the FC water hose connector to release the lock.



a	Protective Tape

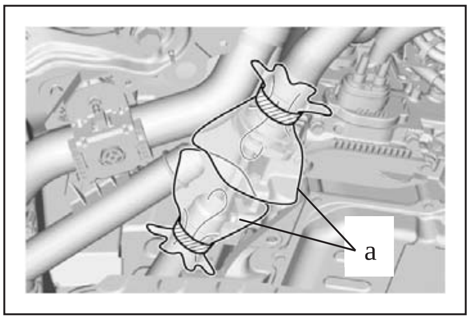
ii. Separate the No. 2 FC cooling water valve inlet hose (with FC water hose connector) from the FC stack cooling water outlet pipe, and drain the coolant (Toyota genuine FC stack coolant).



Notice:

- Disconnect the components slowly to prevent coolant (Toyota genuine FC stack coolant) from splattering.
- Perform the work by hand. Do not use tools.
- Do not rotate or tilt the No. 2 FC cooling water pump outlet hose (with FC water hose connector) when pulling it out.

iii. When working with the No. 2 FC cooling water valve inlet hose (with FC water hose connector) disconnected, to prevent foreign matter from entering, protect the connecting portions of the No. 2 FC cooling water valve inlet hose (with FC water hose connector) and FC stack cooling water outlet pipe with plastic bags.

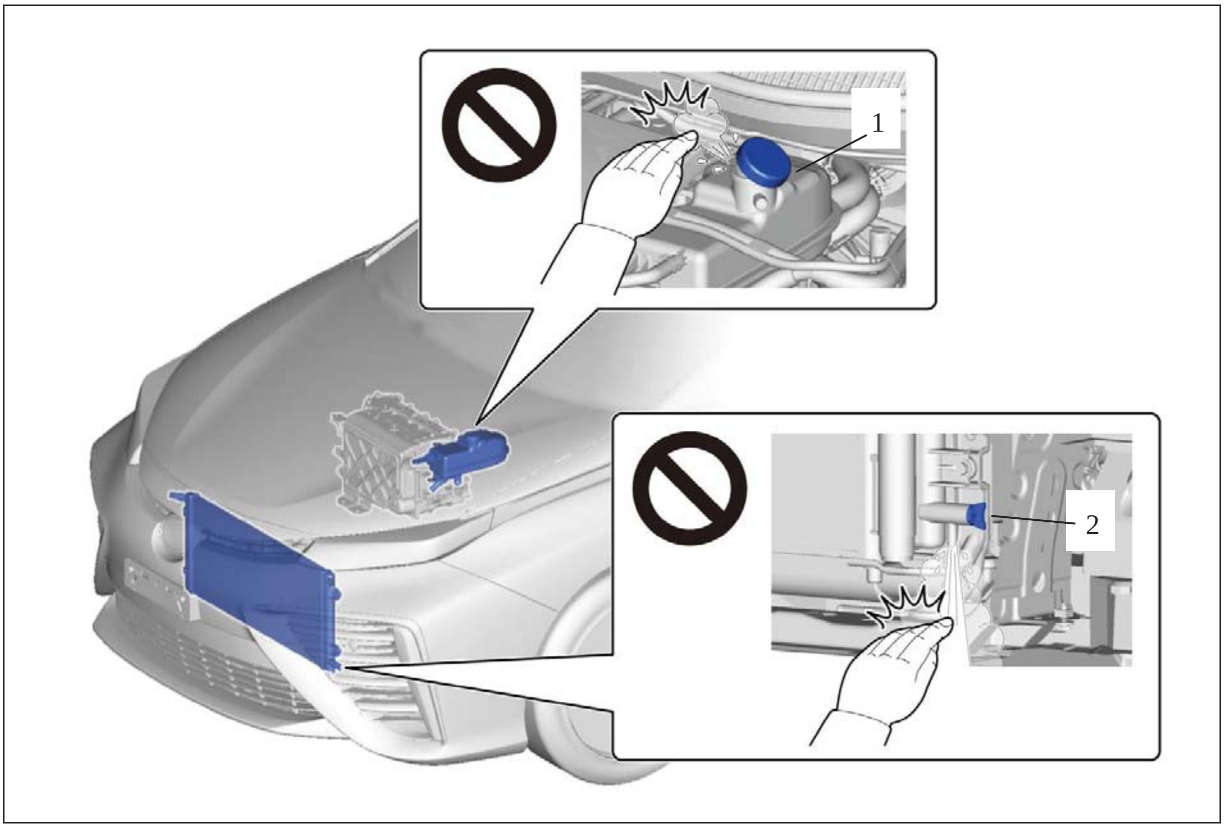


a	Plastic Bag

6. DRAIN INVERTER COOLANT

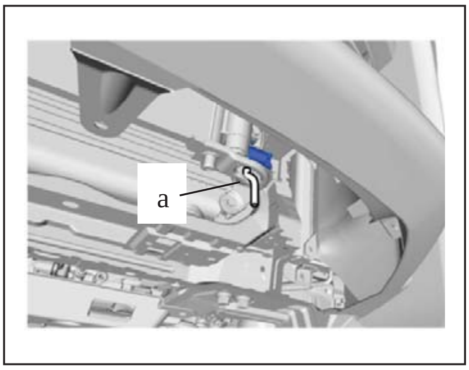
Caution:

- **When coolant (for inverter) is hot, do not remove the inverter reserve tank cap or the drain cock plug of the radiator assembly.**
- **Fluid and steam may spray out due to high pressure, possibly resulting in burns.**



1	Inverter Reserve Tank Cap	2	Radiator Assembly Drain Cock Plug

(1) Connect a hose with an inside diameter of 9 mm (0.354 in.) to the radiator assembly drain cock as shown in the illustration.

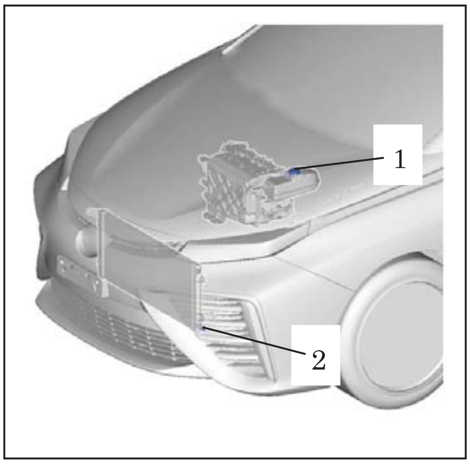


a	Hose

(2) Remove the inverter reserve tank cap.

(3) Loosen the radiator assembly drain cock plug, and drain the coolant (for inverter).

(4) Close the radiator assembly drain cock plug.



1	Inverter Reserve Tank Cap
2	Radiator Assembly Drain Cock Plug

7. DISCONNECT FC CONVERTER POWER OUTLET CABLE

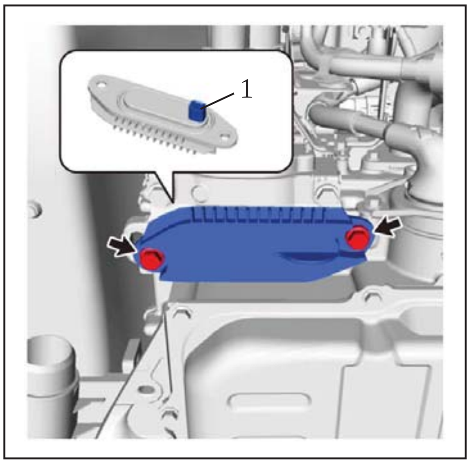
Caution:

Wear insulated gloves.

(1) Remove the 2 bolts and front FC converter service hole cover from the FC converter assembly.

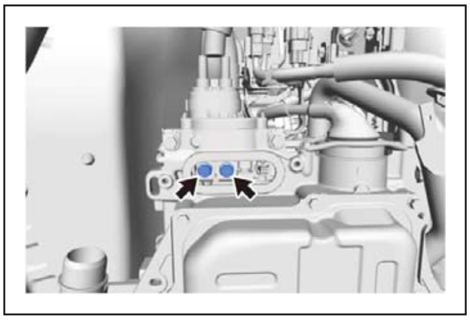
Notice:

- The front FC converter service hole cover has an interlock connector, so pull it down straight.
- Make sure not to drop the gasket of the front FC converter service hole cover.



1	Interlock Connector

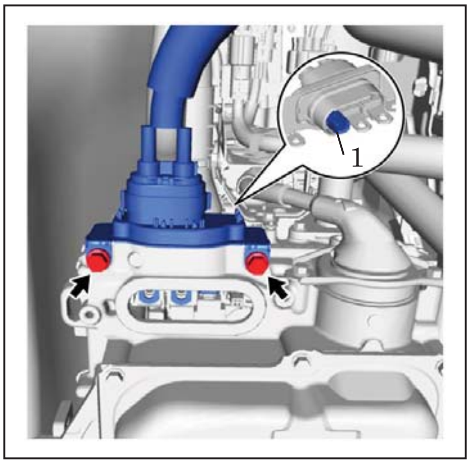
(2) Using an insulated tool, remove the 2 bolts.



(3) Using an insulated tool, remove the 2 bolts and disconnect FC converter power outlet cable from the FC converter assembly.

Notice:

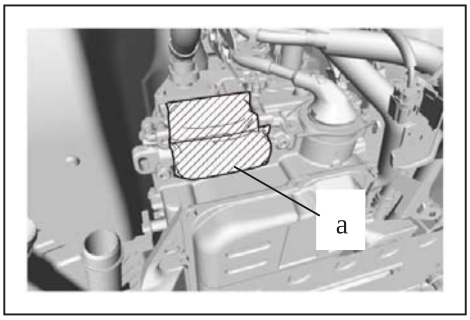
- The FC converter power outlet cable has an interlock connector, so pull it out straight.
- Do not touch the rubber seal or terminal portion of the FC converter power outlet cable.
- Do not apply any impacts to the terminal portion of the FC converter power outlet cable
.



1	Interlock Connector

- Do not scratch or damage the FC converter assembly with the terminal portion of the FC converter power outlet cable.
- Insulate the terminal portion of the FC converter power outlet cable by wrapping it with insulating tape.

(4) To prevent contamination by foreign matter or water droplets, cover the openings of the FC converter assembly with protective tape.



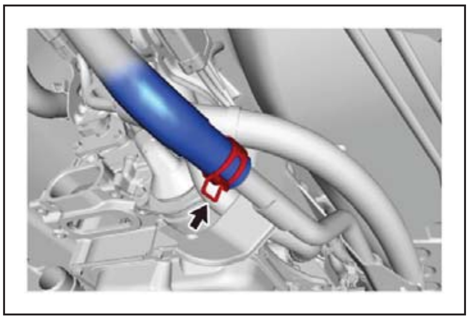
a	Protective Tape

8. DISCONNECT NO. 2 INVERTER COOLING OUTLET HOSE

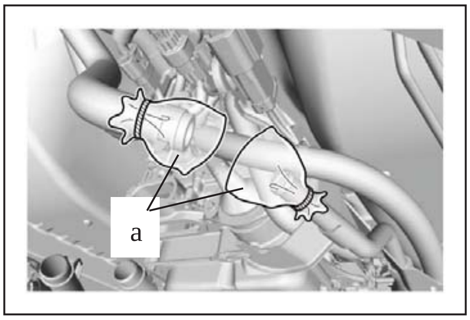
(1) Slide the hose clip and disconnect the No. 2 inverter cooling outlet hose from the FC converter cooling water inlet pipe.

Notice:

Disconnect slowly to prevent coolant (for inverter) from splattering.



(2) To prevent contamination by foreign matter, cover the connecting portions of the No. 2 inverter cooling outlet hose and FC converter cooling water inlet pipe with plastic bags.

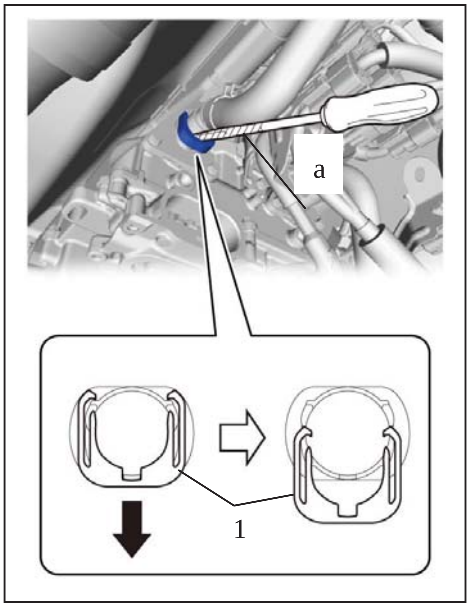


a	Plastic Bag

9. DISCONNECT NO. 2 EV WATER HOSE CONNECTOR

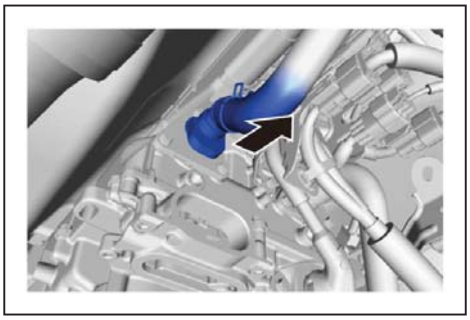
(1) Disconnect the No. 2 EV water hose connector.

i. Using a screwdriver with its tip wrapped in protective tape, press down the retainer of the No. 2 EV water hose connector to release the lock.



1	Retainer
a	Protective Tape

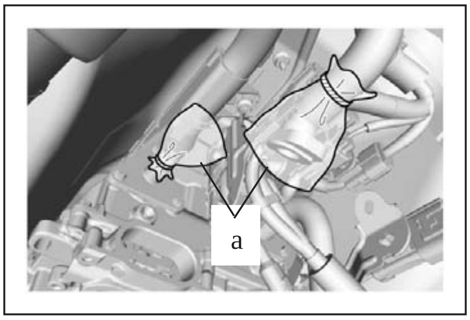
ii. Disconnect the No. 2 EV water hose connector, together with the FC converter cooling water outlet hose, from the FC converter assembly.



Notice:

- Perform the procedures by hand. Do not use any tools.
- Do not forcefully bend, fold, or twist the No. 2 EV water hose connector and FC converter cooling water outlet hose.
- Disconnect slowly to prevent coolant (for inverter) from splattering.

iii. To prevent contamination by foreign matter, cover the connecting portions of the No. 2 EV water hose connector and FC converter assembly with plastic bags.



a	Plastic Bag

10. SEPARATE WIRE HARNESS

Caution:

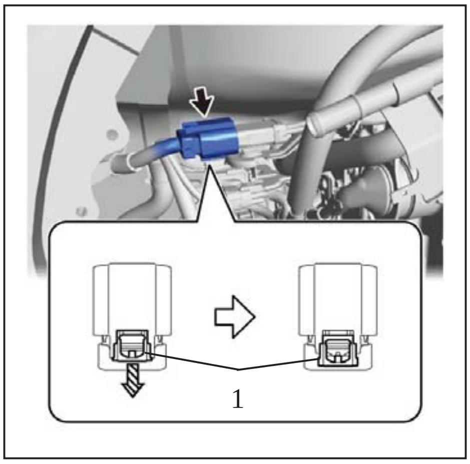
Wear insulated gloves.

(1) Pull out the green lock of the connector and disengage the connector as shown in the illustration.

Notice:

・Do not touch the connector terminals.

・Insulate the opening of the connector by wrapping it with insulating tape.

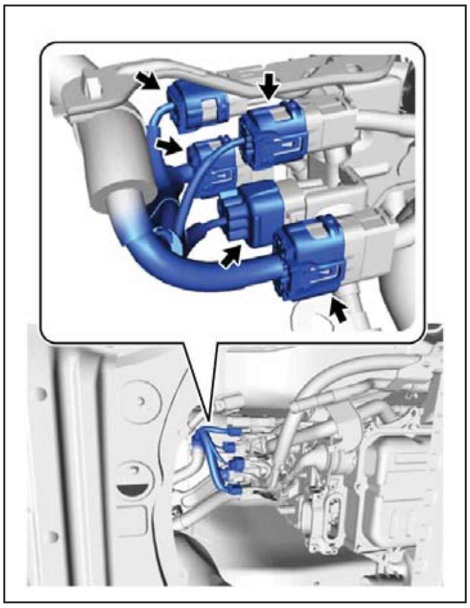


1	Green-colored Lock

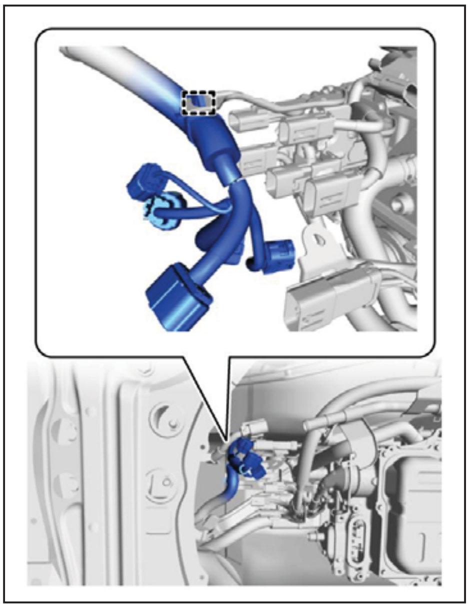
(2) Disconnect the 5 connectors.

Notice:

Do not touch the connector terminals.

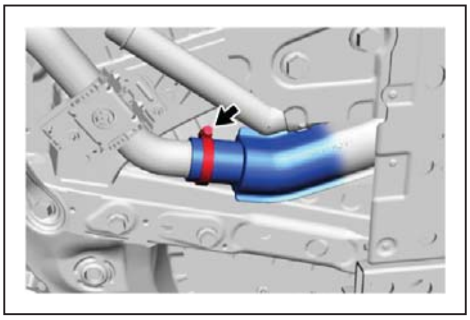


(3) Disengage the clamp to separate the wire harness from the wire harness clamp bracket.

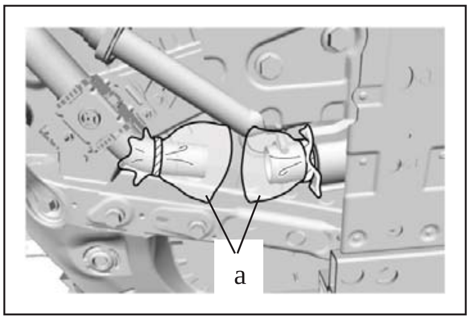


11. DISCONNECT FC STACK AIR INLET HOSE

(1) Loosen the hose clamp and disconnect the FC stack air inlet hose from the No. 2 FC air compressor outlet pipe.



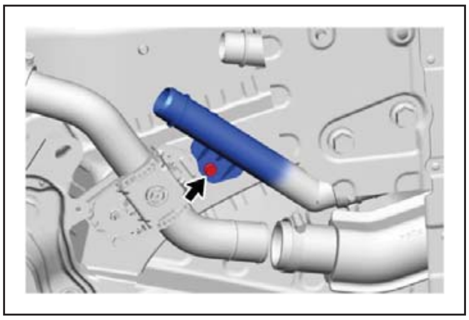
(2) To prevent contamination by foreign matter or water droplets, cover the connecting portions of the FC stack air inlet hose and No. 2 FC air compressor outlet pipe with plastic bags.



a	Plastic Bag

12. SEPARATE FC STACK COOLING WATER OUTLET PIPE

Remove the bolt and separate the FC stack cooling water outlet pipe from the vehicle.

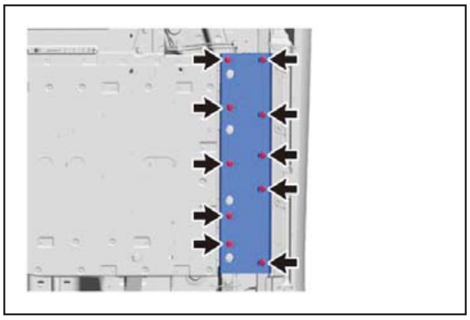


13. REMOVE FRAME REAR CROSSMEMBER EXTENSION LH

Remove the 10 bolts and frame rear crossmember extension LH from the vehicle.

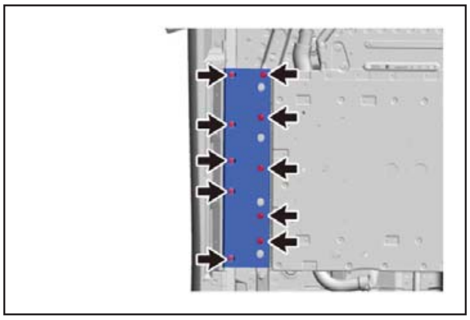
Notice:

Be careful of the brake tube when removing.



14. REMOVE FRAME REAR CROSSMEMBER EXTENSION RH

Remove the 10 bolts and frame rear crossmember extension RH from the vehicle.

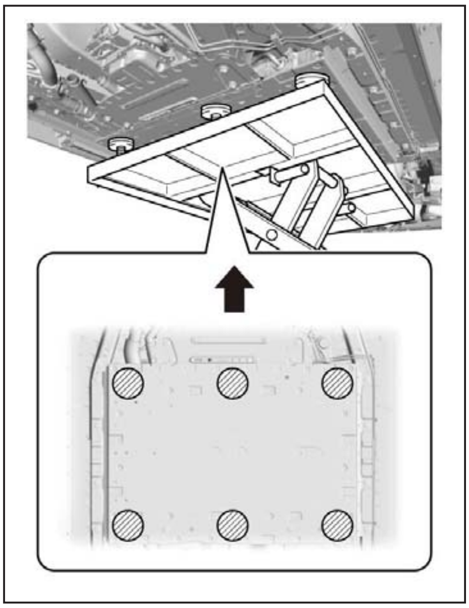


15. REMOVE REAR FRAME ASSEMBLY

(1) Using a height adjustment attachment, set the engine lifter, together with the FC stack with FC converter assembly, to the rear frame assembly.

Notice:

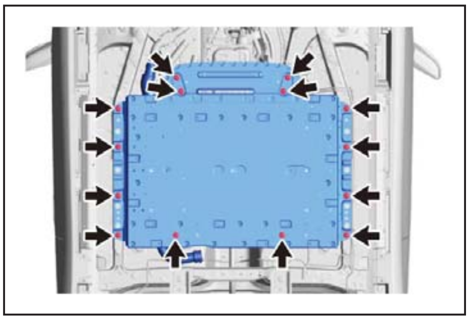
Set so that the rear frame assembly is horizontal and level.



(2) Remove the 14 bolts, and remove the rear frame assembly, together with the FC stack with FC converter assembly, from the vehicle.

Notice:

Be careful of the wire harnesses and hoses when removing.

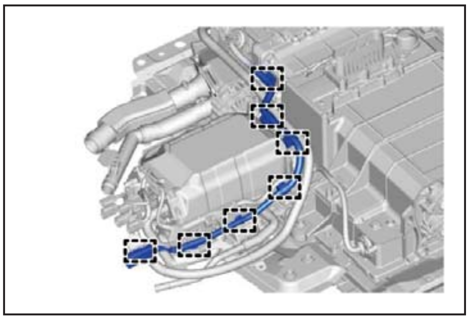


16. SEPARATE WIRE HARNESS

Caution:

Wear insulated gloves.

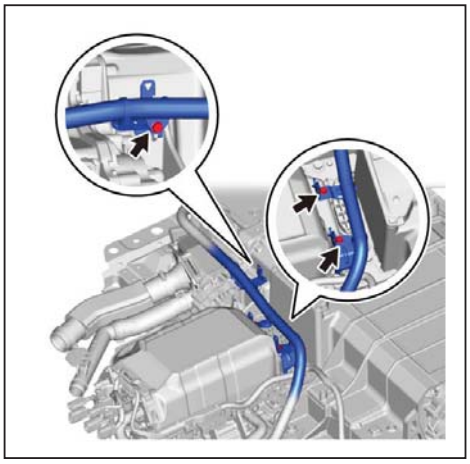
(1) Disengage the 7 clamps to separate the wire harness and connector from the FC converter assembly and FC stack assembly.



(2) Remove the 3 bolts to separate the 3 wire harness clamp brackets from the FC converter assembly and FC stack assembly.

Notice:

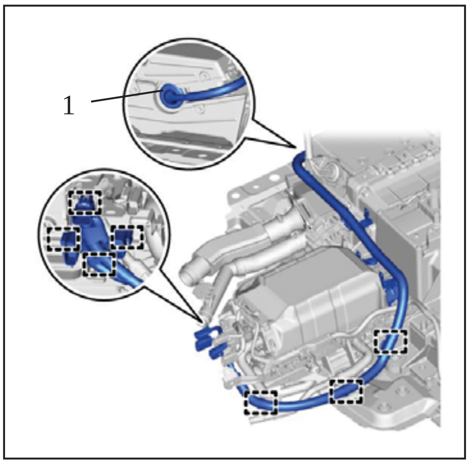
Do not disengage the clamp before removing the wire harness clamp bracket.



(3) Disengage the 7 clamps to separate the wire harness from the wire harness clamp bracket.

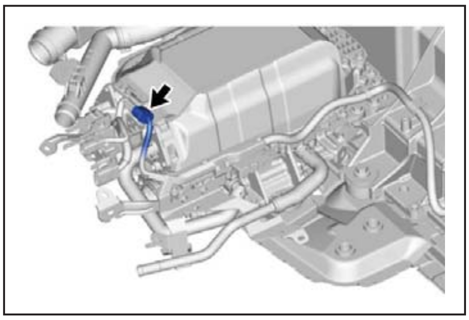
Notice:

Do not remove the grommet.

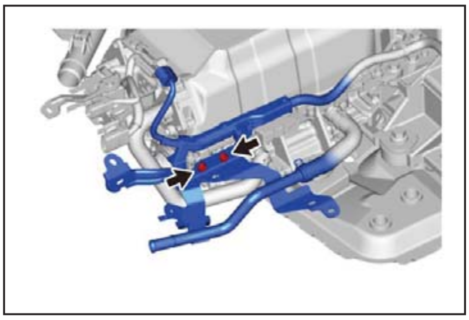


1	Grommet

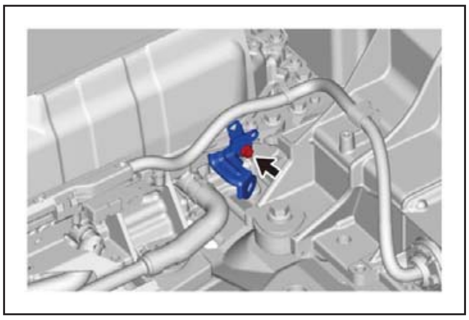
(4) Disconnect the connector.



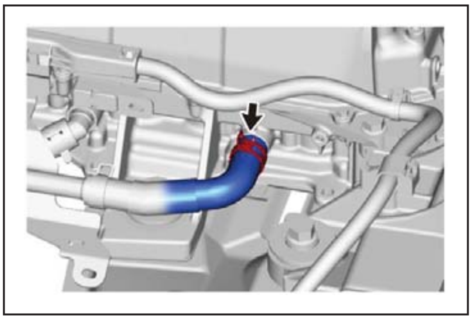
(5) Remove the 2 bolts to separate the FC converter cooling water inlet pipe, together with the wire harness, from the FC converter assembly.



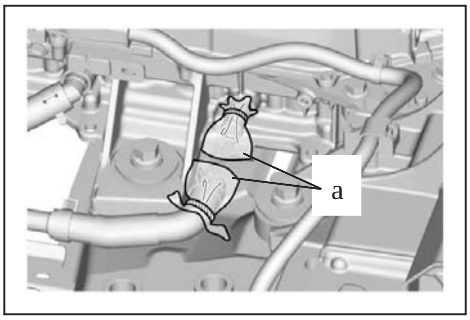
(6) Remove the bolt and wire harness clamp bracket from the FC converter assembly.



(7) Slide the hose clip and disconnect the FC converter cooling water inlet hose from the FC converter assembly.

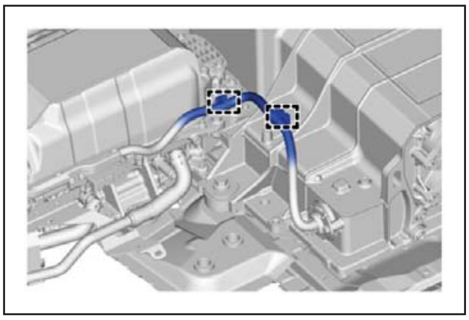


(8) To prevent contamination by foreign matter, cover the connecting portions of the FC converter cooling water inlet hose and FC converter assembly with plastic bags.



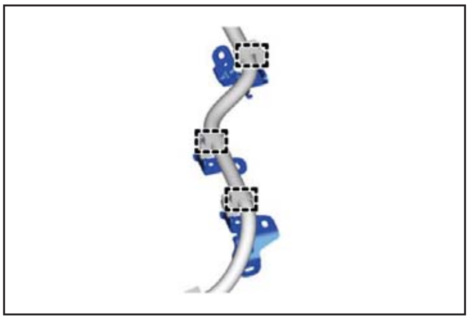
a	Plastic Bag

(9) Disengage the 2 clamps to separate the wire harness from the wire harness clamp bracket.

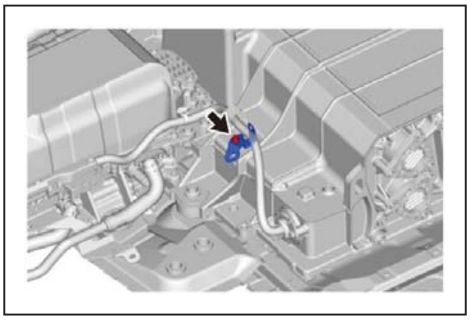


17. REMOVE WIRE HARNESS CLAMP BRACKET

(1) Disengage the 3 clamps to remove the 3 wire harness clamp brackets from the wire harness.

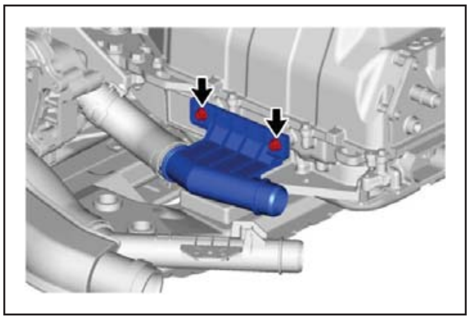


(2) Remove the bolt and wire harness clamp bracket from the FC stack assembly.



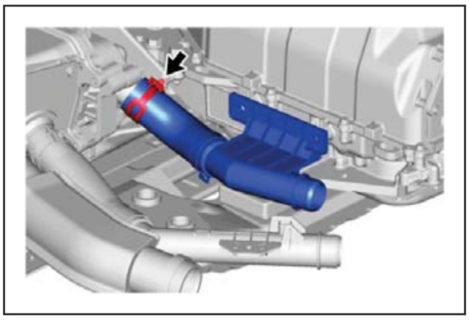
18. SEPARATE FC STACK COOLING WATER INLET PIPE

Remove the 2 bolts to separate the FC stack cooling water inlet pipe from the FC converter assembly.

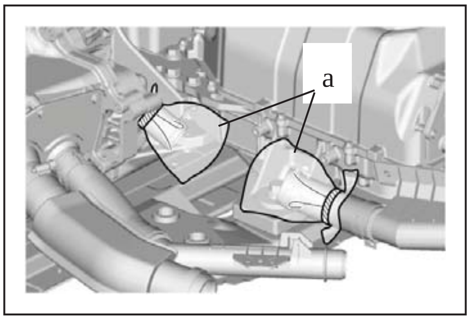


19. REMOVE FC STACK COOLING WATER INLET HOSE

(1) Slide the hose clip and remove the FC stack cooling water inlet hose from the FC stack assembly.



(2) To prevent contamination by foreign matter, cover the connecting portions of the FC stack cooling water inlet hose and FC stack assembly with plastic bags.



a	Plastic Bag

20. REMOVE FC CONVERTER ASSEMBLY

Caution:

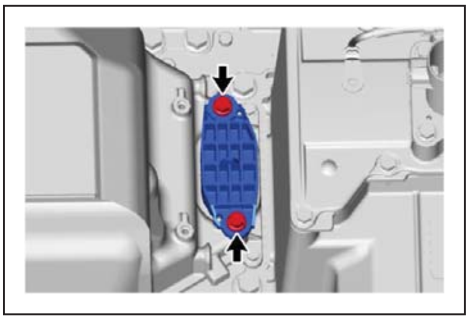
Wear insulated gloves.

(1) To prevent contamination by foreign matter or water droplets, check that the area around the rear FC converter service hole cover has no foreign matter or water droplets, and clean away any foreign matter or water droplets found.

Notice:

Do not allow foreign matter or water droplets to enter any other components.

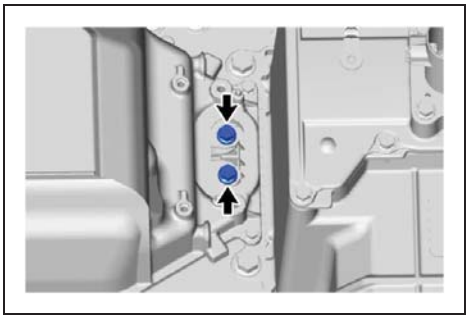
(2) Remove the 2 bolts and rear FC converter service hole cover from the FC converter assembly.



Notice:

Be careful that foreign matter or water droplets do not enter the FC converter assembly.

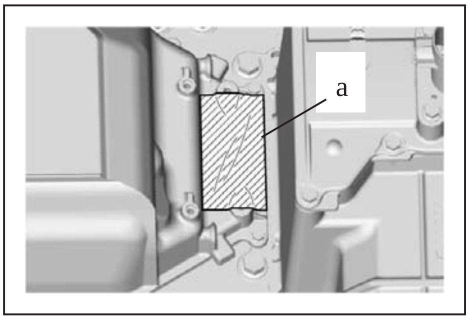
(3) Using an insulated tool, remove the 2 bolts.



Notice:

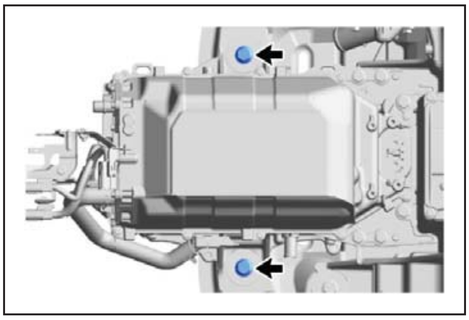
Be careful that foreign matter or water droplets do not enter the FC converter assembly.

(4) To prevent contamination by foreign matter or water droplets, cover the opening of the FC converter assembly with protective tape.

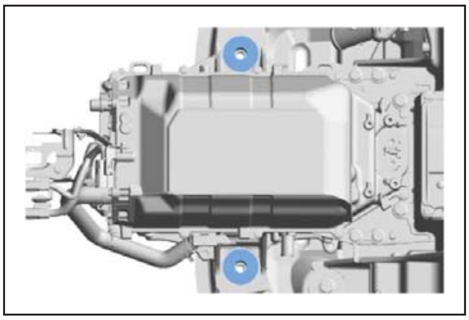


a	Protective Tape

(5) Remove the 2 bolts.



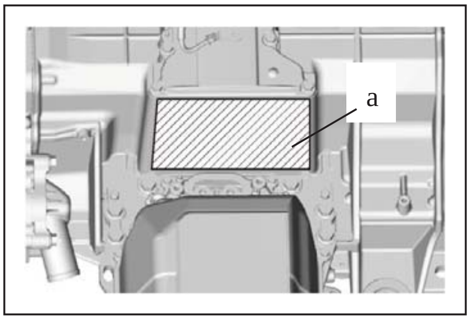
(6) Remove the 2 No. 2 FC stack mounts from the FC converter assembly.



(7) To avoid damaging the No. 1 FC stack caution label, protect the No. 1 FC stack caution label using protective tape or similar.

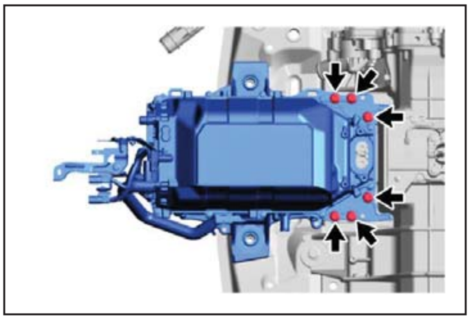
Hint:

This procedure is only performed when the FC stack assembly is not being replaced with a new one.



a	Protective Tape

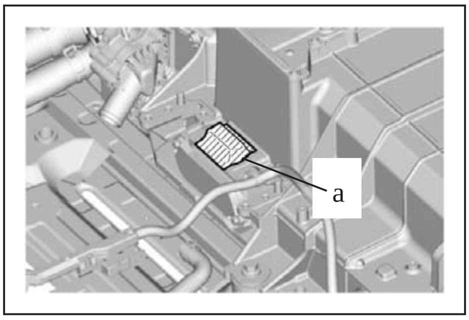
(8) Remove the 6 bolts and FC converter assembly from the FC stack assembly.



Notice:

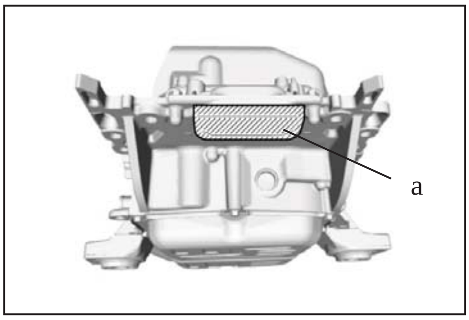
- Do not hold the FC converter assembly by its pipe portion.
- Be careful that foreign matter or water droplets do not enter the FC stack assembly and FC converter assembly.

(9) To prevent contamination by foreign matter or water droplets, cover the opening of the FC stack assembly with protective tape.



a	Protective Tape

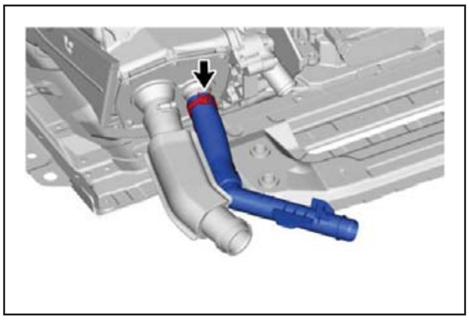
(10) To prevent contamination by foreign matter or water droplets, cover the opening of the FC converter assembly with protective tape.



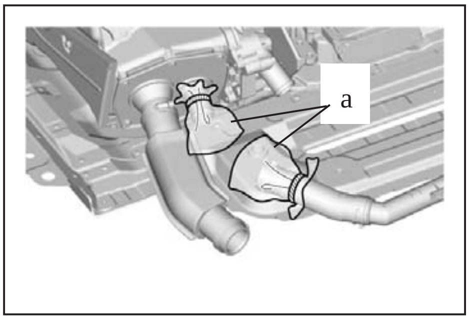
a	Protective Tape

21. REMOVE FC STACK COOLING WATER OUTLET HOSE

(1) Slide the hose clip and remove the FC stack cooling water outlet hose from the FC stack assembly.



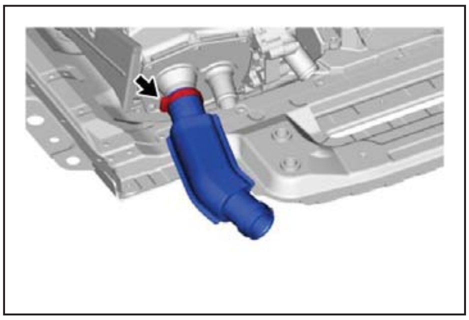
(2) To prevent contamination by foreign matter, cover the connecting portions of the FC stack cooling water outlet hose and FC stack assembly with plastic bags.



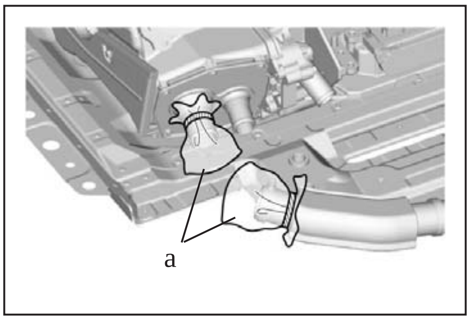
a	Plastic Bag

22. REMOVE FC STACK AIR INLET HOSE

(1) Loosen the hose clamp and remove the FC stack air inlet hose from the FC stack assembly.



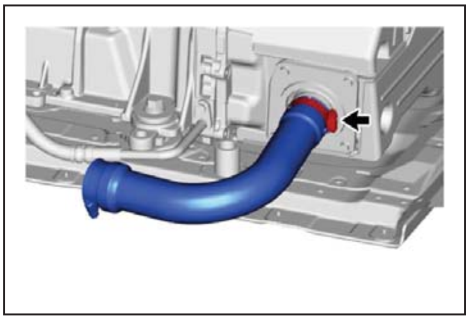
(2) To prevent contamination by foreign matter or water droplets, cover the connecting portions of the FC stack air inlet hose and FC stack assembly with plastic bags.



a	Plastic Bag

23. REMOVE NO. 1 FC EXHAUST PIPE

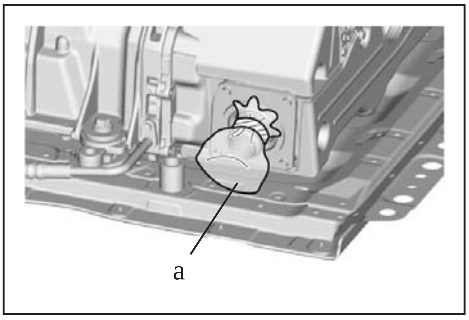
(1) Loosen the clamp and remove the No. 1 FC exhaust pipe from the FC stack assembly.



Caption:

- **If the water remaining inside the No. 1 FC exhaust pipe is hot, do not touch the water directly.**
- **Touching the water remaining inside the No. 1 FC exhaust pipe when it is hot could result in burns.**

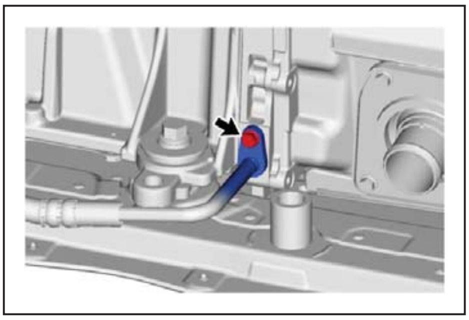
(2) To prevent contamination by foreign matter, cover the connecting portion of the FC stack assembly with a plastic bag.



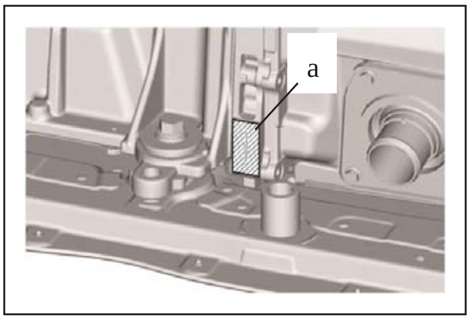
a	Plastic Bag

24. REMOVE NO. 1 HYDROGEN SUPPLY TUBE SUB-ASSEMBLY

(1) Remove the bolt and disconnect the No. 1 hydrogen supply tube sub-assembly from the FC stack assembly.

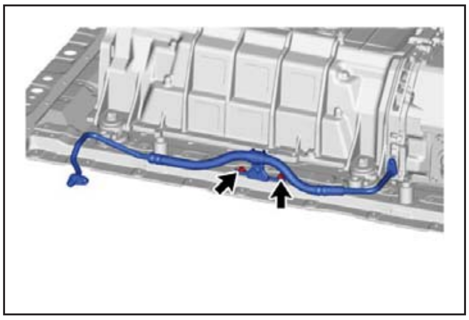


(2) To prevent contamination by foreign matter or water droplets, cover the connecting portion of the FC stack assembly with protective tape.



a	Protective Tape

(3) Remove the 2 bolts and No. 1 hydrogen supply tube sub-assembly from the rear frame assembly.

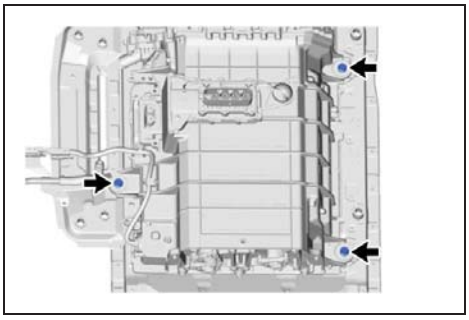


25. REMOVE FC STACK ASSEMBLY

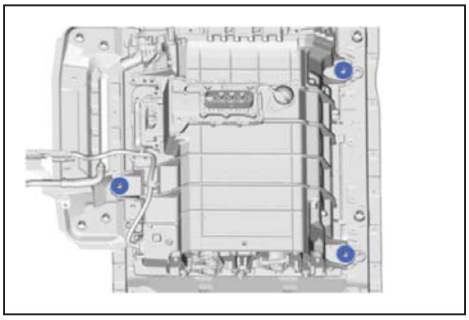
Caution:

Wear insulated gloves.

(1) Remove the 3 bolts.



(2) Remove the 3 No. 2 FC stack mounts from the FC stack assembly.

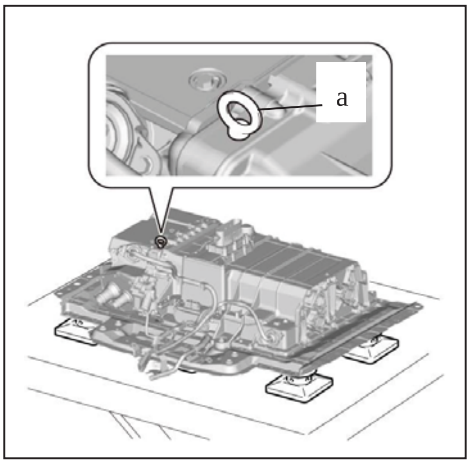


(3) Install an eye bolt in the location shown in the illustration.

Hint:

Eye Bolt Installation Hole Size

Nominal Diameter [mm]	Pitch [mm]	Depth [mm]
M10	1.5	18

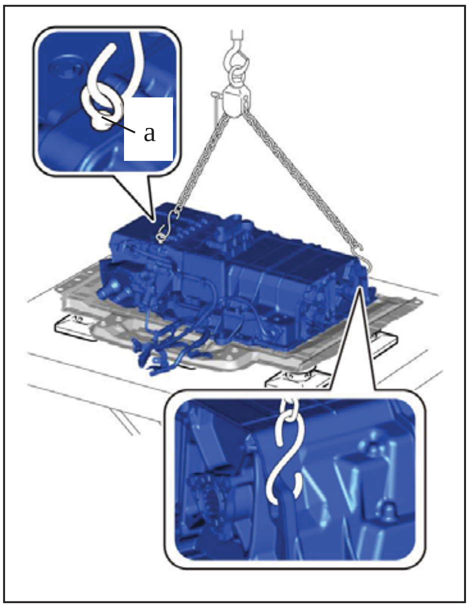


a	Eye Bolt

(4) Using an engine sling device, set it in the location shown in the illustration, and remove the FC stack assembly from the rear frame assembly.

Notice:

- Do not hoist the FC stack assembly from locations other than those shown in the illustration.
- Make sure that wire harnesses are not caught when hoisting.
- To avoid damaging or deforming the FC stack assembly, be careful of the hoisting angle of the engine sling device.
- Set the engine sling device so that the FC stack assembly is horizontal and level.



a	Eye Bolt

FUEL CELL SYSTEM SAFETY

Reference Material

Introduction to Fuel Cell Vehicles
January, 2018

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Fuel Cell (FC) System

- Fuel cell vehicles (FCV) use a motor for driving force in the same way as hybrid vehicles. In order to drive the motor, a high voltage (over 200 V, up to 650 V) is used. Not having an engine, the vehicle uses a motor driven by the power generated by a chemical reaction between the hydrogen fuel and oxygen in the air.
- Fuel cell vehicles (FCV) are equipped with dedicated high voltage components such as an FC stack, hydrogen pump, FC water pump, FC water pump and hydrogen pump inverter, FC boost converter and FC air compressor.
- To use hydrogen for power generation, fuel cell vehicles (FCV) are equipped with hydrogen pipes and hydrogen-related parts such as an FC stack, hydrogen tanks, etc.
- The hydrogen tanks are filled with high pressure hydrogen gas (a maximum of 70 MPa (714 kgf/ cm^2, 10,153 psi) at 15°C (59°F)).
- The hydrogen-related parts are inside cases/covers. Also, some of the insulation on high-pressure hydrogen pipes is in red.
- Hydrogen gas is colorless, odorless, and harmless.
- Hydrogen gas is flammable, and can ignite in a wide range of concentrations (4 to 74.5%). However, it diffuses easily and tends not to accumulate, so a small amount of leak would quickly dissipate to a concentration that cannot ignite.
- In the case of hydrogen leakage, the hydrogen detector equipped on the vehicle detects the hydrogen leak and shuts off the supply of hydrogen to prevent a mass leak. Also, hydrogen-related parts are located outside the cabin to allow leaked hydrogen to be easily diffused.
- If a collision is detected, the supply of hydrogen is shut off to prevent a mass leak due to vehicle damage.
- For details about the installation locations of hydrogen-related parts, refer to the QRS (Quick Reference Sheet) for the vehicle.

WARNING

- If the sound of hydrogen leaking (a loud hissing sound) can be heard when working on the vehicle, or if the hydrogen concentration around the vehicle exceeds 4% when measured with a hydrogen concentration detector, immediately step away from the vehicle as there is a chance that the hydrogen gas may ignite.
- Even after the vehicle is stopped (refer to P69), hydrogen remains inside the FC stack, hydrogen tanks and other hydrogen-related parts, as well as inside the hydrogen pipe. In order to avoid fires and explosions, never cut or damage these hydrogen-related parts or the hydrogen pipe.
- When the person(s) in charge of handling the damaged vehicle are away from the vehicle and someone else accidentally approaches or touches the vehicle, death or serious injury may occur due to electrocution, a rupture, an explosion or fire. To avoid this danger, display “HIGH VOLTAGE DO NOT TOUCH” and ”HIGH-PRESSURE GAS DO NOT TOUCH” signs to warn others (print and use page 25 and 36 of this guide).

CAUTION:
HIGH-PRESSURE GAS
DO NOT TOUCH.
Person in charge:

CAUTION:

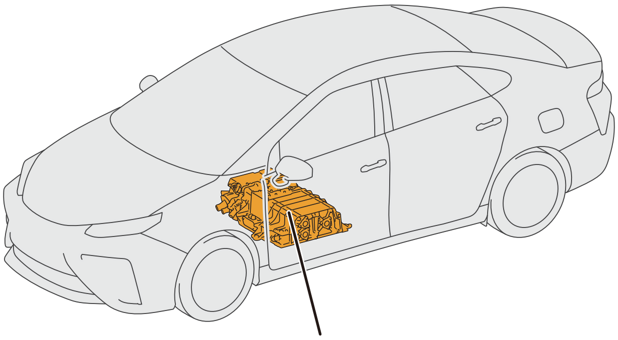
HIGH-PRESSURE GAS

DO NOT TOUCH.

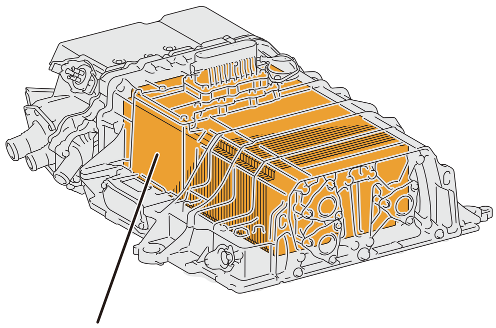
Person in charge: ____________________

FC Stack

- The FC stack is a device to generate electricity through the chemical reaction between hydrogen and oxygen. Using the hydrogen supplied by the hydrogen tank and oxygen in the air drawn in from outside the vehicle, a high voltage of 200 V or higher is generated.
- The FC stack is installed underneath the floor.
- The FC stack generates power using so called “cells”, which are comprised of an electrolyte membrane sandwiched by separators. A few hundred cells are connected in a row to generate a high voltage.
- The cells are contained inside a metal case so that they are not easily touched.
- Water is generated through the chemical reaction between hydrogen and oxygen during power generation, and discharged via the discharge outlet.

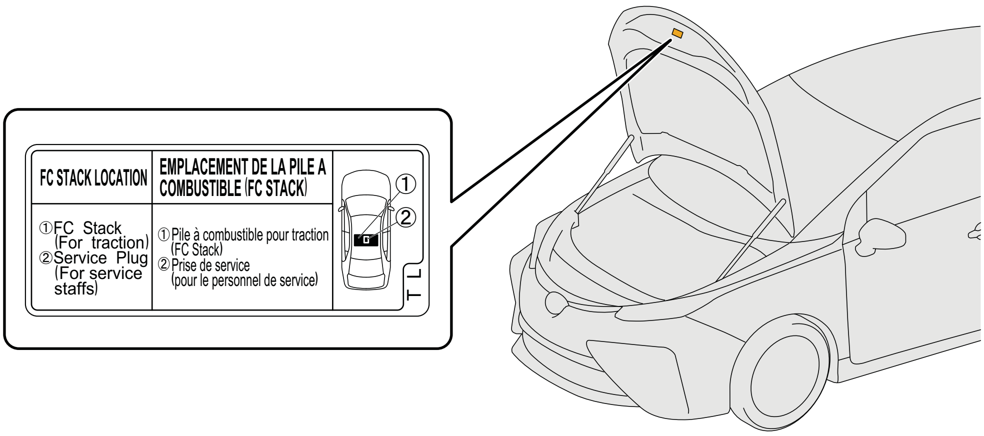


FC Stack



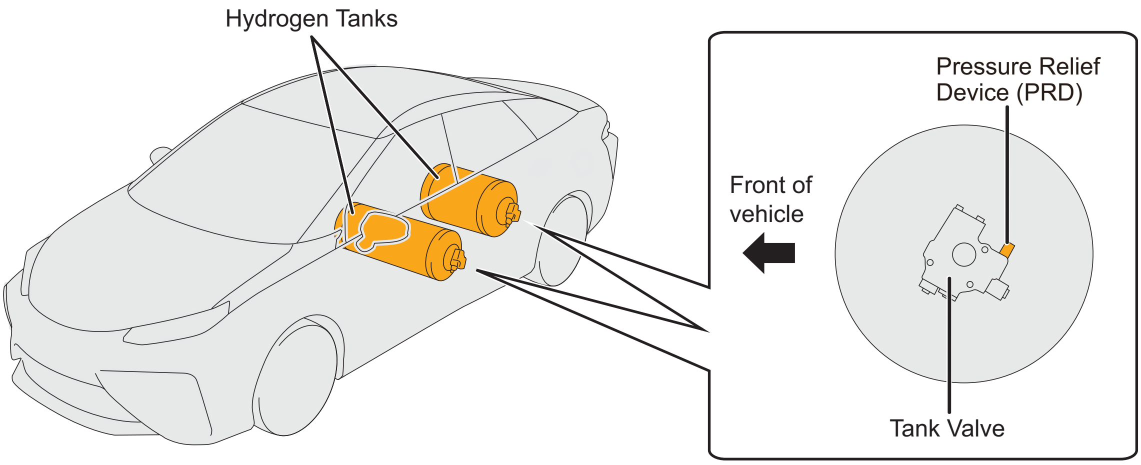
Cell

- An under-hood label shows the location of the FC stack.



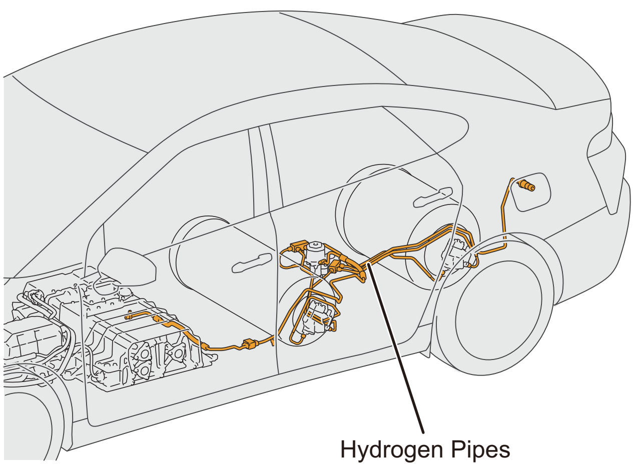
Hydrogen Tank

- The hydrogen tanks are filled with high pressure hydrogen gas (a maximum of 70 MPa (714 kgf/cm^2, 10,153 psi) at 15°C (59°F)) that is supplied to the FC stack.
- The hydrogen tanks are made of carbon fiber-reinforced plastic and located underneath the floor.
- The hydrogen detector used to detect hydrogen leaks is located near the tanks. If a specified concentration of hydrogen leakage is detected, the FC system cuts off the supply of hydrogen.
- Each tank is equipped with a pressure relief device (PRD) in order to prevent an explosion when the temperature of the hydrogen reaches abnormal levels due to a vehicle fire. The pressure relief device will open at approximately 110°C (230°F) to release the hydrogen gas in the tank outside of the vehicle.



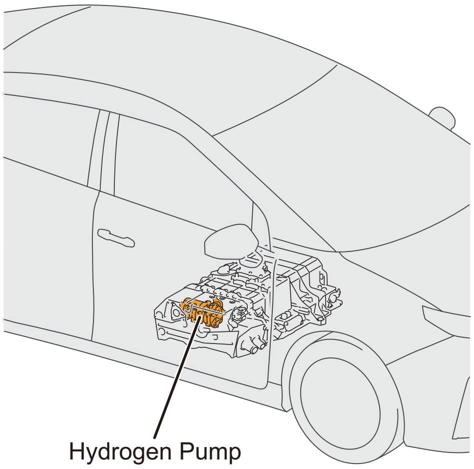
Hydrogen Pipes

- The hydrogen pipes connect the hydrogen-related parts such as the FC stack and hydrogen tanks.
- The hydrogen pipes are located underneath the floor.
- Some of the high-pressure hydrogen pipes are identified in red.



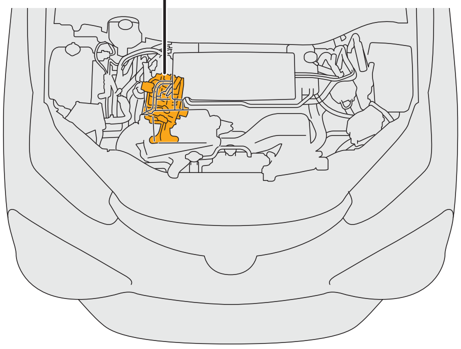
Hydrogen Pump

- The hydrogen pump circulates the hydrogen supplied from the hydrogen tanks into the FC stack.
- The hydrogen pump has a built-in motor that is operated using the high voltage from the FC water pump and hydrogen pump inverter. The hydrogen pump is installed underneath a cover at the side of the FC stack.



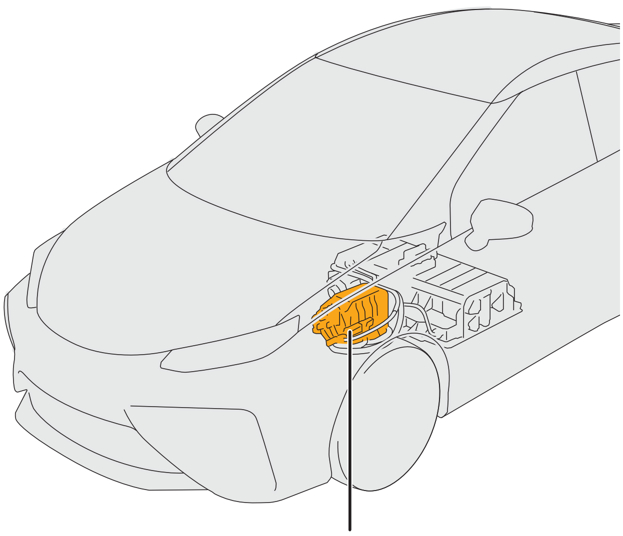
FC Water Pump and Hydrogen Pump Inverter

- The FC water pump and hydrogen pump inverter converts DC from the high voltage battery to AC, and supplies this current to the hydrogen pump and FC water pump.
- The FC water pump and hydrogen pump inverter is installed in the motor compartment.



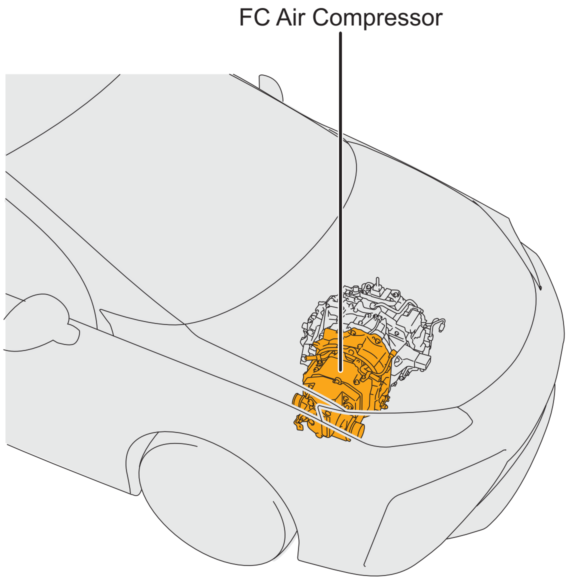
FC Boost Converter

- The FC boost converter increases the voltage of DC generated by the FC stack to a maximum of 650 V for motor operation, and then supplies this current to the inverter/converter.
- The FC boost converter is installed in the center tunnel (outside the cabin).



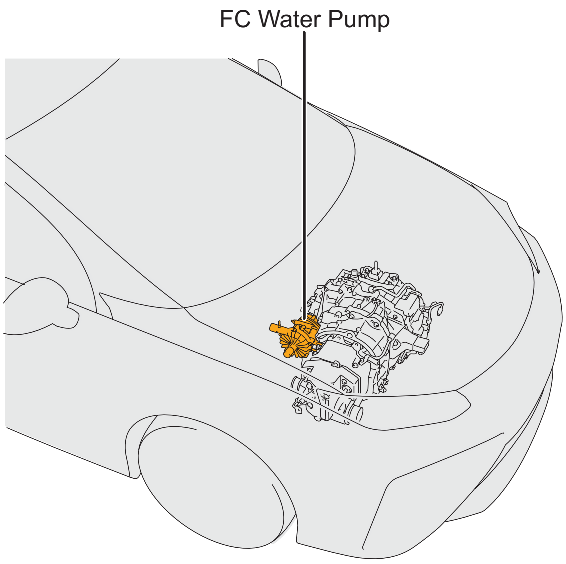
FC Air Compressor

- The FC air compressor supplies air (oxygen) to the FC stack.
- The FC air compressor has a built-in motor which is driven using the output voltage from the inverter/converter (up to 650 V), and is installed in the motor compartment.



FC Water Pump

- The FC water pump circulates the coolant to cool the FC stack.
- The FC water pump has a built-in motor which is driven using the high voltage from the FC water pump and hydrogen pump inverter, and is installed in the motor compartment.



HIGH-VOLTAGE SYSTEM SAFETY

Reference Material

Introduction to Fuel Cell Vehicles
January, 2018

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WARNING

- The high voltage system may remain charged for up to 10 minutes after the vehicle is shut off and disabled (see page 69). Failure to shut off and disable the vehicle before emergency response procedures are performed may result in serious injury or death from severe burns and electric shock from the high voltage electrical system.
- To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or breaching any orange high voltage power cable or high voltage component. Wear appropriate protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components.
- When the person(s) in charge of handling the damaged vehicle is away from the vehicle, other person(s) may accidentally touch the vehicle and be electrocuted, resulting in severe injury or death. To avoid this danger, display a “HIGH VOLTAGE DO NOT TOUCH” sign to warn others (print and use page 25 of this guide).

Person in charge:

CAUTION:

HIGH-VOLTAGE

DO NOT TOUCH.

CAUTION:

HIGH-VOLTAGE

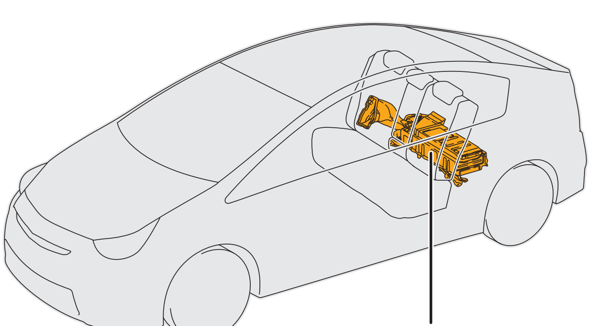
DO NOT TOUCH.

Person in charge:

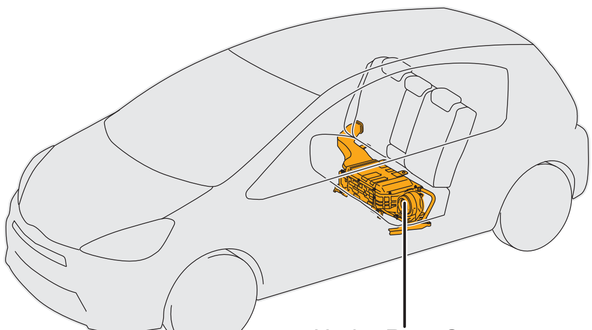
When performing work on the HV system, fold this sign and put it on the roof of the vehicle.

High Voltage Battery

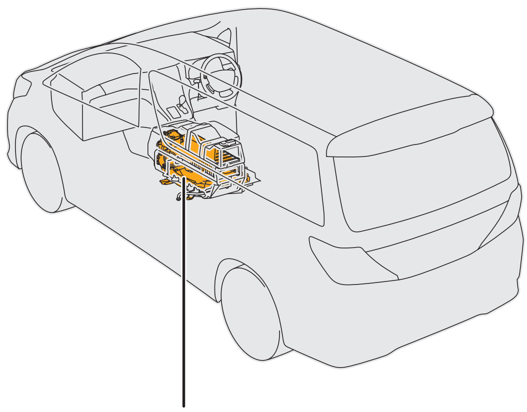
■ The high voltage battery for the motor stores high voltage electricity (144 to 310.8 V). Depending on the model the battery is installed in the luggage compartment, under the rear seats, under the center console or under the floor.



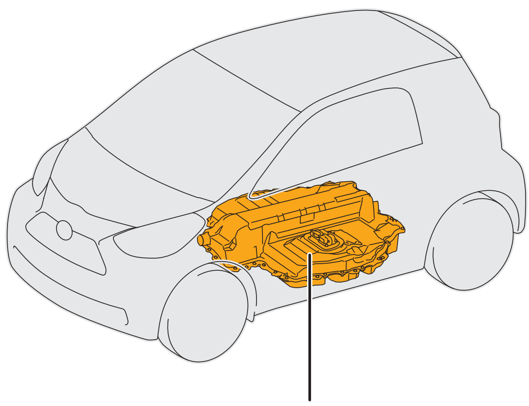
Luggage Compartment



Under Rear Seat

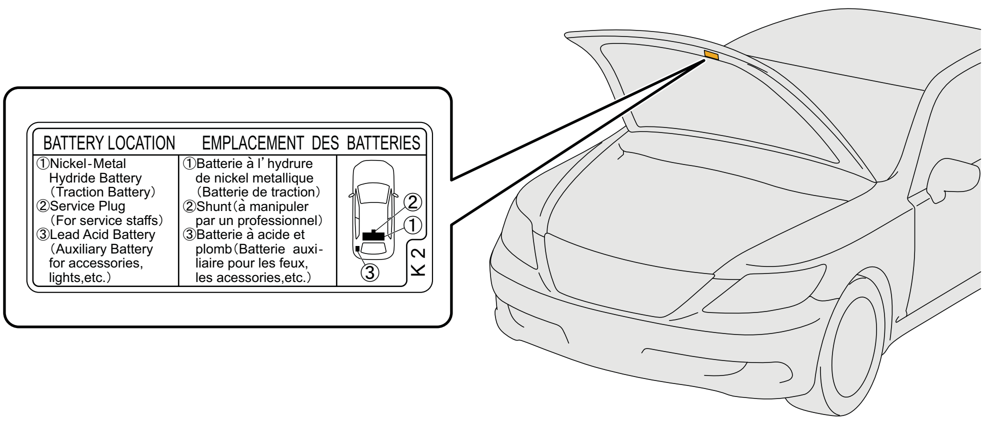


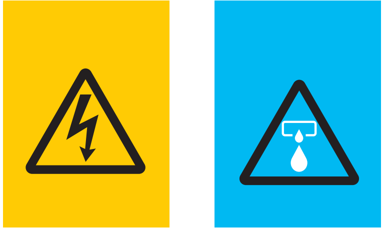
Under Center Console



Undercarriage

■ An under-hood label shows the location of the high voltage battery.

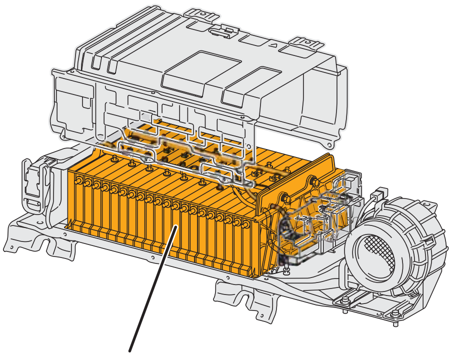


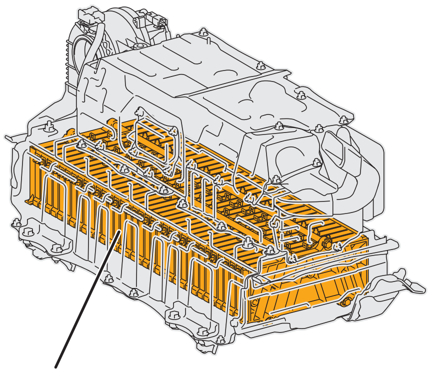


■ A Nickel-metal hydride (Ni-MH) battery or lithium ion (Li-ion) battery is used as the high voltage battery.

1. Nickel-metal hydride (Ni-MH) battery

- Ni-MH batteries consist of 20 to 40 modules, each consisting of six 1.2 V cells, connected in series to obtain high voltage (144 to 288 V).
- The battery modules are contained within a metal case and accessibility is limited.
- A catastrophic crash that would breach both the metal battery pack case and a metal battery module would be a rare occurrence.
- The Ni-MH battery contains a strong alkaline electrolyte (pH 13.5). The electrolyte, however, is absorbed in the cell plates and will not normally spill or leak out even if a battery module is cracked.
- Electrolyte leakage from the HV battery pack is unlikely due to its construction and the amount of available electrolyte contained within the Ni-MH modules. Any spillage would not warrant a declaration as a hazardous material incident.



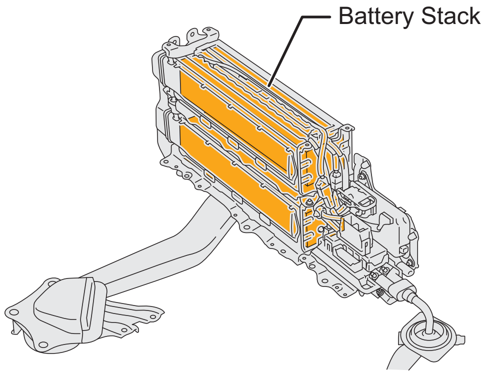


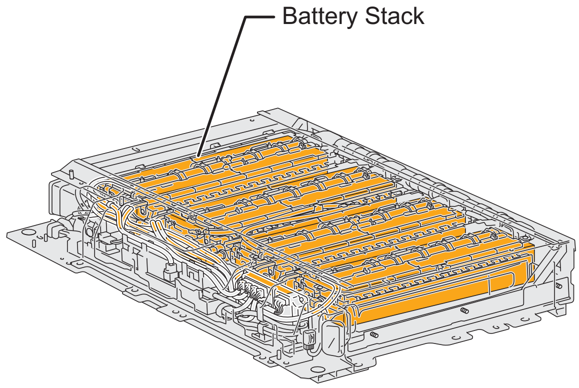
WARNING

■ Strong alkaline electrolyte (pH 13.5) is harmful to the human body. To avoid injury by coming in contact with the electrolyte, wear appropriate protective equipment such as rubber gloves and safety goggles when there is a risk of touching electrolyte.

2. Lithium ion (Li-ion) battery

- Li-ion batteries consist of multiple stacks, each stack consisting of 14 to 42 cells. Two to four battery stacks are connected in series to obtain high voltage (201.6 to 310.8 V).
- The battery cells are contained within a case and accessibility is limited.
- A catastrophic crash that would breach both the metal battery stack case or battery frame and a metal battery cells would be a rare occurrence.
- The Li-ion battery electrolyte, mainly consisted of carbonate ester, is a flammable organic electrolyte. The electrolyte is absorbed into the battery cell separators, even if the battery cells are crushed or cracked, it is unlikely that liquid electrolyte will leak.
- Any liquid electrolyte that leaks from a Li-ion battery cell quickly evaporates.



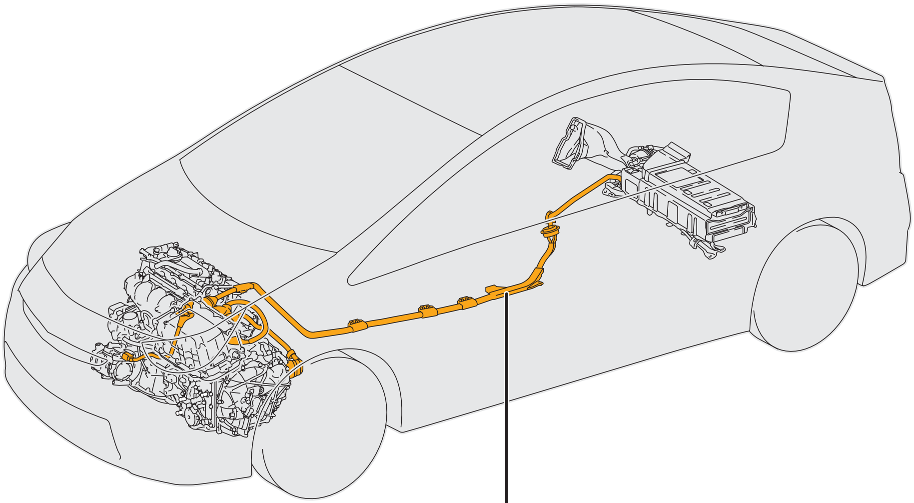


WARNING

- The flammable organic electrolyte which primarily contains carbonate ester is harmful to the human body. In case of contact with the electrolyte, it may irritate the eyes, nose, throat and skin. In case of contact with the smoke or vapor from leaked electrolyte or a burning battery, it may irritate the eyes, nose or throat. To avoid injury by coming in contact with the electrolyte or vapor, wear appropriate protective equipment such as rubber gloves, safety goggles, protective mask or SCBA when there is a risk of touching electrolyte.
- If the electrolyte spills, keep it away from fire and ensure the area is well ventilated. Absorb the electrolyte with a waste cloth or equivalent absorbing material and keep it in an airtight container until disposed of.

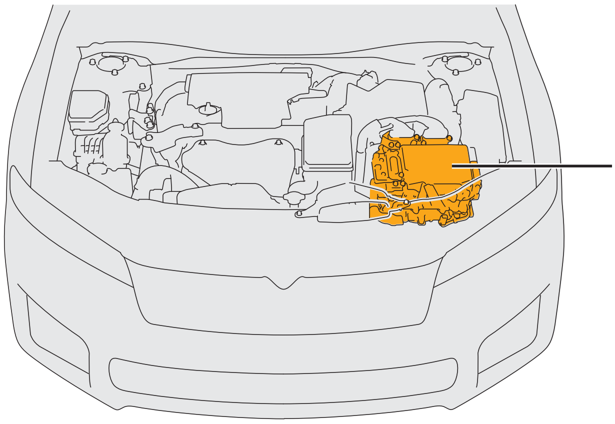
High Voltage Power Cable

- High voltage power cables are indicated by an orange color and are used to connect high voltage electrical components such as the high voltage battery inverter/converter, electric motor, A/C compressor and charger.
- The high voltage power cables are installed in the engine/motor compartment and in the center of the vehicle (routed through the center tunnel) or on either side away from the rocker panels.
- Also, high voltage cables are used in the plug-in charging system (refer to P32).



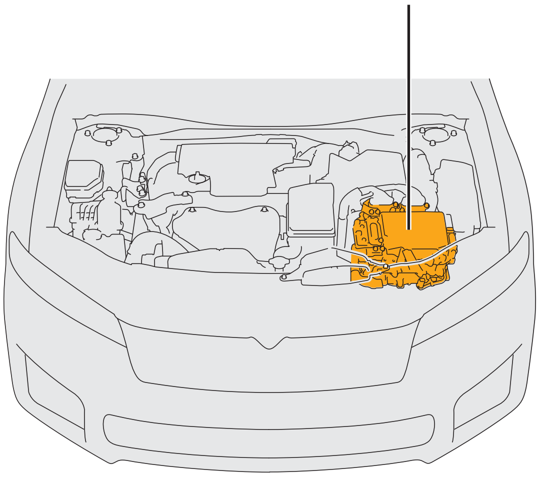
Inverter/Converter

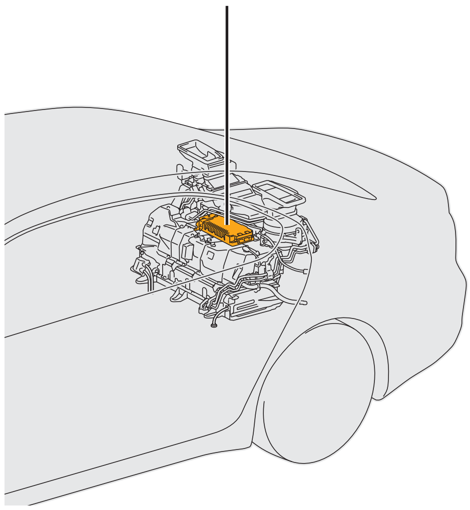
- The inverter/converter installed in the engine/motor compartment boosts and inverts the DC electricity from the high voltage battery to AC electricity that drives the electric motor.
- The inverter/converter of fuel cell vehicles (FCV) also supplies an electric current converted to AC to the FC air compressor.



DC/DC Converter

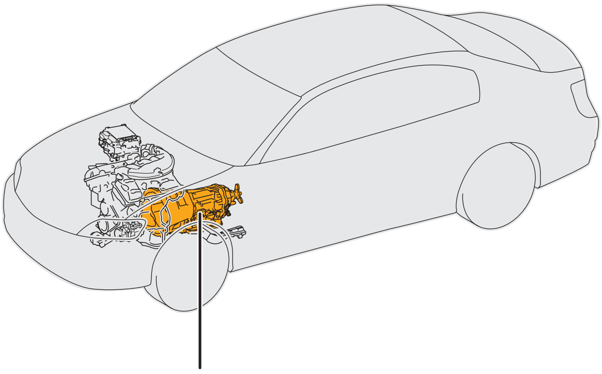
- The DC/DC converter lowers the DC electricity from the high voltage battery to supply it to electric accessories such as the headlights and power windows, and to charge the 12 V battery.
- The DC/DC converter is built into the inverter/converter or installed in the area near the high voltage battery on some models.

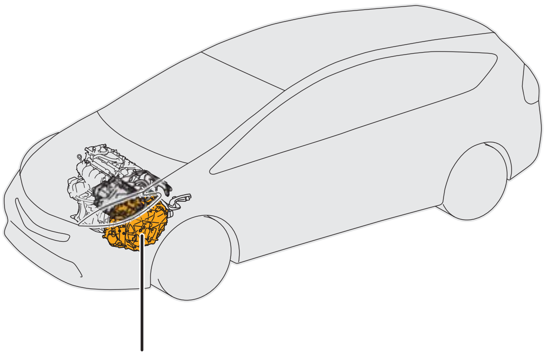




HV/EV/FCV Transmission
HV/EV/FCV Transaxle

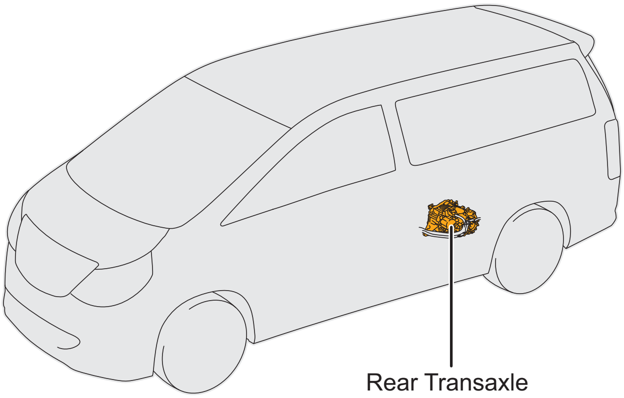
- The HV/EV/FCV transmission/transaxle contains an electric motor/generator that is powered by output voltage (up to 650 V) from the inverter/converter, and charges the high voltage battery.
- The HV/EV/FCV transmission/transaxle is installed in the engine compartment or motor compartment. Location varies depending on layout.





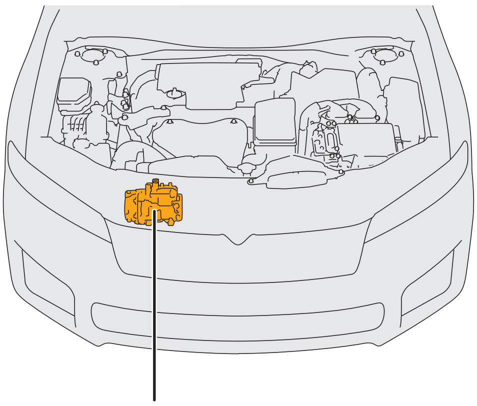
Rear Drive Motor

- The rear drive motor is powered by output voltage (up to 650 V) from the inverter/converter.
- It is built into the rear transaxle and located above the rear driveshafts.



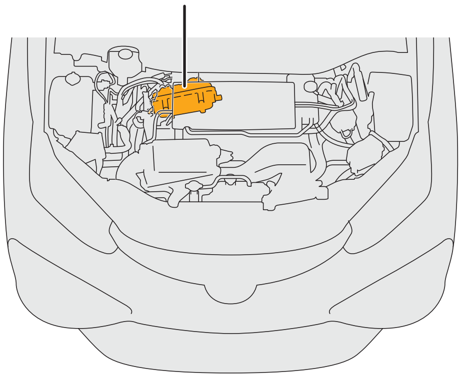
A/C Compressor

- The A/C compressor used on hybrid vehicles (HV), electric vehicles (EV) and fuel cell vehicles (FCV) contains an electric motor that is powered by electricity from the high voltage battery. It is installed in the engine/motor compartment.



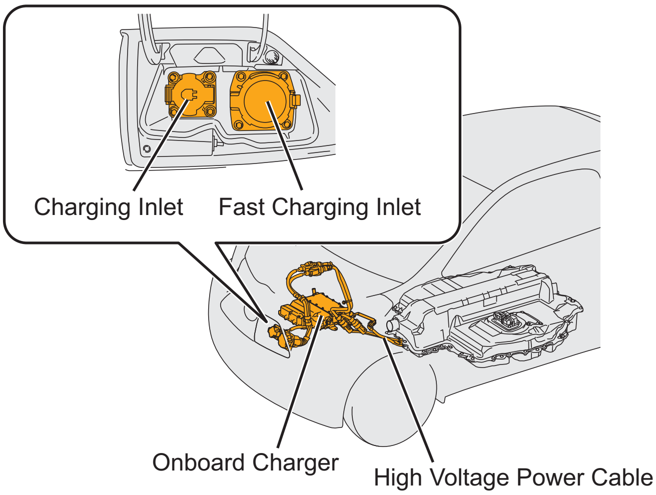
Coolant Heater

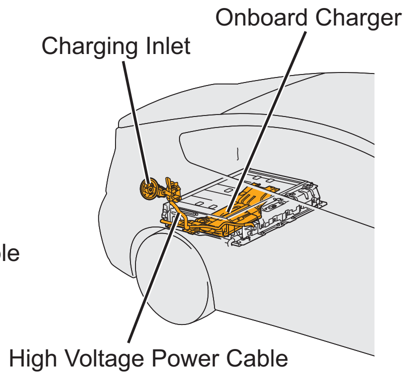
- Fuel cell vehicles (FCV) is equipped with a coolant heater to heat the coolant, installed inside the motor compartment.
- The coolant heater is operated using the power from the high voltage battery.

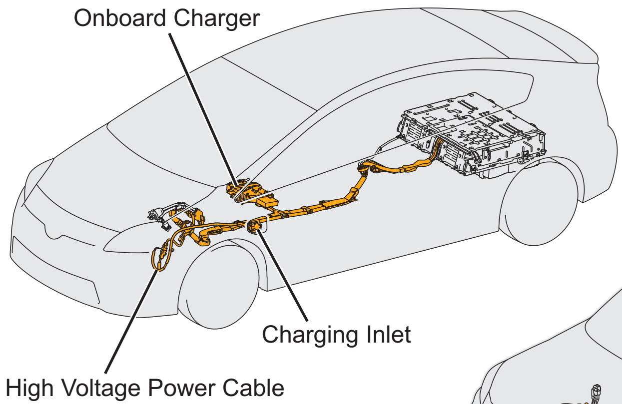


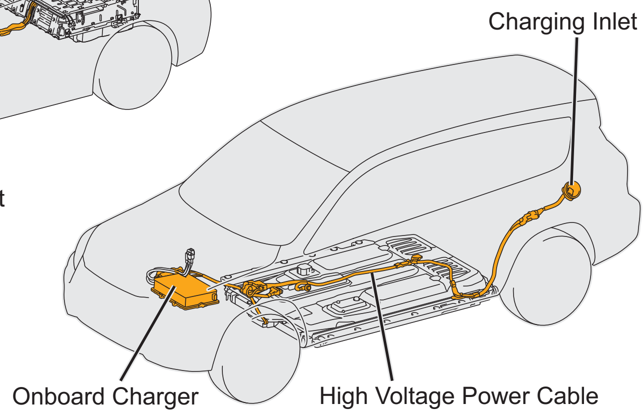
Plug-in Charging System

- Plug-in hybrid vehicles (PHV) and electric vehicles (EV) are equipped with a plug-in charging system in order to charge the high voltage battery from an external power source.
- The plug-in charging system is mainly comprised of an onboard charger and charging inlet.
- The onboard charger converts the AC supplied from an external power source to DC, boosts it, and then uses it to charge the high voltage battery.
- The charger inlet receives the charge to the high voltage battery from an external power source. Also, some electric vehicles have a separate fast charging inlet which can be used at fast chargers (DC 500 V).
- The orange power cables are connected to the charging inlet, which is supplied high voltage during charging.







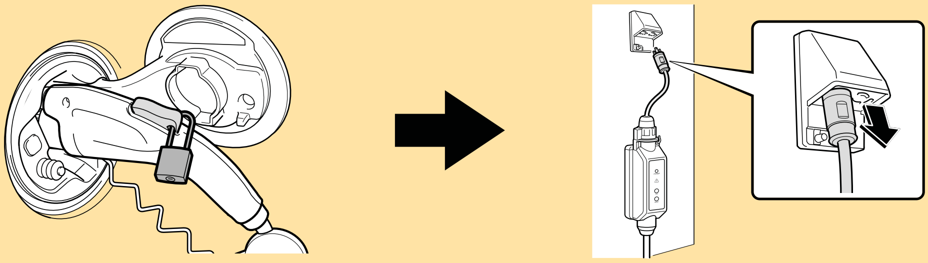


WARNING

■ To prevent serious injury or death from severe burns or electric shock, shut off the utility circuit supplying power to the charge cable before disconnecting it if the vehicle, charge cable or charger is submerged in water.

NOTICE

■ If the lock of the charge cable assembly connector cannot be released, turn OFF or unplug the external charger, or turn its main breaker OFF.



■ The lock of the charge cable assembly connector cannot be released during fast charging. If charging does not stop even when the charger is turned OFF, turn its main breaker OFF.

HYDROGEN & HIGH-VOLTAGE SAFETY

Reference Material

Introduction to Fuel Cell Vehicles
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

Hydrogen Safety

About Hydrogen

Hydrogen can be produced using a number of primary energy sources other than petroleum, such as natural gas or ethanol. Also, solar power or wind power can be used to produce hydrogen from water.

Characteristics of Hydrogen

Compared to gasoline, hydrogen has disadvantages such as "easy leakage due to small molecular size", "odorless and colorless and thus difficult to detect", and "highly flammable at a wide range of concentrations". However, it also has advantages such as "easily dispersed due to low specific gravity", "does not easily auto ignite due to high ignition temperature", and due to the wide detonation concentration range, "does not easily explode" unless confined in an enclosed space together with oxygen.

Item	Hydrogen	Natural Gas	Gasoline	Hydrogen Characteristics
Molecular Weight	2	16	106	Leaks easily
Coloring / Odor	None	Colorless / Odorant can be added	Yes	Difficult to detect leaks
Flammability Concentration Range	4.0 - 74.5%	5.3 - 15.0%	1.0 - 7.6%	Burns readily
Detonation Concentration Range	18.3 - 59%	6.3 - 13.5%	1.1 - 3.3%	Does not readily explode
Specific Gravity (air= 1)	0.07	0.55	3.4 - 4.0	Easily dispersed
Ignition Temperature	527(°C)	540(°C)	228(°C)	Difficult to ignite

Hydrogen Safety (Continued)

Basic Safety Concepts for Hydrogen System Components

Prevent Leaks	Difficult-to-leak Design	The connection portions of hydrogen fuel piping have been designed with a strong focus on leak prevention.
	Selection of Materials	Appropriate materials have been selected with regard to hydrogen embrittlement
Detect and Stop	Equip with Hydrogen Detector	In the unlikely event that a hydrogen leak occurs, the hydrogen detector detects the leaked hydrogen and the hydrogen tank valve operates to prevent a large leak of hydrogen fuel.
	Equip with Collision Sensor	If the vehicle receives an impact that is judged to be a collision, the hydrogen tank valve operates to prevent a large leak of hydrogen fuel.
Prevent Accumulation of Leaked Hydrogen		In the unlikely event that hydrogen fuel leaks out, the vehicle is designed to prevent the leaked hydrogen from remaining inside.
Keep Ignition Sources Away		The vehicle is designed so that potential ignition sources are not located near the hydrogen system.

Caution

Fuel cell vehicles use high pressure hydrogen fuel at 70 MPa, and improper handling can cause hydrogen leakage possibly resulting in vehicle fires or explosions.

High Voltage Safety

The EV battery powers the high voltage electrical system with DC electricity. The power cable is a high voltage, high current electrical line. It is primarily used between the EV battery and FC inverter input junction block assembly, between the inverter with converter assembly and FC air compressor with motor assembly, and between the inverter with converter assembly and FC control ECU. To enable technicians to visually distinguish between the high voltage power cable and the normal low voltage electrical lines, the power cable and its corrugated tube have been standardized with an orange color.

The inverter with converter contains a circuit that boosts the EV battery voltage from 244.8 to 650 Volts DC. The inverter with converter creates 3-phase AC to power the motors.

The following systems are intended to help keep occupants in the vehicle and emergency responders safe from high voltage electricity:

High Voltage Safety System

- A high voltage fuse ❶* provides short circuit protection in the EV battery.

- Positive and negative high voltage power cables ❷* connected to the EV battery and FC stack assembly are controlled by 12 Volt normally open relays ❸*. When the vehicle is shut off, the relays stop electricity flow from leaving the EV battery.

⚠ ***WARNING:***

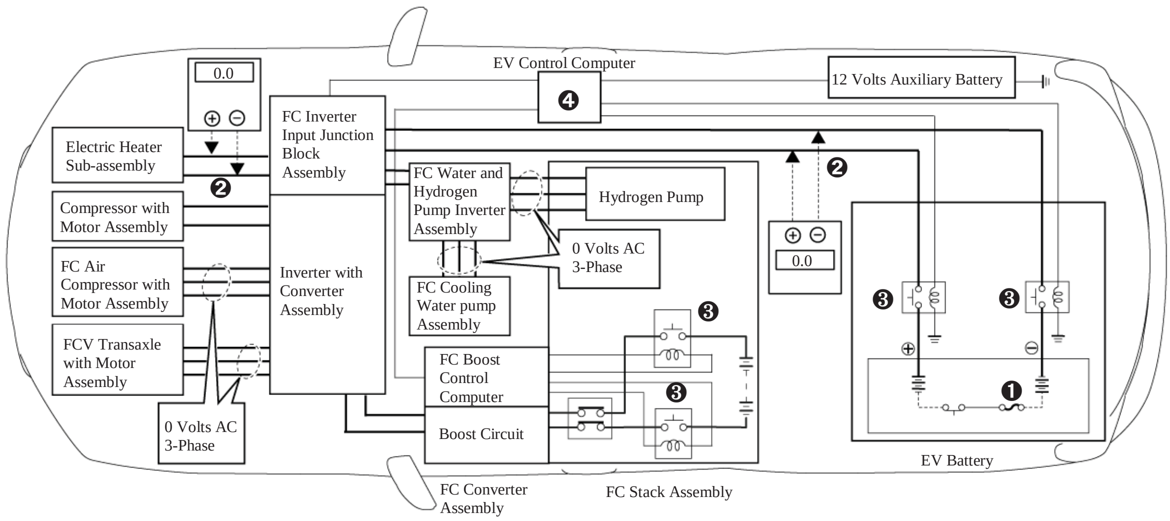
- ***The high voltage system may remain powered for up to 10 minutes after the vehicle is shut off or disabled. To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or opening any orange high voltage power cable or high voltage component.***

- Both positive and negative power cables ❷* are insulated from the metal body. High voltage electricity flows through these cables and not through the metal vehicle body.
  The metal vehicle body is safe to touch because it is insulated from the high voltage components.
- A ground fault monitor ❹* continuously monitors for high voltage leakage to the metal chassis while the vehicle is running. If a malfunction is detected, the EV control computer ❹* will illuminate the master warning light ⚠ in the instrument cluster and indicate "FC System Malfunction" on the multi-information display.
- The EV battery relays will automatically open to stop electricity flow in a collision sufficient to activate the SRS.

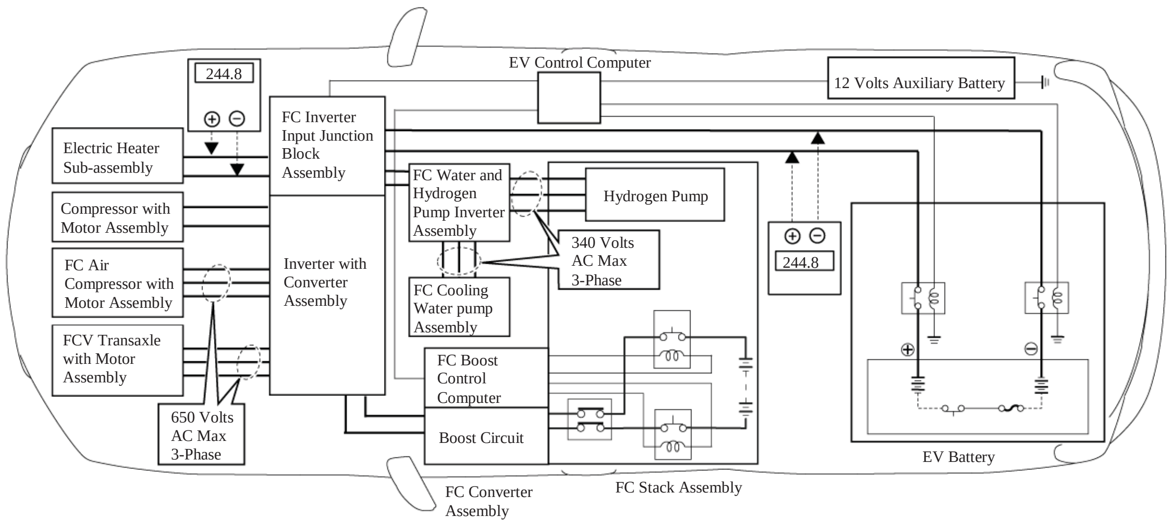
High Voltage Safety (Continued)

Service Plug Grip

- The high voltage circuit is cut by removing the service plug grip (see page 78).



High Voltage Safety System – Vehicle Shut Off (READY-OFF)



High Voltage Safety System – Vehicle On and Operational (READY-ON)

Precaution to be observed when dismantling the vehicle

⚠ ***WARNING:***

- ***The high voltage system may remain powered for up to 10 minutes after the vehicle is shut off or disabled. To prevent serious injury or death from severe burns or electric shock, avoid touching, cutting, or opening any orange high voltage power cable or high voltage component.***
- ***When discharging pressurized hydrogen gas from the from the hydrogen tank assembly, do not perform the procedure in an indoor area with poor ventilation.***
- ***Do not install or remove any hydrogen system components without first performing depressurization procedures.***

Necessary Items

- Protective clothing such as insulated gloves (electrically insulated), rubber gloves, safety goggles, and safety shoes.
- Insulating tape such as electrical tape that has a suitable electrical insulation rating.
- Before wearing insulated gloves, make sure that they are not cracked, ruptured, torn, or damaged in any way. Do not wear wet insulated gloves.
- An electrical tester that is capable of measuring DC 750 Volts or more.

HYDROGEN COMPRESSED GAS DATA SHEET

Introduction to Fuel Cell Vehicles
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

Reference Material

Hydrogen, compressed

Safety Data Sheet P-4604

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Date of issue: 01/01/1980 Revision date: 10/17/2016 Supersedes: 06/03/2015

SECTION: 1. Product and company identification

1.1. Product identifier

Product form	:	Substance
Name	:	Hydrogen, compressed
CAS No	:	1333-74-0
Formula	:	H2
Other means of identification	:	Dihydrogen, parahydrogen, refrigerant gas R702, water gas

1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of the substance/mixture	:	Industrial use. Use as directed.

1.3. Details of the supplier of the safety data sheet

Praxair, Inc.
10 Riverview Drive
Danbury, CT 06810-6268 - USA
T 1-800-772-9247 (1-800-PRAXAIR) - F 1-716-879-2146
www.praxair.com

1.4. Emergency telephone number

Emergency number : Onsite Emergency: 1-800-645-4633

CHEMTREC, 24hr/day 7days/week
— Within USA: 1-800-424-9300, Outside USA: 001-703-527-3887
(collect calls accepted, Contract 17729)

SECTION 2: Hazard identification

2.1. Classification of the substance or mixture

GHS-US classification

Flam. Gas 1	H220
Compressed gas	H280

2.2. Label elements

GHS-US labeling

Hazard pictograms (GHS-US) :

GHS02 GHS04

Signal word (GHS-US) : DANGER

Hazard statements (GHS-US) :
H220 - **EXTREMELY FLAMMABLE GAS**
H280 - CONTAINS GAS UNDER PRESSURE; MAY EXPLODE IF HEATED
OSHA-H01 - MAY DISPLACE OXYGEN AND CAUSE RAPID SUFFOCATION
CGA-HG04 - MAY FORM EXPLOSIVE MIXTURES WITH AIR
CGA-HG08 - BURNS WITH INVISIBLE FLAME

Precautionary statements (GHS-US) :
P202 - Do not handle until all safety precautions have been read and understood
P210 - Keep away from Heat, Open flames, Sparks, Hot surfaces. - No smoking
P271+P403 - Use and store only outdoors or in a well-ventilated place
P377 - Leaking gas fire: Do not extinguish, unless leak can be stopped safely
P381 - Eliminate all ignition sources if safe to do so
CGA-PG05 - Use a back flow preventive device in the piping
CGA-PG10 - Use only with equipment rated for cylinder pressure
CGA-PG12 - Do not open valve until connected to equipment prepared for use
CGA-PG06 - Close valve after each use and when empty
CGA-PG02 - Protect from sunlight when ambient temperature exceeds 52°C (125°F)

2.3. Other hazards

Other hazards not contributing to the classification : None.

2.4. Unknown acute toxicity (GHS US)

No data available

SECTION 3: Composition/Information on ingredients

3.1. Substance

Name : Hydrogen, compressed

CAS No : 1333-74-0

Name	Product identifier	%
Hydrogen	(CAS No) 1333-74-0	99.5 - 100

3.2. Mixture

Not applicable

SECTION 4: First aid measures

4.1. Description of first aid measures

First-aid measures after inhalation : Remove to fresh air and keep at rest in a position comfortable for breathing. If not breathing, give artificial respiration. If breathing is difficult, trained personnel should give oxygen. Call a physician.

First-aid measures after skin contact : Adverse effects not expected from this product.

First-aid measures after eye contact : Immediately flush eyes thoroughly with water for at least 15 minutes. Hold the eyelids open and away from the eyeballs to ensure that all surfaces are flushed thoroughly. Contact an ophthalmologist immediately.. Get immediate medical attention.

First-aid measures after ingestion : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

No additional information available

4.3. Indication of any immediate medical attention and special treatment needed

None.

SECTION 5: Firefighting measures

5.1. Extinguishing media

Suitable extinguishing media : Carbon dioxide, dry chemical powder, water spray, fog.

5.2. Special hazards arising from the substance or mixture

Fire hazard : **EXTREMELY FLAMMABLE GAS**. The hydrogen flame is nearly invisible. Hydrogen has a low ignition energy; escaping hydrogen gas may ignite spontaneously. A fireball forms if the gas cloud ignites immediately after release. Hydrogen forms explosive mixtures with air and oxidizing agents.

Explosion hazard : **EXTREMELY FLAMMABLE GAS**. Forms explosive mixtures with air and oxidizing agents.

Reactivity : No reactivity hazard other than the effects described below.

5.3. Advice for firefighters

Firefighting instructions : If venting or leaking gas catches fire, do not extinguish flames. Flammable vapors may spread from leak, creating an explosive reignition hazard. Vapors can be ignited by pilot lights, other flames, smoking, sparks, heaters, electrical equipment, static discharge, or other ignition sources at locations distant from product handling point. Explosive atmospheres may linger. Before entering an area, especially a confined area, check the atmosphere with an appropriate device

Evacuate all personnel from the danger area. Use self-contained breathing apparatus (SCBA) and protective clothing. Immediately cool containers with water from maximum distance. Stop flow of gas if safe to do so, while continuing cooling water spray. Remove ignition sources if safe to do so. Remove containers from area of fire if safe to do so. On-site fire brigades must comply with OSHA 29 CFR 1910.156 and applicable standards under 29 CFR 1910 Subpart L—Fire Protection.

Protection during firefighting	:	Compressed gas: asphyxiant. Suffocation hazard by lack of oxygen.
Special protective equipment for fire fighters	:	Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters.
Specific methods	:	Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas containers to rupture. Cool endangered containers with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems Stop flow of product if safe to do so Use water spray or fog to knock down fire fumes if possible.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

General measures : **DANGER: EXTREMELY FLAMMABLE GAS. Forms explosive mixtures with air and oxidizing agents.** See section 5. Evacuate personnel to a safe area. Appropriate self-contained breathing apparatus may be required. Approach suspected leak area with caution. Remove all sources of ignition. if safe to do so. Reduce gas with fog or fine water spray. Stop flow of product if safe to do so. Ventilate area or move container to a well-ventilated area. Flammable gas may spread from leak. Before entering the area, especially a confined area, check the atmosphere with an appropriate device.

6.1.1. For non-emergency personnel

No additional information available

6.1.2. For emergency responders

No additional information available

6.2. Environmental precautions

Prevent waste from contaminating the surrounding environment. Prevent soil and water pollution. Dispose of contents/container in accordance with local/regional/national/international regulations. Contact supplier for any special requirements.

6.3. Methods and material for containment and cleaning up

No additional information available

6.4. Reference to other sections

See also sections 8 and 13.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Precautions for safe handling : Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. Use only non-sparking tools. Use only explosion-proof equipment

Wear leather safety gloves and safety shoes when handling cylinders. Protect cylinders from physical damage; do not drag, roll, slide or drop. While moving cylinder, always keep in place removable valve cover. Never attempt to lift a cylinder by its cap; the cap is intended solely to protect the valve. When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders. Never insert an object (e.g, wrench, screwdriver, pry bar) into cap openings; doing so may damage the valve and cause a leak. Use an adjustable strap wrench to remove over-tight or rusted caps. Slowly open the valve. If the valve is hard to open, discontinue use and contact your supplier. Close the container valve after each use; keep closed even when empty. Never apply flame or localized heat directly to any part of the container. High temperatures may damage the container and could cause the pressure relief device to fail prematurely, venting the container contents. For other precautions in using this product, see section 16.

7.2. Conditions for safe storage, including any incompatibilities

Storage conditions : Store only where temperature will not exceed 125°F (52°C). Post "No Smoking/No Open Flames" signs in storage and use areas. There must be no sources of ignition. Separate packages and protect against potential fire and/or explosion damage following appropriate codes and requirements (e.g, NFPA 30, NFPA 55, NFPA 70, and/or NFPA 221 in the U.S.) or according to requirements determined by the Authority Having Jurisdiction (AHJ). Always secure containers upright to keep them from falling or being knocked over. Install valve protection cap, if provided, firmly in place by hand when the container is not in use. Store full and empty containers separately. Use a first-in, first-out inventory system to prevent storing full containers for long periods. For other precautions in using this product, see section 16

OTHER PRECAUTIONS FOR HANDLING, STORAGE, AND USE: When handling product under pressure, use piping and equipment adequately designed to withstand the pressures to be encountered. Never work on a pressurized system. Use a back flow preventive device in the piping. Gases can cause rapid suffocation because of oxygen deficiency; store and use with adequate ventilation. If a leak occurs, close the container valve and blow down the system in a safe and environmentally correct manner in compliance with all international, federal/national, state/provincial, and local laws; then repair the leak. Never place a container where it may become part of an electrical circuit.

7.3. Specific end use(s)

None.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

Hydrogen, compressed (1333-74-0)		
ACGIH	Not established	
USA OSHA	Not established	

Hydrogen (1333-74-0)		
ACGIH	Remark (ACGIH)	Simple asphyxiant
USA OSHA	Not established	

8.2. Exposure controls

Appropriate engineering controls : Use an explosion-proof local exhaust system. Local exhaust and general ventilation must be adequate to meet exposure standards. MECHANICAL (GENERAL): **Inadequate - Use only in a closed system.** Use explosion proof equipment and lighting.

Eye protection : Wear safety glasses with side shields.

Respiratory protection : An air-supplied respirator must be used while working with this product in confined spaces. The respiratory protection used must conform with OSHA rules as specified in 29 CFR 1910.134. Select per OSHA 29 CFR 1910.134 and ANSI Z88.2.

Thermal hazard protection : None necessary.

Other information : Consider the use of flame resistant anti-static safety clothing. Wear safety shoes while handling containers.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Physical state : Gas

Appearance : Colorless gas.

Molecular mass : 2 g/mol

Color : Colorless.

Odor : Odorless.

Odor threshold : No data available

pH : Not applicable.

Relative evaporation rate (butyl acetate=1) : No data available

Relative evaporation rate (ether=1) : Not applicable.

Melting point : -259.2 °C (-434.56°F)

Freezing point	:	No data available
Boiling point	:	-252.9 °C (-422.97°F)
Flash point	:	No data available
Critical temperature	:	-239.9 °C (-399.82°F)
Auto-ignition temperature	:	566 °C (1051°F)
Decomposition temperature	:	No data available
Flammability (solid, gas)	:	No data available
Vapor pressure	:	Not applicable.
Relative vapor density at 20 °C	:	No data available
Relative density	:	No data available
Density	:	0.089 g/l (0.0056 lb/ft3) (at STP = 0°C and 1atm)
Relative gas density	:	0.07
Solubility	:	Water: 1.6 mg/l
Log Pow	:	Not applicable.
Log Kow	:	Not applicable.
Viscosity, kinematic	:	Not applicable.
Viscosity, dynamic	:	Not applicable.
Explosive properties	:	Not applicable.
Oxidizing properties	:	None.
Explosion limits	:	4 - 77 vol %

9.2. Other information

Gas group	:	Compressed gas
Additional information	:	BURNS WITH INVISIBLE FLAME

SECTION 10: Stability and reactivity

10.1. Reactivity

No reactivity hazard other than the effects described below.

10.2. Chemical stability

Stable under normal conditions.

10.3. Possibility of hazardous reactions

Can form explosive mixture with air. May react violently with oxidants.

10.4. Conditions to avoid

Keep away from heat/sparks/open flames/hot surfaces. – No smoking.

10.5. Incompatible materials

Oxidizing agents. Lithium. Halogens.

10.6. Hazardous decomposition products

Under normal conditions of storage and use, hazardous decomposition products should not be produced.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity : Not classified

Hydrogen, compressed (\f)1333-74-0	
LC50 inhalation rat (ppm)	> 15000 ppm/1h

Hydrogen (1333-74-0)	
LC50 inhalation rat (ppm)	> 15000 ppm/1h

Skin corrosion/irritation : Not classified
pH: Not applicable.

Serious eye damage/irritation : Not classified
pH: Not applicable.

Respiratory or skin sensitization : Not classified

Germ cell mutagenicity : Not classified

Carcinogenicity : Not classified

Reproductive toxicity : Not classified

Specific target organ toxicity (single exposure) : Not classified

Specific target organ toxicity (repeated exposure) : Not classified

Aspiration hazard : Not classified

SECTION 12: Ecological information

12.1. Toxicity

Ecology - general : No ecological damage caused by this product.

12.2. Persistence and degradability

Hydrogen, compressed (1333-74-0)	
Persistence and degradability	No ecological damage caused by this product.

Hydrogen (1333-74-0)	
Persistence and degradability	No ecological damage caused by this product.

12.3. Bioaccumulative potential

Hydrogen, compressed (1333-74-0)	
BCF fish 1	(no bioaccumulation expected)
Log Pow	Not applicable.
Log Kow	Not applicable.
Bioaccumulative potential	No ecological damage caused by this product.

Hydrogen (1333-74-0)	
BCF fish 1	(no bioaccumulation expected)
Log Pow	Not applicable.
Log Kow	Not applicable.
Bioaccumulative potential	No ecological damage caused by this product.

12.4. Mobility in soil

Hydrogen, compressed (1333-74-0)	
Mobility in soil	No data available.
Ecology - soil	No ecological damage caused by this product.

Hydrogen (1333-74-0)	
Mobility in soil	No data available.
Ecology - soil	No ecological damage caused by this product.

12.5. Other adverse effects

Effect on ozone layer : None

Effect on the global warming : No known effects from this product

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Waste disposal recommendations : Dispose of contents/container in accordance with local/regional/national/international regulations. Contact supplier for any special requirements.

SECTION 14: Transport information

In accordance with DOT

Transport document description	:	UN1049 Hydrogen, compressed, 2.1
UN-No.(DOT)	:	UN1049
Proper Shipping Name (DOT)	:	Hydrogen, compressed
Class (DOT)	:	2.1 - Class 2.1 - Flammable gas 49 CFR 173.115
Hazard labels (DOT)	:	2.1 - Flammable gas

DOT Special Provisions (49 CFR 172.102)	:	N89 - When steel UN pressure receptacles are used, only those bearing the “H” mark are authorized

Additional information

Emergency Response Guide (ERG) Number	:	115 (UN1049)
Other information	:	No supplementary information available.
Special transport precautions	:	Avoid transport on vehicles where the load space is not separated from the driver's compartment. Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency. Before transporting product containers: - Ensure there is adequate ventilation. - Ensure that containers are firmly secured. - Ensure cylinder valve is closed and not leaking. - Ensure valve outlet cap nut or plug (where provided) is correctly fitted. - Ensure valve protection device (where provided) is correctly fitted.

Transport by sea

UN-No. (IMDG)	:	1049
Proper Shipping Name (IMDG)	:	HYDROGEN, COMPRESSED
Class (IMDG)	:	2 - Gases
MFAG-No	:	115

Air transport

UN-No. (IATA)	:	1049
Proper Shipping Name (IATA)	:	Hydrogen, compressed
Class (IATA)	:	2
Civil Aeronautics Law	:	Gases under pressure/Gases flammable under pressure

SECTION 15: Regulatory information

15.1. US Federal regulations

Hydrogen, compressed (1333-74-0)	
Listed on the United States TSCA (Toxic Substances Control Act) inventory	
SARA Section 311/312 Hazard Classes	Sudden release of pressure hazard Fire hazard

All components of this product are listed on the Toxic Substances Control Act (TSCA) inventory.

This product or mixture does not contain a toxic chemical or chemicals in excess of the applicable de minimis concentration as specified in 40 CFR §372.38(a) subject to the reporting requirements of section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372.

15.2. International regulations

CANADA

Hydrogen, compressed (1333-74-0)
Listed on the Canadian DSL (Domestic Substances List)

Hydrogen (1333-74-0)
Listed on the Canadian DSL (Domestic Substances List)

EU-Regulations

Hydrogen, compressed (1333-74-0)
Listed on the EEC inventory EINECS (European Inventory of Existing Commercial Chemical Substances)

15.2.2. National regulations

Hydrogen, compressed (1333-74-0)
Listed on the AICS (Australian Inventory of Chemical Substances) Listed on IECSC (Inventory of Existing Chemical Substances Produced or Imported in China) Listed on the Korean ECL (Existing Chemicals List) Listed on NZIoC (New Zealand Inventory of Chemicals) Listed on PICCS (Philippines Inventory of Chemicals and Chemical Substances) Listed on INSQ (Mexican National Inventory of Chemical Substances)

15.3. US State regulations

Hydrogen, compressed(1333-74-0)	
U.S. - California - Proposition 65 - Carcinogens List	No
U.S. - California - Proposition 65 - Developmental Toxicity	No
U.S. - California - Proposition 65 - Reproductive Toxicity - Female	No
U.S. - California - Proposition 65 - Reproductive Toxicity - Male	No
State or local regulations	U.S. - Massachusetts - Right To Know List U.S. - New Jersey - Right to Know Hazardous Substance List U.S. - Pennsylvania - RTK (Right to Know) List

California Proposition 65 - This product does not contain any substances known to the state of California to cause cancer, developmental and/or reproductive harm

Hydrogen (1333-74-0)				
U.S. - California - Proposition 65 - Carcinogens List	U.S. - California - Proposition 65 - Developmental Toxicity	U.S. - California - Proposition 65 - Reproductive Toxicity - Female	U.S. - California - Proposition 65 - Reproductive Toxicity - Male	Non-significant risk level (NSRL)
No	No	No	No	

Hydrogen (1333-74-0)
U.S. - Massachusetts - Right To Know List U.S. - New Jersey - Right to Know Hazardous Substance List U.S. - Pennsylvania - RTK (Right to Know) List

SECTION 16: Other information

Other information : When you mix two or more chemicals, you can create additional, unexpected hazards. Obtain and evaluate the safety information for each component before you produce the mixture. Consult an industrial hygienist or other trained person when you evaluate the end product. Before using any plastics, confirm their compatibility with this product

Praxair asks users of this product to study this SDS and become aware of the product hazards and safety information. To promote safe use of this product, a user should (1) notify employees, agents, and contractors of the information in this SDS and of any other known product hazards and safety information, (2) furnish this information to each purchaser of the product, and (3) ask each purchaser to notify its employees and customers of the product hazards and safety information

The opinions expressed herein are those of qualified experts within Praxair, Inc. We believe that the information contained herein is current as of the date of this Safety Data Sheet. Since the use of this information and the conditions of use are not within the control of Praxair, Inc, it is the user's obligation to determine the conditions of safe use of the product

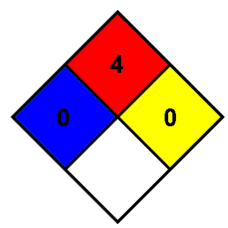
Praxair SDSs are furnished on sale or delivery by Praxair or the independent distributors and suppliers who package and sell our products. To obtain current SDSs for these products, contact your Praxair sales representative, local distributor, or supplier, or download from www.praxair.com. If you have questions regarding Praxair SDSs, would like the document number and date of the latest SDS, or would like the names of the Praxair suppliers in your area, phone or write the Praxair Call Center (Phone: 1-800-PRAXAIR/1-800-772-9247; Address: Praxair Call Center, Praxair, Inc, P.O. Box 44, Tonawanda, NY 14151-0044)

PRAXAIR and the Flowing Airstream design are trademarks or registered trademarks of Praxair Technology, Inc. in the United States and/or other countries.

NFPA health hazard : 0 - Exposure under fire conditions would offer no hazard beyond that of ordinary combustible materials.

NFPA fire hazard : 4 - Will rapidly or completely vaporize at normal pressure and temperature, or is readily dispersed in air and will burn readily.

NFPA reactivity : 0 - Normally stable, even under fire exposure conditions, and are not reactive with water.



HMIS III Rating

Health : 0 Minimal Hazard - No significant risk to health

Flammability : 4 Severe Hazard

Physical : 3 Serious Hazard

SDS US (GHS HazCom 2012) - Praxair

This information is based on our current knowledge and is intended to describe the product for the purposes of health, safety and environmental requirements only. It should not therefore be construed as guaranteeing any specific property of the product.

HYDROGEN SUPPLY & CONTROL

Introduction to Fuel Cell Vehicles
January, 2018

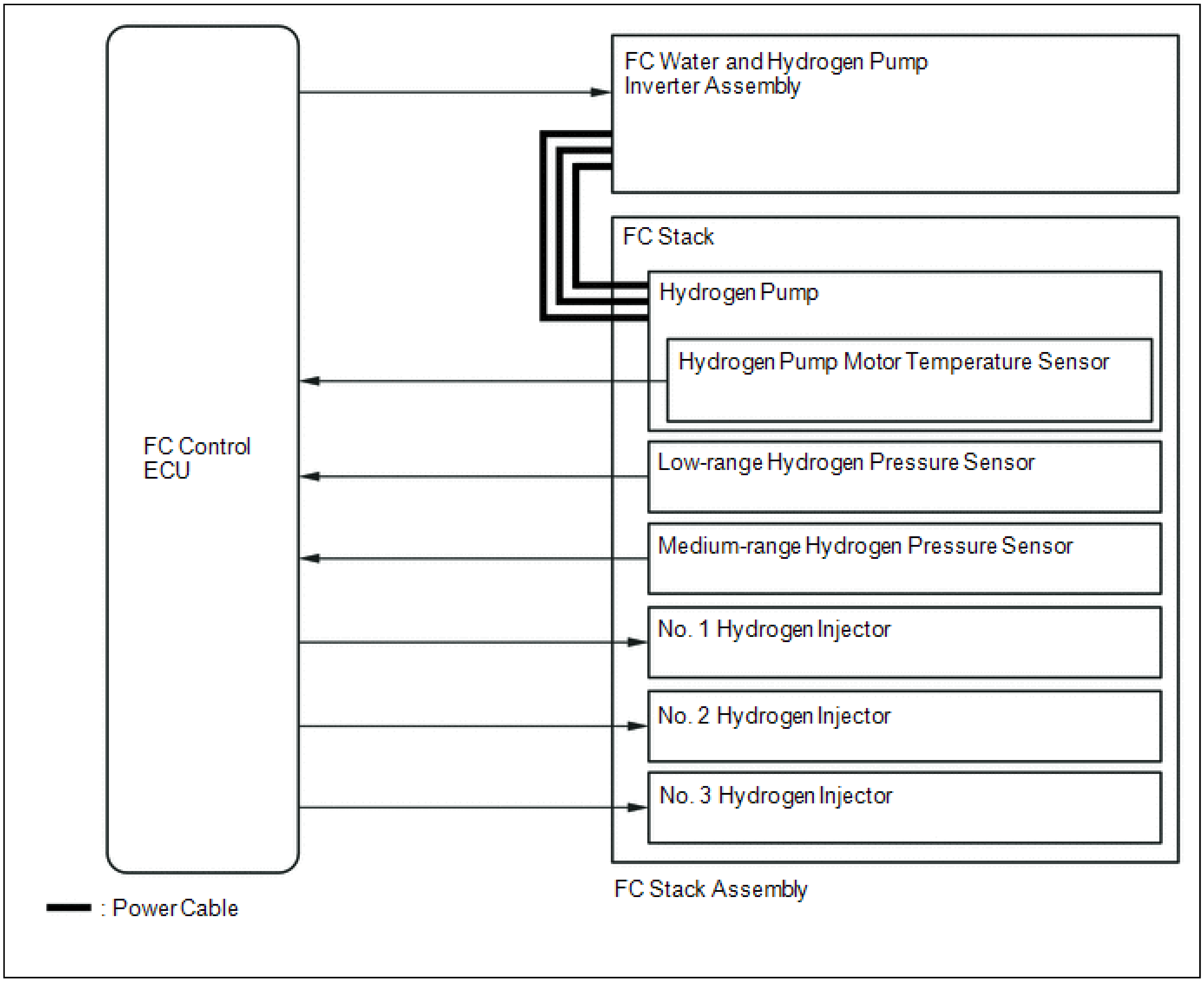
LOS ANGELES TRADE-TECH
LATTC
A Community College

Reference Material

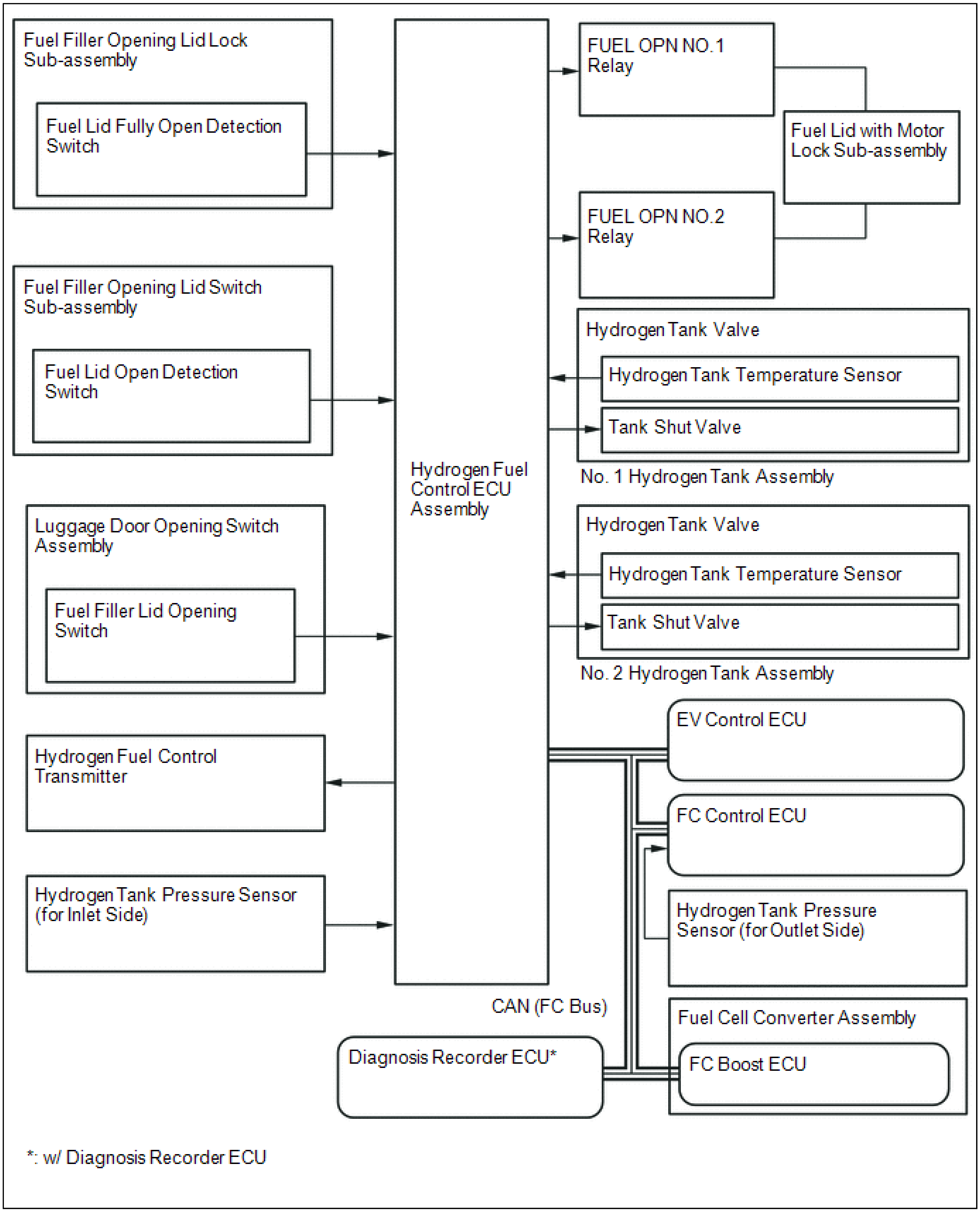
Last Modified: 12-21-2017	6.8:8.0.48	**Doc ID:** NM100000000LFYF
Model Year Start: 2016	**Model:** Mirai	**Prod Date Range:** [06/2015 -]
Title: FUEL: HYDROGEN CONTROL SYSTEM: SYSTEM DIAGRAM; 2016 - 2018 MY Mirai [06/2015 -]		

SYSTEM DIAGRAM

Hydrogen Supply / Circulation Control



Hydrogen Filling Control


Fuel Filler Opening Lid Lock Sub-assembly
Fuel Lid Fully Open Detection Switch
Fuel Filler Opening Lid Switch Sub-assembly
Fuel Lid Open Detection Switch
Luggage Door Opening Switch Assembly
Fuel Filler Lid Opening Switch
Hydrogen Fuel Control Transmitter
Hydrogen Tank Pressure Sensor (for Inlet Side)
Hydrogen Fuel Control ECU Assembly
FUEL OPN NO.1 Relay
Fuel Lid with Motor Lock Sub-assembly
FUEL OPN NO.2 Relay
Hydrogen Tank Valve
Hydrogen Tank Temperature Sensor
Tank Shut Valve
No. 1 Hydrogen Tank Assembly
Hydrogen Tank Valve
Hydrogen Tank Temperature Sensor
Tank Shut Valve
No. 2 Hydrogen Tank Assembly
EV Control ECU
FC Control ECU
Hydrogen Tank Pressure Sensor (for Outlet Side)
CAN (FC Bus)
Fuel Cell Converter Assembly
FC Boost ECU
Diagnosis Recorder ECU*
*: w/ Diagnosis Recorder ECU

NEUTRALIZING NiMH HV BATTERY ELECTROLYTE

Introduction to Fuel Cell Vehicles
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

Reference Material

Spills

The MIRAI contains the same common automotive fluids used in other non-hybrid Toyota vehicles, with the exception of the NiMH electrolyte used in the EV battery. The NiMH battery electrolyte is a caustic alkaline (pH 13.5) that is damaging to human tissues. The electrolyte, however, is absorbed in the cell plates and will not normally spill or leak out even if a metal battery module is cracked.
A catastrophic crash that would breach both the metal battery pack case and a metal battery module would be a rare occurrence.

A caustic alkaline is at the opposite end of the pH scale from a strong acid. A safe (neutral) substance is approximately in the middle of this scale. Adding a weak acidic mixture, such as a dilute boric acid solution or vinegar, to the caustic alkaline electrolyte will cause the electrolyte to be neutralized. This is similar but opposite to the use of baking soda to neutralize a lead-acid battery electrolyte spill.

- Handle NiMH electrolyte spills using the following Personal Protective Equipment (PPE):
    - Splash shield or safety goggles. A fold down face shield is not acceptable for acid or electrolyte spills.
    - Rubber, latex or nitrile gloves.
    - Apron suitable for alkaline.
    - Rubber boots.

- Neutralize NiMH electrolyte.
    - Use a boric acid solution or vinegar.
    - Boric acid solution - 800 grams boric acid to 20 liters water or 5.5 ounces boric acid to 1 gallon of water.

Dismantling the vehicle

Caution

- **The hydrogen tanks contain high-pressure hydrogen.**
- **Never dismantle a vehicle without first removing and depressurizing the hydrogen tanks. Failure to observe this precaution may lead to serious injury or death caused by high-pressure gas.**

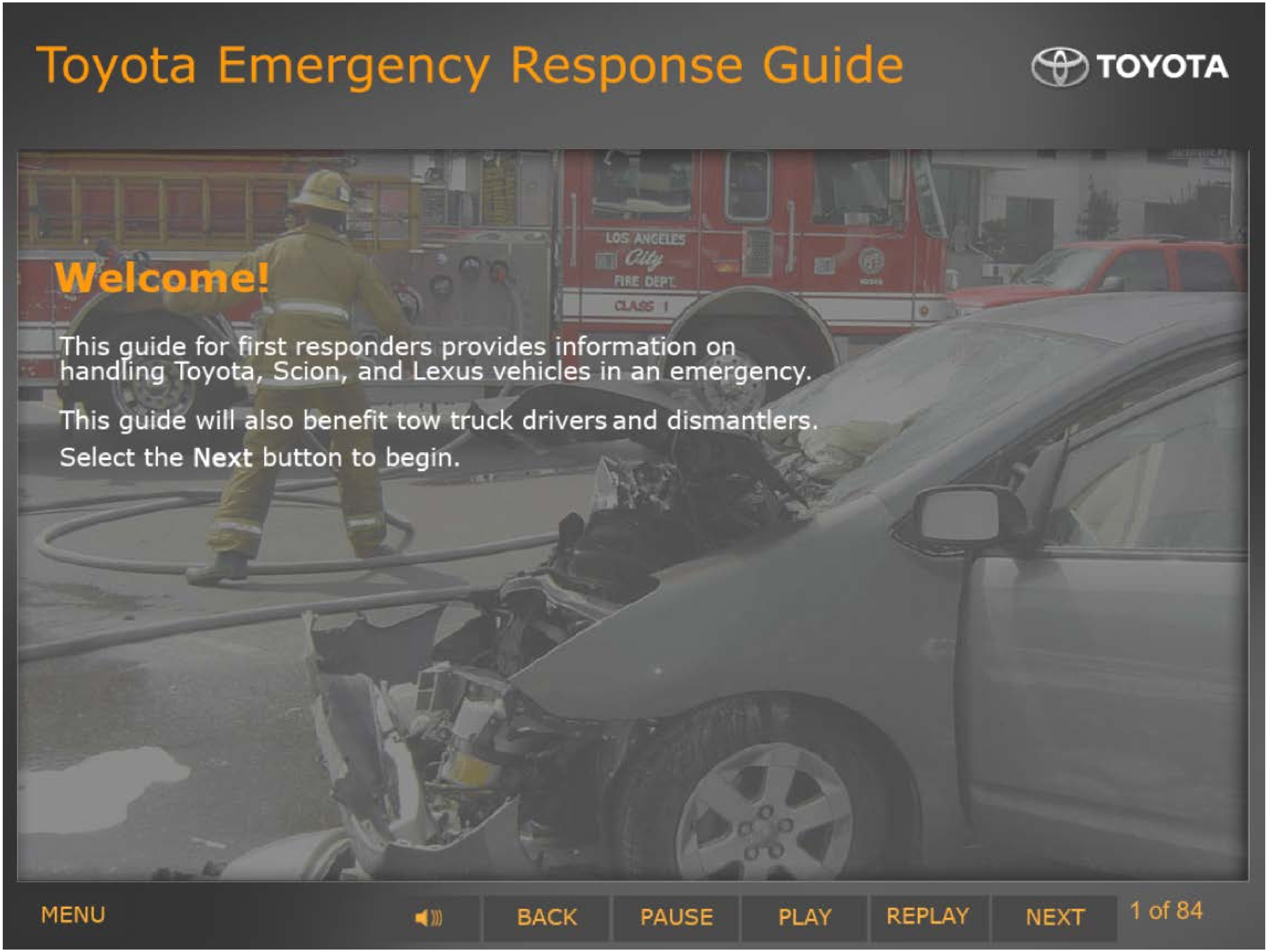
TOYOTA EMERGENCY RESPONSE GUIDE (ERG)

Complete Version

Introduction to Fuel Cell Vehicles
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

Reference Material


Toyota Emergency Response Guide
TOYOTA
Welcome!
This guide for first responders provides information on handling Toyota, Scion, and Lexus vehicles in an emergency.
This guide will also benefit tow truck drivers and dismantlers.
Select the Next button to begin.
LOS ANGELES City FIRE DEPT.
MENU
BACK
PAUSE
PLAY
REPLAY
NEXT
1 of 84

Toyota Emergency Response Guide

TOYOTA

Course Sections

Select a section below or use the Next button to view the sections in order

First Responders (law enforcement, firefighters, paramedics)

Second Responders (towing, storage, dismantlers)

Introduction

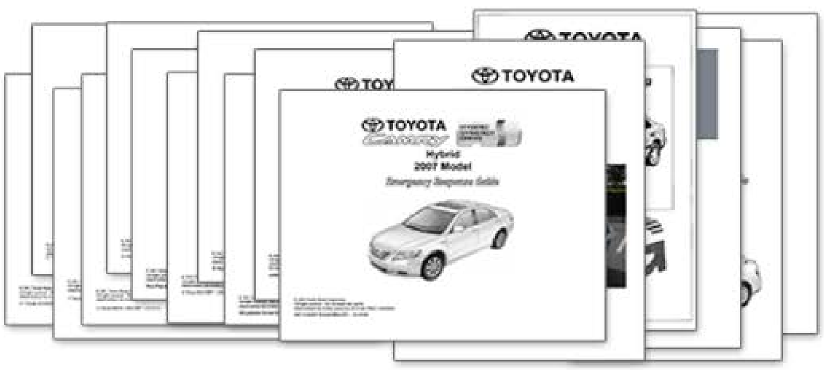
This guide supplements other Toyota emergency response resources.

Beginning with the 2014 Toyota Highlander, Toyota will no longer produce Emergency Response Guides (ERGs) for individual models. They will be replaced with:

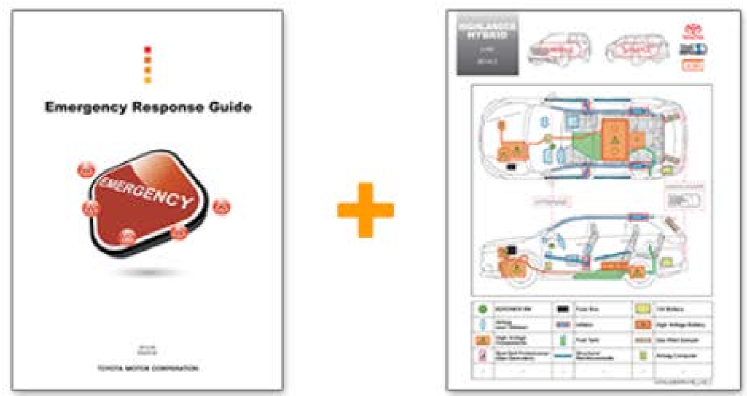
- A single ERG for **all** models
- A 2-page Emergency Response Quick Reference Sheet for each model

The individual ERGs for older models will still be available.

Section 2 shows you how to access these resources using Toyota Techinfo.



ERGs for each model



A Single ERG and Quick Reference Sheets

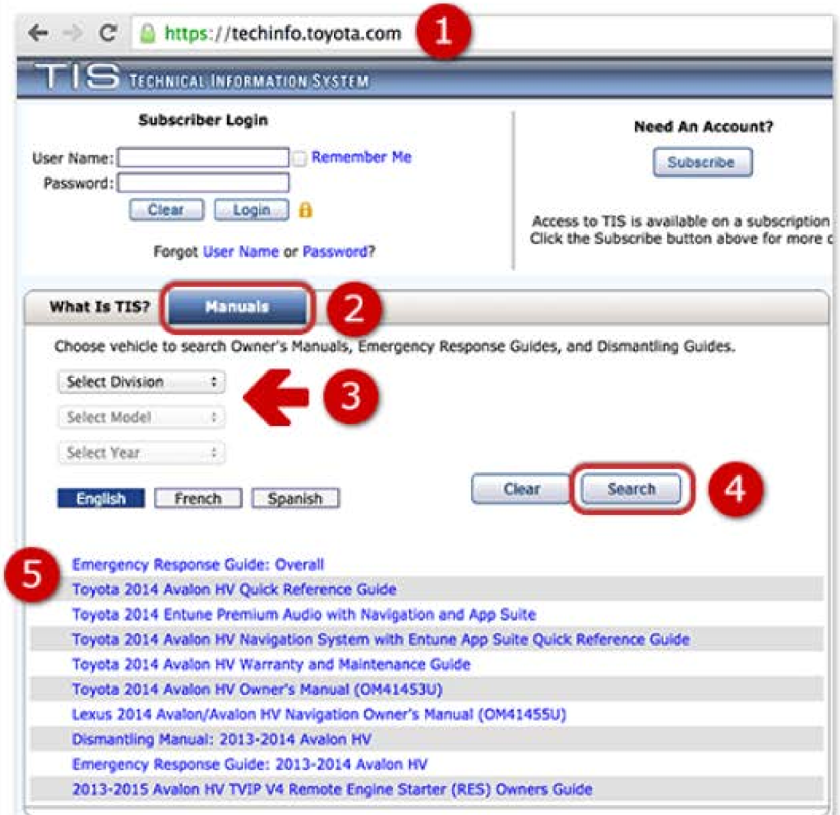
Toyota Emergency Response Guide

TOYOTA

First Responder Resources

MENU BACK PAUSE PLAY REPLAY NEXT

ERG Resources



To access emergency response resources:

1. Type techinfo.toyota.com into your browser.

   This is an open site that does not require subscriber login.

2. Click the Manuals tab.
3. Using the dropdowns, select a Division, Model, and Model Year.
4. Click the Search button.
5. A list of results will be displayed. Click a document to open it in a browser window. Documents include:
   - Emergency Response Guide: Overall
   - Emergency Response Quick Reference
   - Individual ERGs for older models

SAE Standard J2990

Society of Automotive Engineers (SAE) standard J2990, "Hybrid and EV First and Second Responder Recommended Practice," provides first and second responders with the ability to avoid the hazards associated with the high voltage system, communicate hazard identification to other incident responders, and manage the risks in a manner consistent with the best practices utilized by first responders, second responders, vehicle manufacturers, and other responsible organizations.

You may purchase this standard from SAE International by:

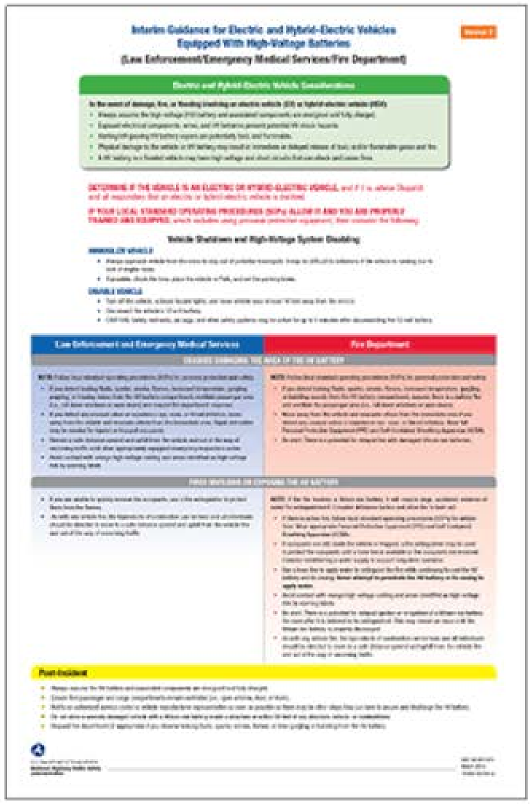
- Calling 1-877-606-7323
- Ordering online at http://standards.sae.org/j2990_201211/

NHTSA

The National Highway Traffic Safety Administration (NHTSA) has released three variations of "Interim Guidance for Electric and Hybrid-Electric Vehicles:"

- Emergency Responders
- Tow/Recovery/Storage
- Owners

Select the image to open the version for first responders.

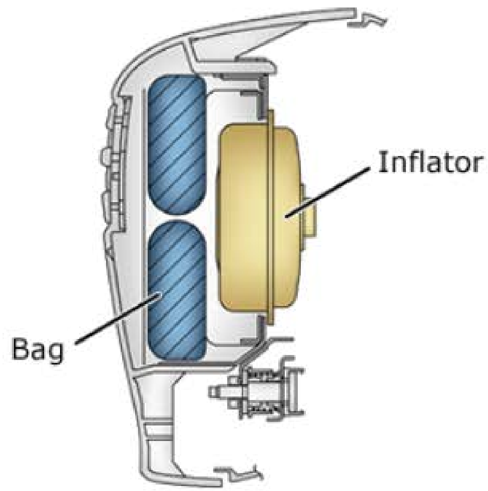

Interim Guidance for Electric and Hybrid-Electric Vehicles
Equipped With High-Voltage Batteries
(Law Enforcement/Emergency Medical Services/Fire Department)

TOYOTA

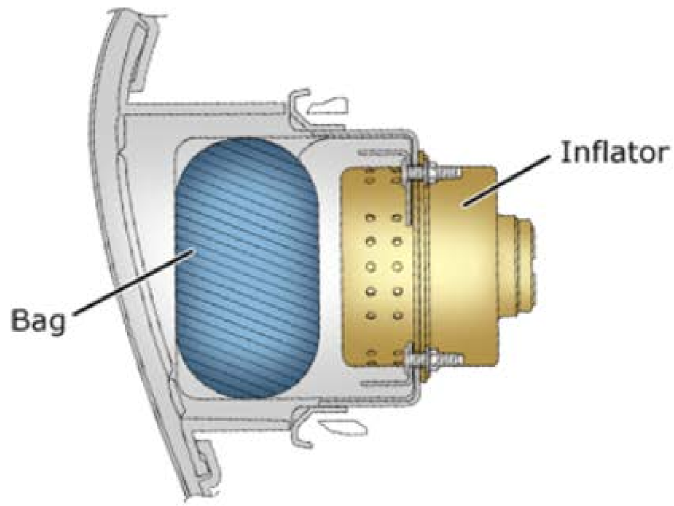
SRS Airbags

Operation

- Supplemental Restraint System (SRS) airbags supplement the seat belts to help reduce impacts to the driver and passengers in a collision
- During a collision, the airbag Electronic Control Unit (ECU) uses information from airbag sensors and sends a deployment signal to the appropriate airbag assembly (or assemblies)
- The deployment signal ignites an inflator, which generates gas to inflate the airbag



SRS Driver Airbag Assembly Cross Section



SRS Front Passenger Airbag Assembly Cross Section

Warnings

- The SRS may remain powered for up to 90 seconds after the vehicle is shut off and disabled
- After shutting off and disabling the vehicle, wait 90 seconds before performing emergency response procedures to avoid unintentional airbag deployment causing serious injury or death
- Cutting an undeployed SRS airbag inflator may cause it to explode
- Immediately after airbag deployment, SRS components are extremely hot and may cause burns if touched
- If an SRS airbag deploys with all doors and windows closed, inflation gas may cause breathing difficulty
- If residue produced during SRS deployment contacts the skin, rinse it off immediately to prevent irritation

SRS Airbags

Warnings

- The SRS may remain powered for up to 90 seconds after the vehicle is shut off and disabled
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- Cutting an undeployed SRS airbag inflator may cause it to explode
- Immediately after airbag deployment, SRS components are extremely hot and may cause burns if touched
- If an SRS airbag ... may cause breathing difficulty
- If residue produ... mmediately to prevent irritation

Disable Vehicle

To shut the vehicle off, press the Engine/Power switch once or turn the ignition switch to the Lock (OFF) position.

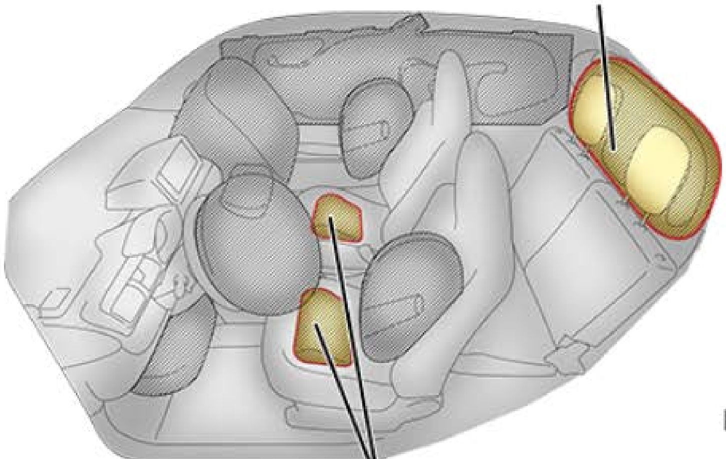
When equipped with an Engine/Power switch, keep the electrical key transmitter outside the detection area (16 ft. or more away from the vehicle).

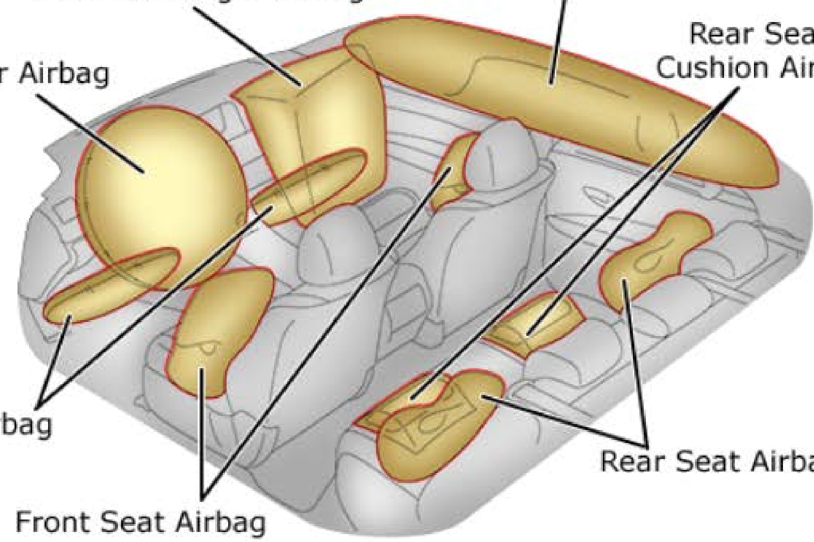
Disconnect the negative terminal of the 12 V battery. Refer to each vehicle's Emergency Response Guide or Emergency Response Quick Reference Sheet for the location of the 12 V battery.

Location

Depending on the model, multiple airbags may be located throughout the cabin. Consult the vehicle's Emergency Response Guide/Quick Reference Sheet for specific airbag and airbag inflator locations.

Select the highlighted airbags to learn more.



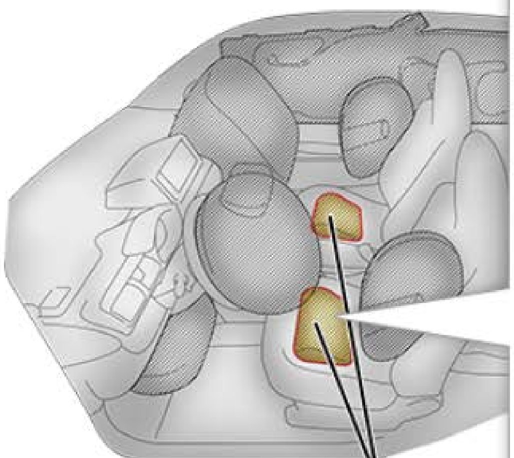


Location

Depending on the model, multiple airbags may be located throughout the cabin. Consult the vehicle's Emergency Response Guide/Quick Reference Sheet for specific airbag and airbag inflator locations.

Select the highlighted airbags to learn more.

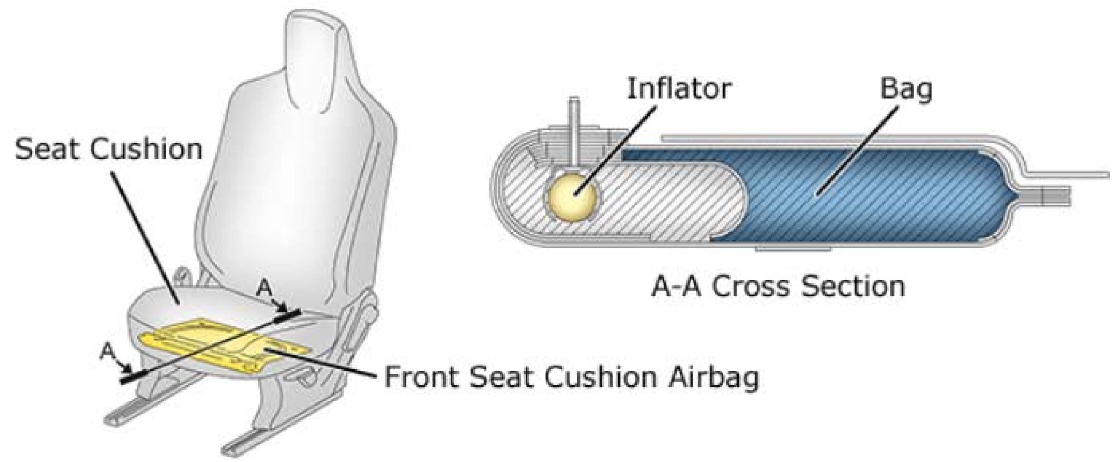
Rear Window Curtain Sh



Front Seat
Cushion Airbag

Front Seat Cushion Airbag

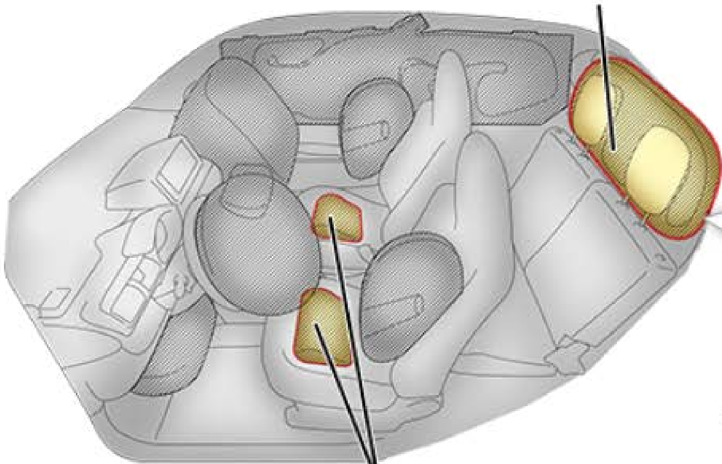
- Mounted in the driver and front passenger seat cushions
- Activated in a frontal collision



Location

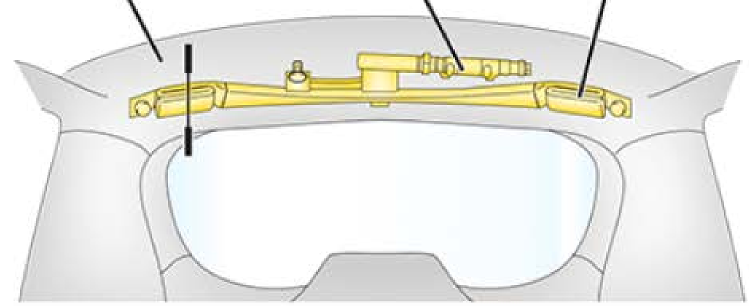
Depending on the model, multiple airbags may be located throughout the cabin. Consult the vehicle's Emergency Response Guide/Quick Reference Sheet for specific airbag and airbag inflator locations.

Select the highlighted airbags to learn more.



Rear Window Curtain Shield Airbag

- Mounted in the upper rear back panel (back door mounting section)
- Activated in a rear collision

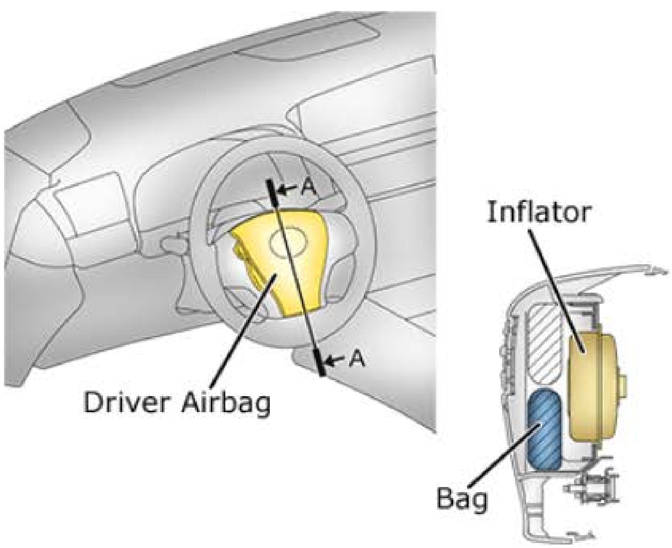


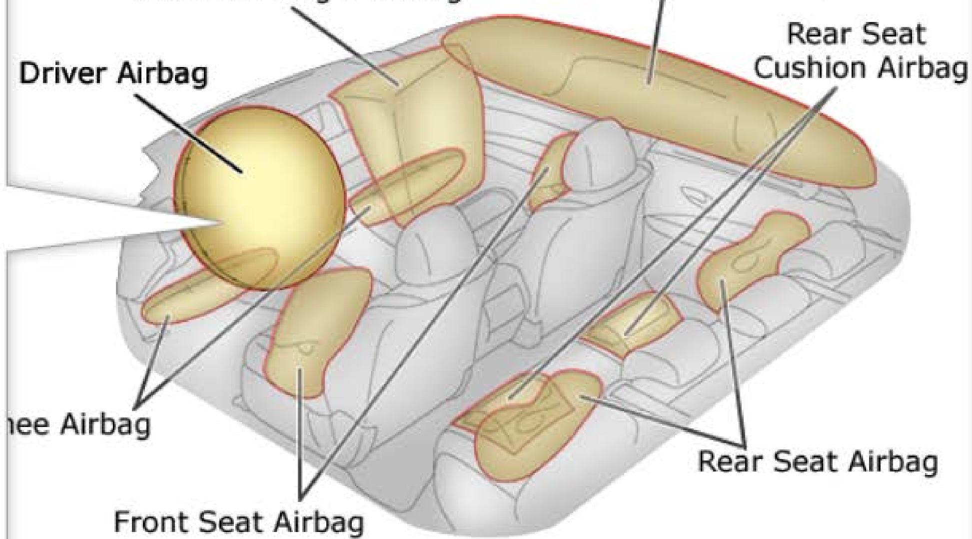
Location

Depending on the model, multiple airbags may be located throughout the cabin. Consult the vehicle's Emergency Response Guide/Quick Reference Sheet for specific airbag and airbag inflator locations.

Driver Airbag

- Mounted in the steering wheel pad
- Activated in a frontal collision



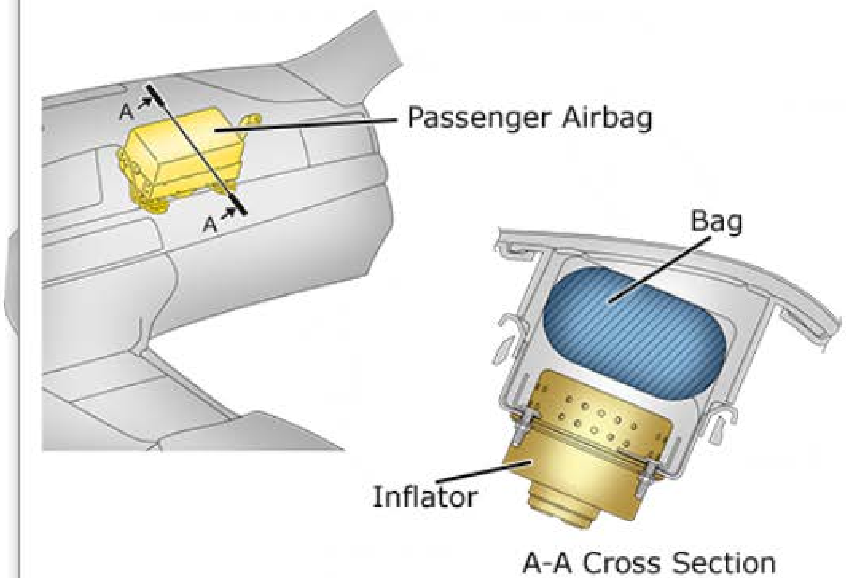


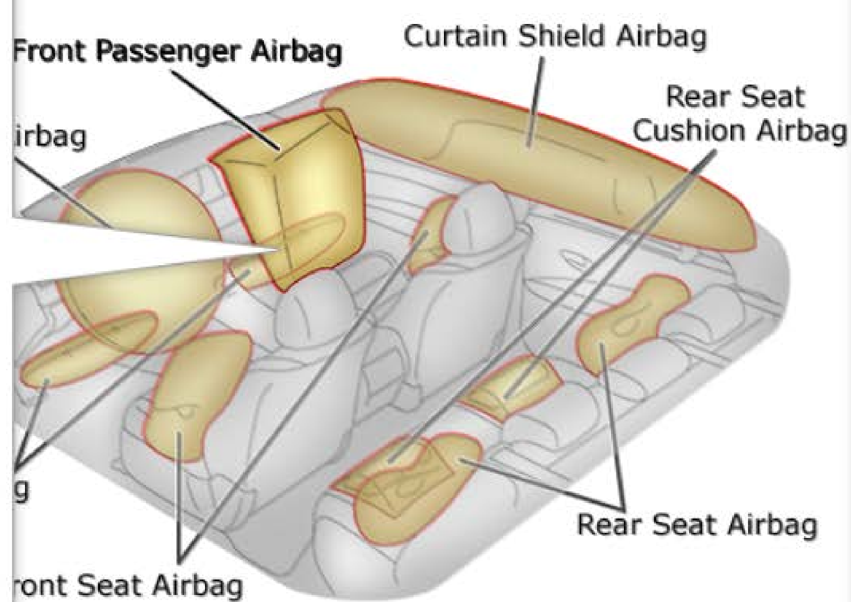
Location

Depending on the model, multiple airbags may be located throughout the cabin. Consult the vehicle's ific airbag and airbag inflator locations.

Front Passenger Airbag

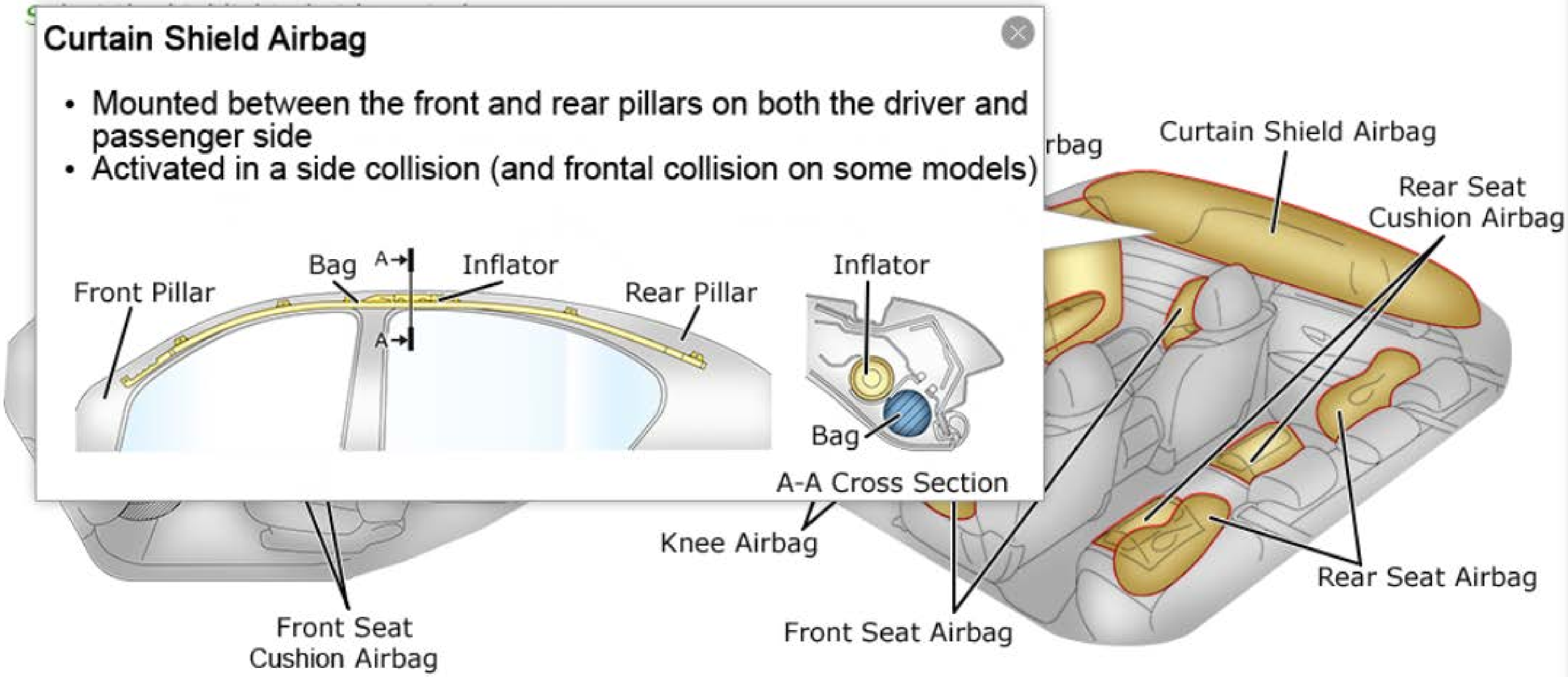
- Mounted in the upper passenger-side instrument panel
- Activated in a frontal collision





Location

Depending on the model, multiple airbags may be located throughout the cabin. Consult the vehicle's Emergency Response Guide/Quick Reference Sheet for specific airbag and airbag inflator locations.



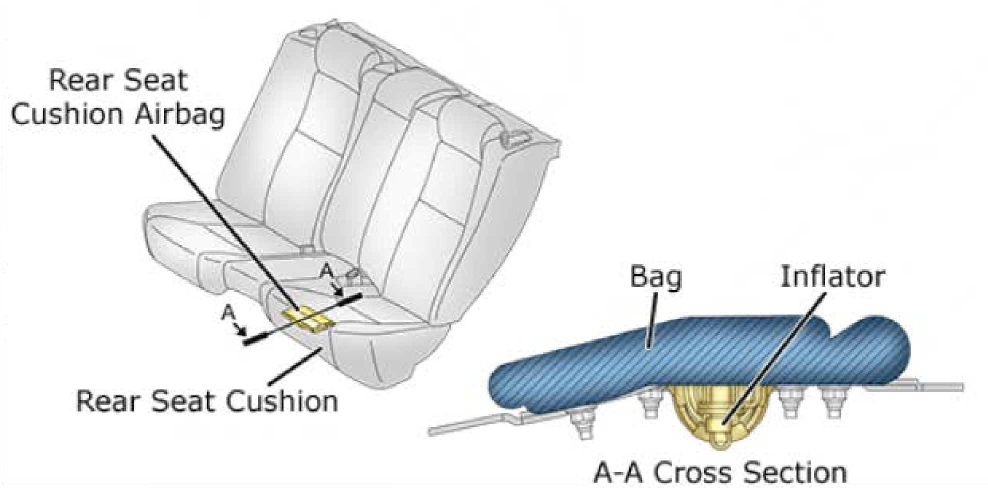
Location

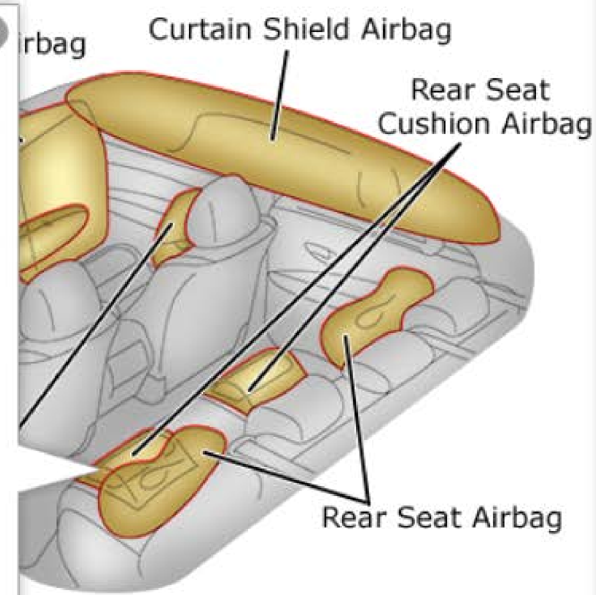
Depending on the model, multiple airbags may be located throughout the cabin. Consult the vehicle's Emergency Response Guide/Quick Reference Sheet for specific airbag and airbag inflator locations.

Select the highlighted airbags to learn more.

Rear Seat Cushion Airbag

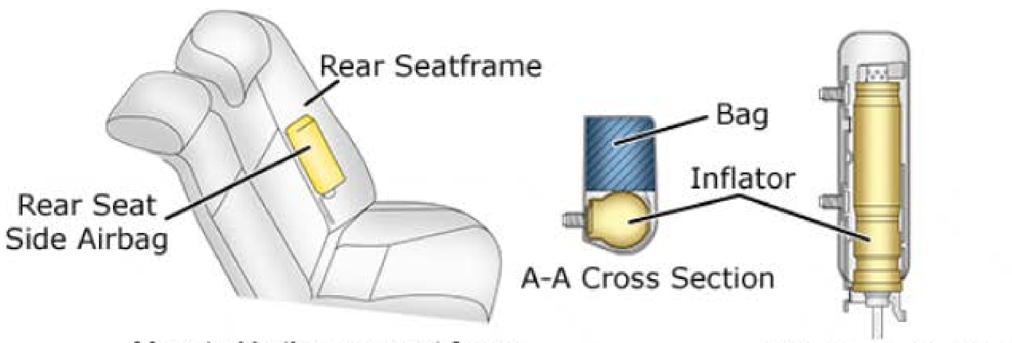
- Mounted in select rear seat cushions
- Activated in a frontal collision



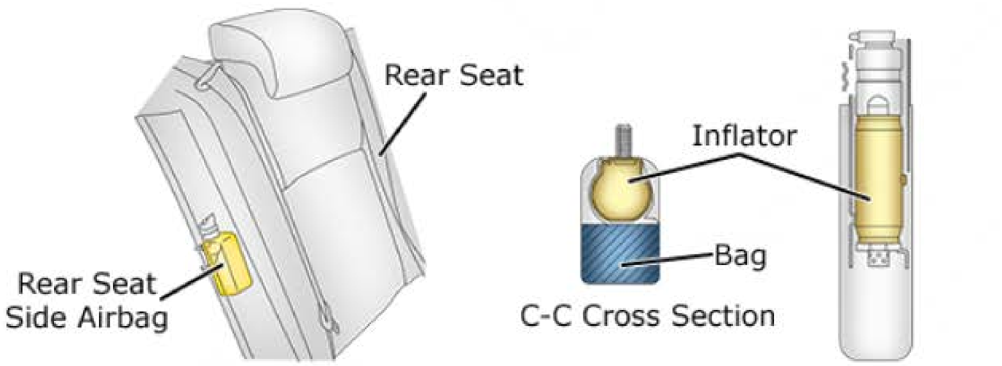


Rear Seat Airbag

- Mounted in the side of the rear seat frame or side garnish
- Activated in a side collision (and frontal collision on some vehicles)

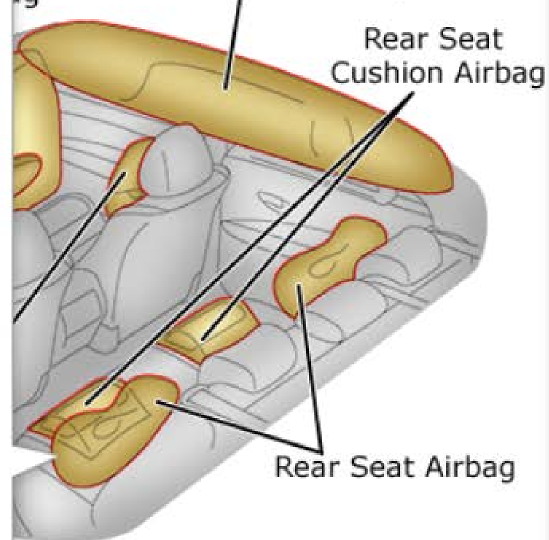


Mounted in the rear seat frame



Mounted in the rear seat side garnish

Consult the vehicle's
inflator locations.

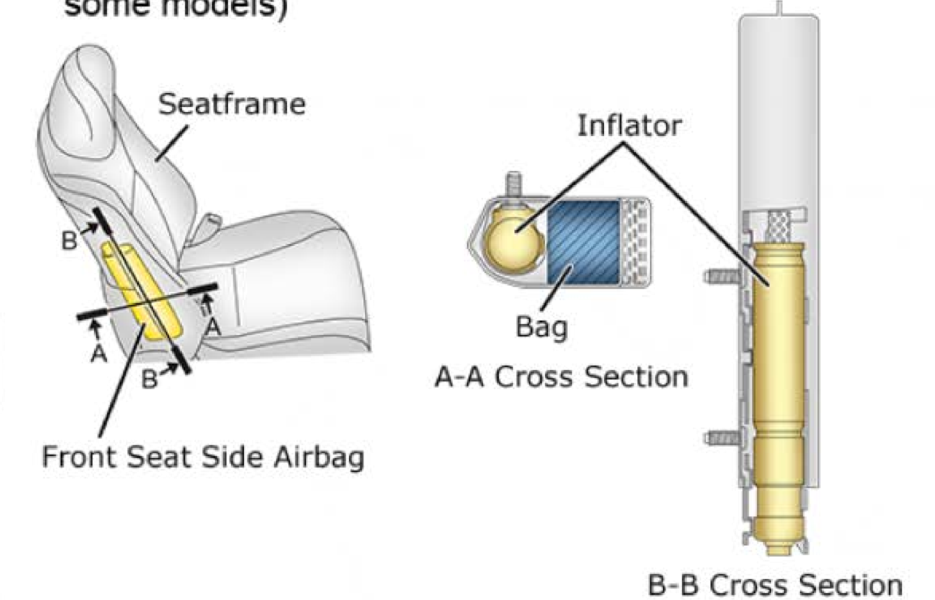


SRS Airbags

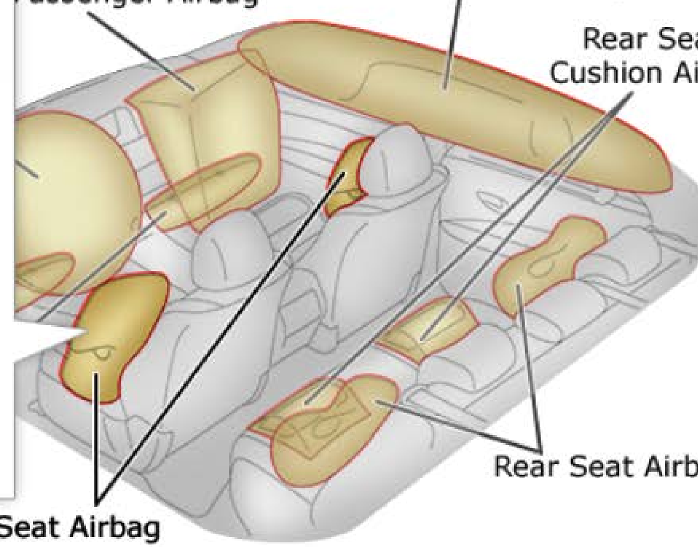
Location

Front Seat Airbag

- Mounted in the driver and front passenger seat frames
- Activated in a side collision (and frontal collision on some models)



hout the cabin. Consult the vehicle's
rbag and airbag inflator locations.

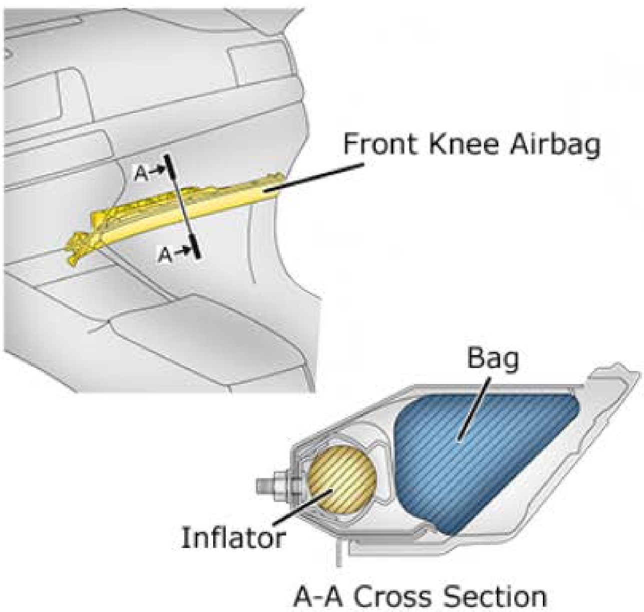


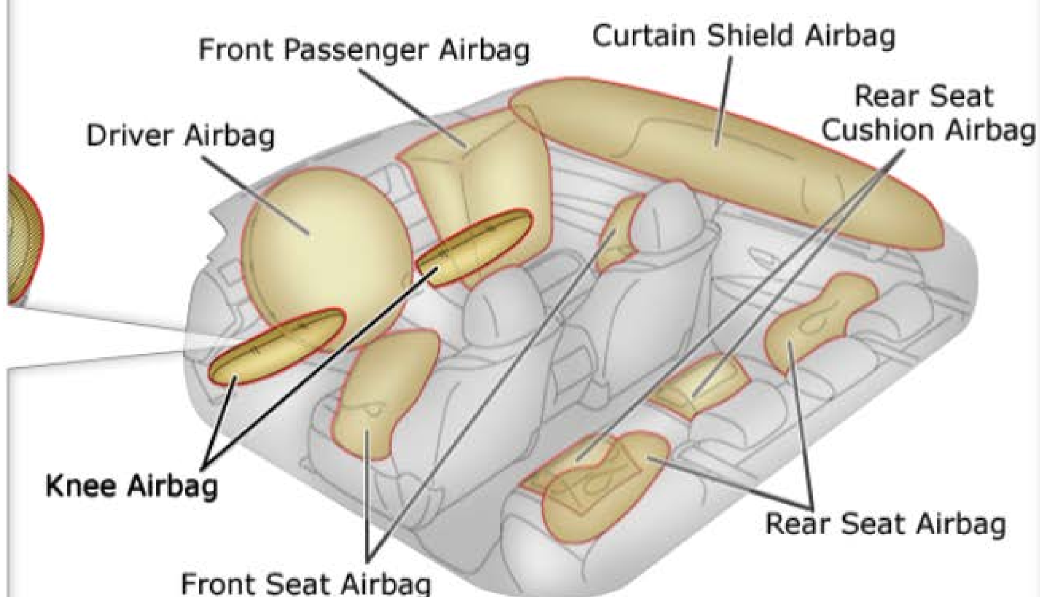
Location

Depending on the model, multiple airbags may be located throughout the cabin. Consult the vehicle's Emergency Response Guide/Quick Reference Sheet for specific airbag and airbag inflator locations.

Knee Airbag

- Mounted in the lower instrument panel on the driver and front passenger sides
- Activated in a frontal collision





Identification

Standard SRS identifiers are located near each airbag.

Select to view each image

"SRS" is embossed on the steering wheel, dashboard, and overhead roof rails

Seat airbags are identified by Airbag tags in the seat cover seams

Identification

Standard SRS identifiers are located near each airbag.

Select to view each image

"SRS" is embossed on the steering wheel, dashboard, and overhead roof rails

Seat airbags are identified by Airbag tags in the seat cover seams

Toyota Emergency Response Guide

TOYOTA

SRS Airbags

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Toyota Emergency Response Guide

TOYOTA

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Identification

Standard SRS identifiers are located near each airbag.

Select to view each image

"SRS" is embossed on the steering wheel, dashboard, and overhead roof rails

Seat airbags are identified by Airbag tags in the seat cover seams

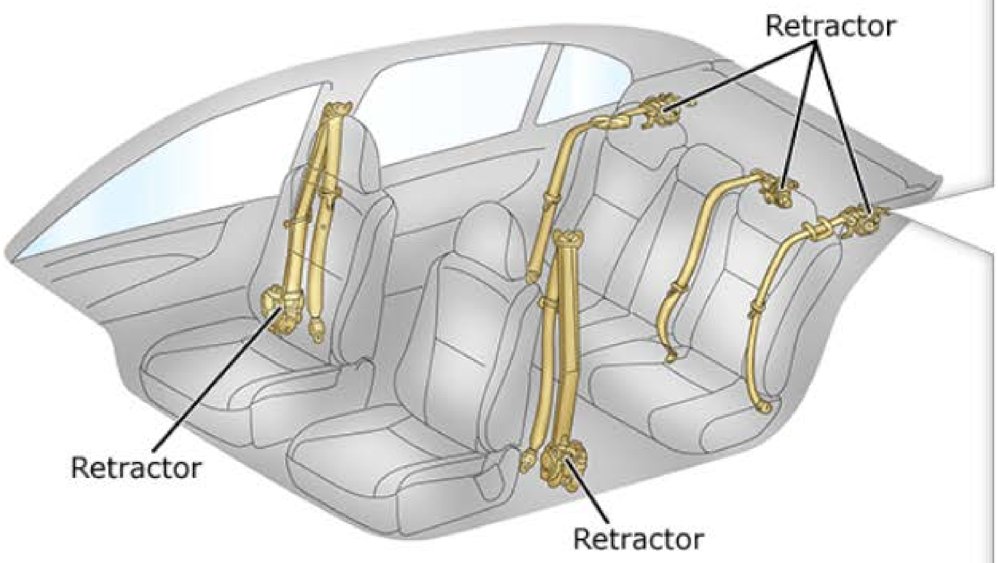
Seatbelt Pretensioners

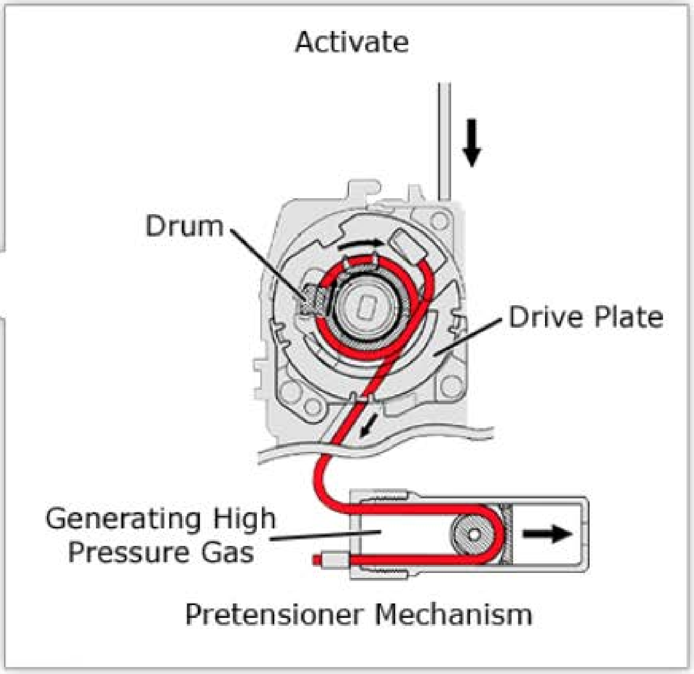
Toyota Emergency Response Guide

Seatbelt Pretensioners

Operation

- A pretensioner mechanism is integrated with the seatbelt retractors
- In a strong frontal impact, the seatbelts may retract to restrain the occupants
  - The airbag sensor assembly sends a signal to ignite the gas generator
  - Pressure rotates a gear that retracts the seatbelt
- Some models have rear seatbelt pretensioners





Warnings

- Seatbelt pretensioners may remain powered for up to 90 seconds after the vehicle is shut off and disabled
- After shutting off and disabling the vehicle, wait 90 seconds before performing emergency response procedures to avoid unintentional pretensioner actuation causing serious injury or death
- To prevent serious injury or death from unintentional actuation, do not breach the seatbelt pretensioners

Seatbelt Pretensioners

Warnings

- Seatbelt pretensioners may remain powered for up to 90 seconds after the vehicle is shut off and disabled
- After shutting off and disabling the vehicle, wait 90 seconds before performing emergency response procedures to avoid unintentional pretensioner actuation causing serious injury or death
- To prevent serious injury or death from unintentional actuation, do not breach the seatbelt pretensioners

Disable Vehicle

To shut the vehicle off, press the Engine/Power switch once or turn the ignition switch to the Lock (OFF) position.

When equipped with an Engine/Power switch, keep the electrical key transmitter outside the detection area (16 ft. or more away from the vehicle).

Disconnect the negative terminal of the 12 V battery. Refer to each vehicle's Emergency Response Guide or Emergency Response Quick Reference Sheet for the location of the 12 V battery.

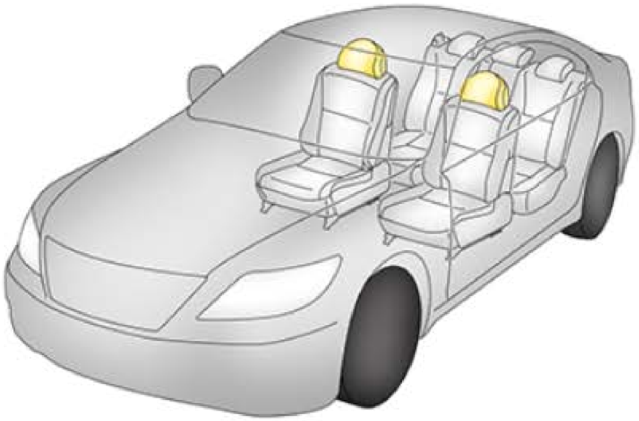
TOYOTA

Active Headrest System

Operation

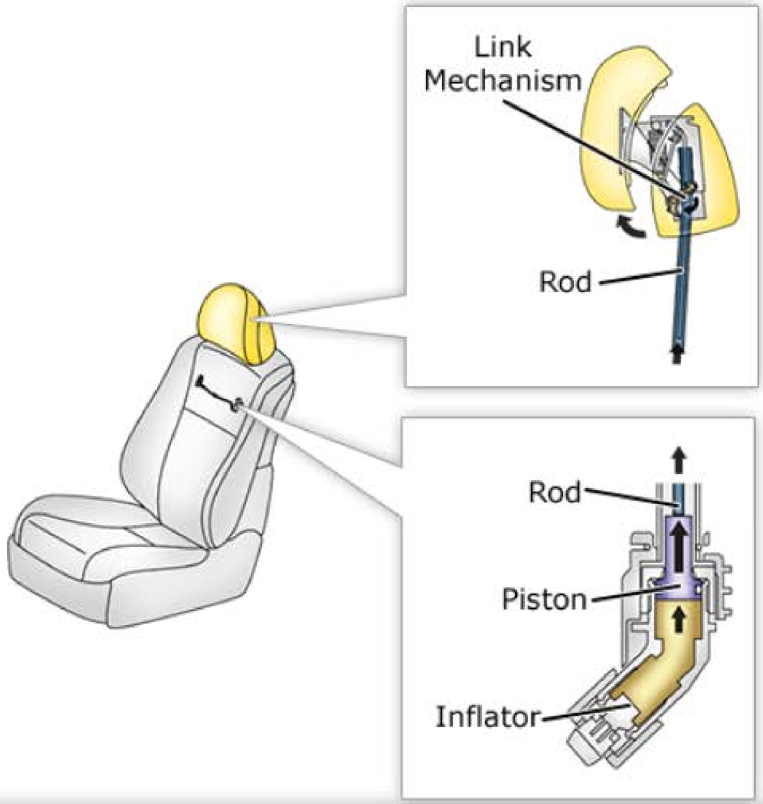
Pushes the headrest forward, helping reduce the possibility of whiplash injuries in a rear impact.

- During a rear impact, the airbag sensor assembly sends an ignition signal to the inflator
- Pressure pushes a rod inside the headrest stay, releasing a lock
- A spring pushes the headrest forward



Location

- Built into the front headrests of some models
- Refer to the individual vehicle Emergency Response Guide/Emergency Response Quick Reference Sheet



Warnings

- Active headrests may remain powered for up to 90 seconds after the vehicle is shut off and disabled
- After shutting off and disabling the vehicle, wait 90 seconds before performing emergency response procedures to avoid unintentional active headrest actuation causing serious injury or death
- To prevent serious injury or death from unintentional actuation, do not breach the active headrest inflators

Warnings

- Active headrests may remain powered for up to 90 seconds after the vehicle is shut off and disabled
- After shutting off and disabling the vehicle, wait 90 seconds before performing emergency response procedures to avoid unintentional active headrest actuation causing serious injury or death
- To prevent serious injury or death from unintentional actuation, do not breach the active headrest inflators

Disable Vehicle

To shut the vehicle off, press the Engine/Power switch once or turn the ignition switch to the Lock (OFF) position.

When equipped with an Engine/Power switch, keep the electrical key transmitter outside the detection area (16 ft. or more away from the vehicle).

Disconnect the negative terminal of the 12 V battery. Refer to each vehicle's Emergency Response Guide or Emergency Response Quick Reference Sheet for the location of the 12 V battery.

Gas-Filled Dampers

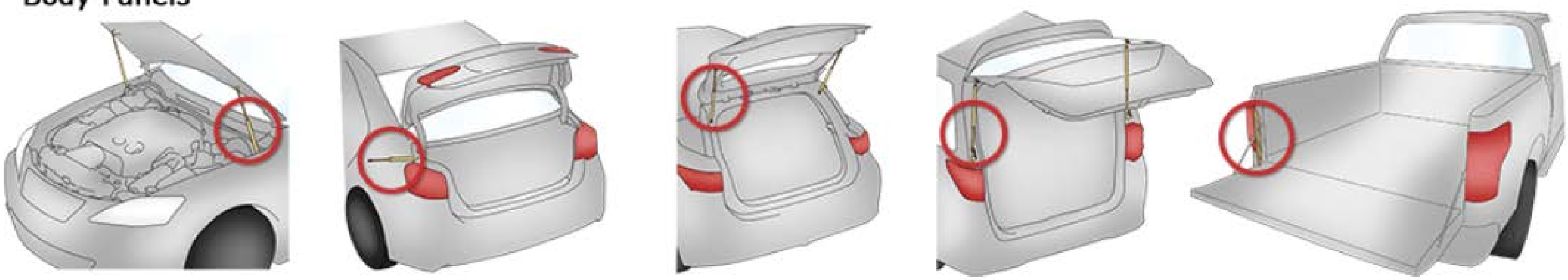
Gas-Filled Dampers

Location

Nitrogen (N2) gas-filled dampers are used in the suspension and to hold body panels open.

Suspension
- Shocks
- Suspension tower dampers
- Performance dampers

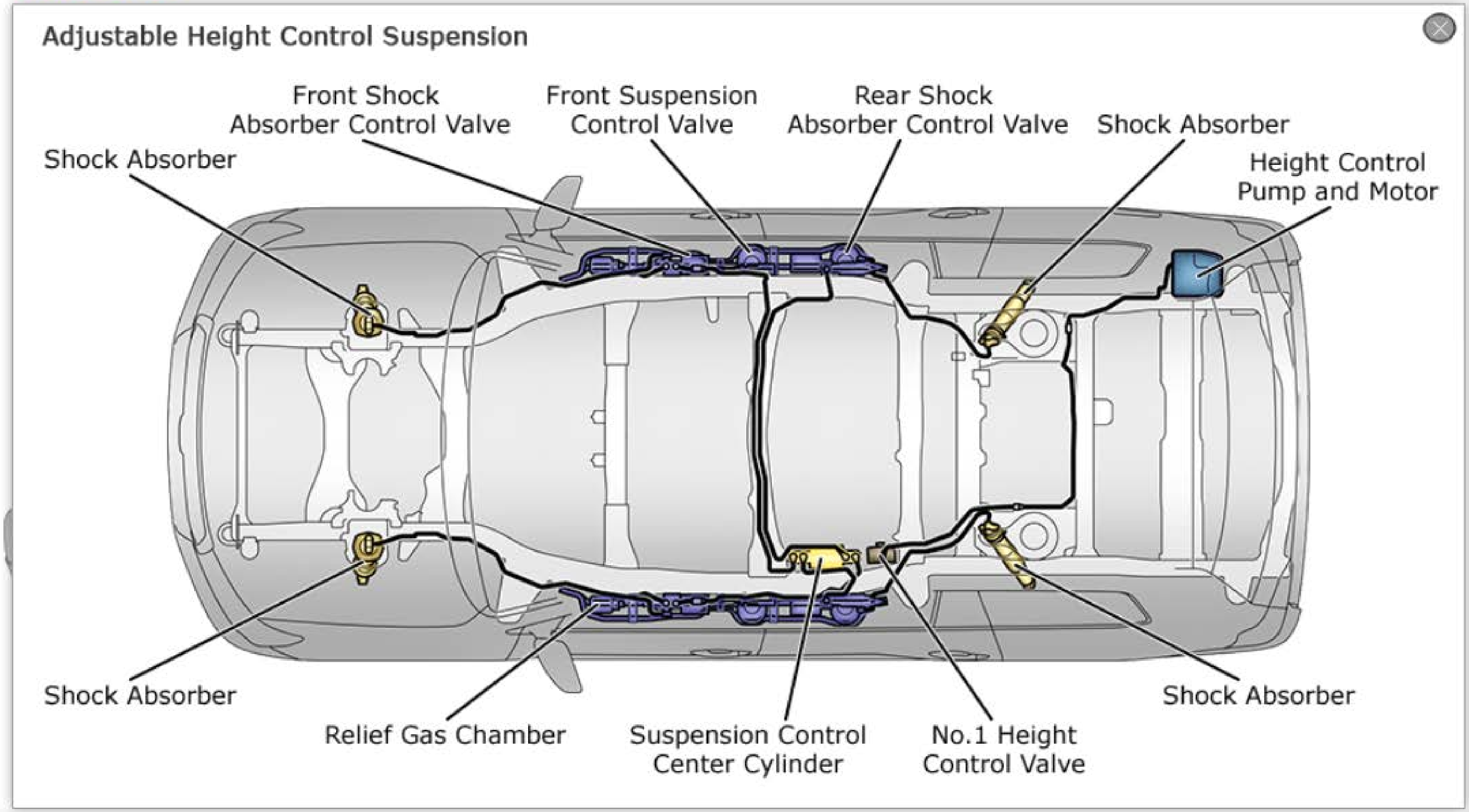
Body Panels



Dampers are installed on both the left and right sides of the body panel.

Vehicles equipped with adjustable height control suspension use compressed air to automatically control vehicle height. The pneumatic cylinders are at a higher pressure than conventional shock absorbers.
Select the link to learn more.

Location


Adjustable Height Control Suspension
Front Shock Absorber Control Valve
Front Suspension Control Valve
Rear Shock Absorber Control Valve
Shock Absorber
Shock Absorber
Height Control Pump and Motor
Shock Absorber
Relief Gas Chamber
Suspension Control Center Cylinder
No.1 Height Control Valve
Shock Absorber

Gas-Filled Dampers

Warnings

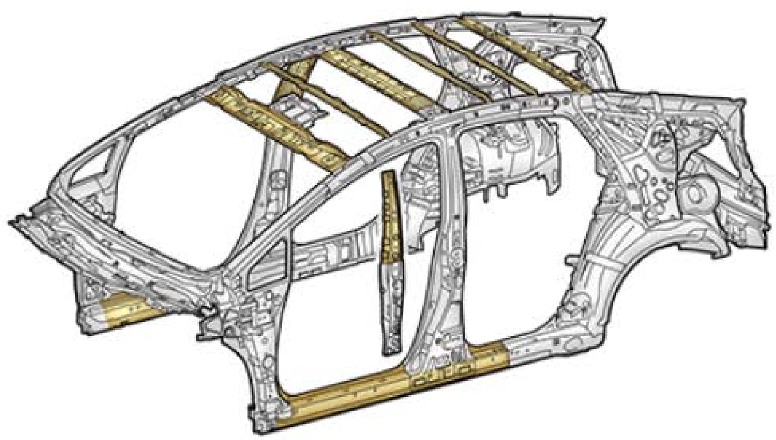
- Nitrogen expands when heated; in a vehicle fire, dampers may explode, possibly causing an injury
- Wear eye protection when cutting gas-filled dampers

Note: Nitrogen gas is colorless, odorless, and harmless.


LOS ANGELES
City
FIRE DEPT.
CLASS I
Body

Ultra High Strength Steel

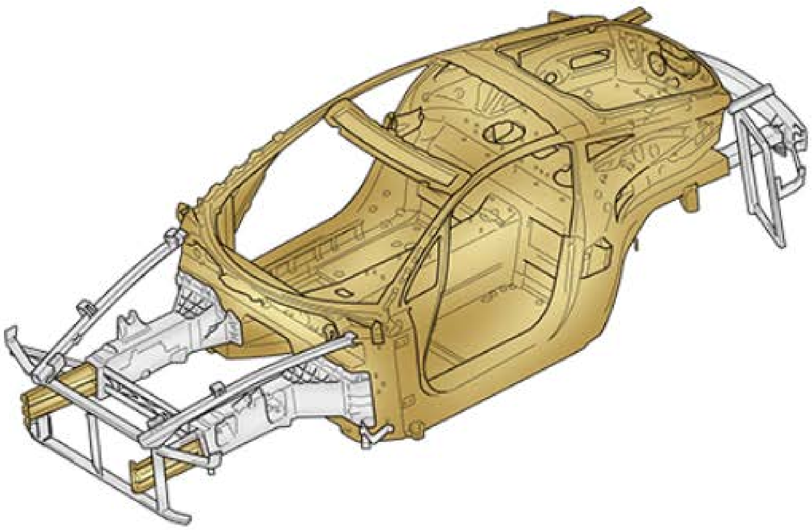
- Approximately 1.3 times higher strength than standard high strength sheet steel
- Used on body structural components on some models
- Refer to the individual vehicle Emergency Response Guide/Emergency Response Quick Reference Sheet for the location of Ultra High Strength Steel



- It is difficult to cut through ultra high strength steel using conventional cutters
- Avoid cutting through structural reinforcements made of ultra high strength steel

Carbon Fiber Reinforced Plastic (CFRP)

- Lightweight and highly rigid
- Used on body structural components on certain models
- Can be cut and deformed using cutters during rescue

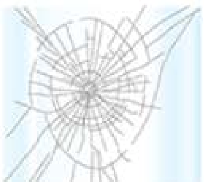


- Cutting CFRP creates carbon fiber dust and requires wearing protective equipment such as a dust mask, eye protection, and safety gloves
- CFRP is conductive and may cause a short circuit if carbon fiber dust lands on an electrical circuit
  - Keep electrical circuits free from carbon fiber dust when cutting CFRP

Glass

Laminated Glass

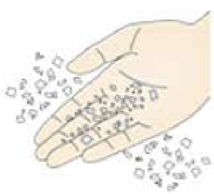
- Windshield (and some front door glass)
- Identified by "LAMISAFE" printed on the glass



- 2 layers of glass bonded with film
- Does not break easily even when struck
- Objects are less likely to penetrate the glass
- Glass shards tend to remain adhered to the film

Tempered Glass

- Door, roof, and back window glass
- Identified by "TEMPERLITE" printed on the glass



- 3 to 5 times stronger than conventional glass
- Breaks into very small pieces when broken

Body High Voltage Components

High Intensity Discharge (HID) Headlights

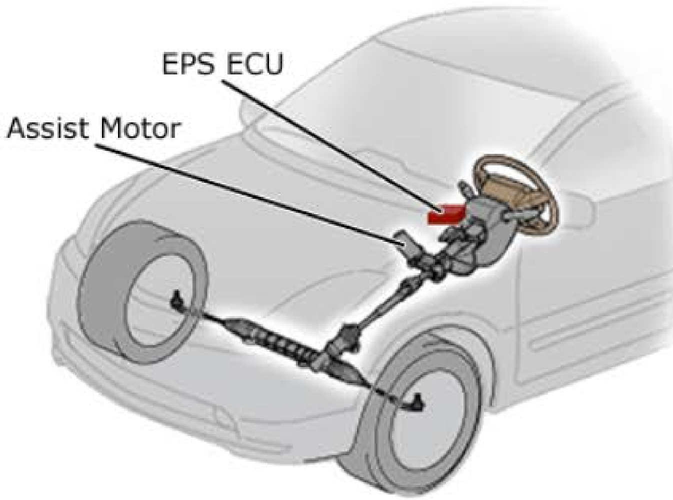
- Some vehicles use High Intensity Discharge (HID) headlights
- Emit light by creating an electric discharge between electrodes inside the bulbs
- When turned on, instantaneously generate 20,000 to 30,000 V
- Refer to the vehicle's Emergency Response Guide/Emergency Response Quick Reference Sheet for the location of high voltage components

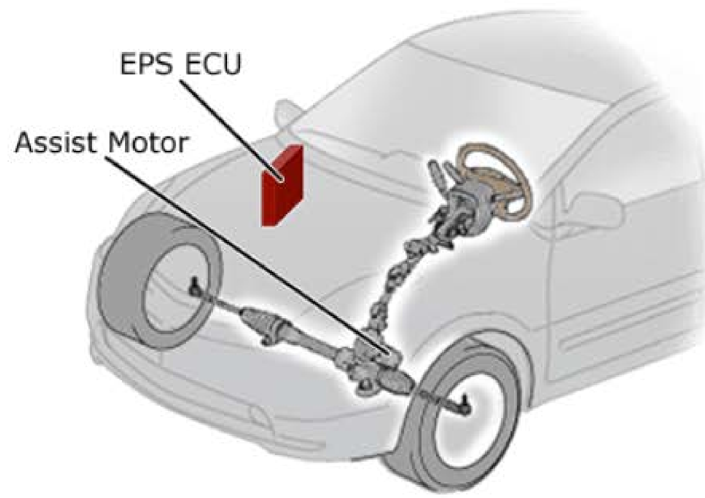
- To prevent serious injury or death from electric shock, avoid touching, cutting, or breaching HID headlight bulbs, sockets, electric circuits, or components
- To prevent burns, avoid touching high voltage sockets or the metal parts on the back of the headlights while they are on and immediately after they are turned off

Electric Power Steering (EPS)

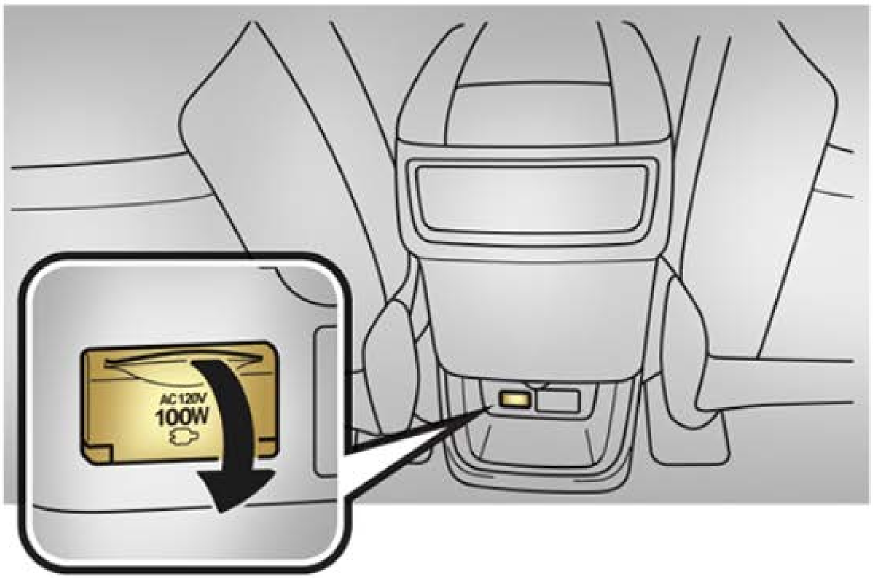
While Electric Power Steering is not considered high voltage, first responders should be aware of its higher arc potential.

- The EPS ECU boosts 12 V up to 46 V to drive an EPS assist motor
  - On some hybrid models, the DC/DC converter lowers voltage (up to 46 V) from the high voltage battery to drive the assist motor
- A wire carrying up to 46 V connects the EPS ECU to the EPS assist motor
- EPS component locations vary by model
  - The EPS assist motor is integrated with the steering gear box or steering column
  - The EPS ECU is located in the engine compartment or instrument panel





Accessory Outlet



Some HVs, EVs, and conventional gasoline engine vehicles may have an accessory outlet that uses its own inverter to convert DC voltage from the high voltage battery to AC voltage that can supply power to electronic devices.

Toyota Emergency Response Guide

TOYOTA

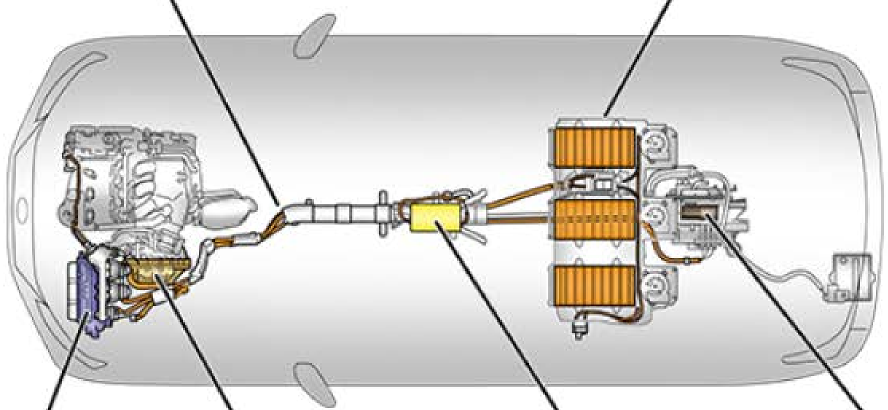
Powertrain High Voltage System

Operation

High voltage electricity drives the electric motor in HVs, PHVs, and EVs. The high voltage system is:

- Deactivated when the ignition switch or Engine/Power switch is turned OFF
- Automatically disabled if SRS airbags deploy or if the hybrid computer detects a decrease in the high voltage system's insulation resistance

The vehicle is shut off only when the READY indicator is Off. When the READY indicator is illuminated, the high voltage system is on. On HVs and PHVs, the gasoline engine may be silent but can start up at any time while the READY indicator is On.

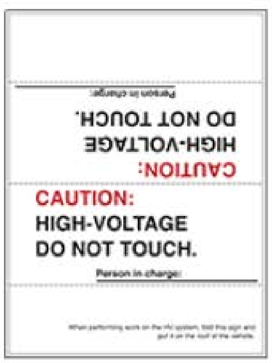


- The vehicle body is insulated from high voltage
- High voltage components have insulated covers

Model-specific diagrams can be found in individual Emergency Response Guides

Warnings

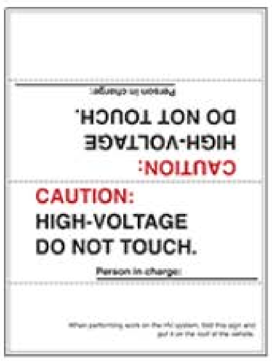
- The high voltage system may remain powered for up to 10 minutes after the vehicle is shut off and disabled
  - Failure to shut off and disable the vehicle before performing emergency response procedures may result in serious injury or death from severe burns and electric shock
- To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component
- Wear protective equipment including insulated gloves when there is a risk of touching a high voltage power cable or component
- To avoid electrocution resulting in severe injury or death, display a sign on the roof of the damaged vehicle warning others not to touch the vehicle when the person in charge is away from it



Select the icon to print a warning sign

Warnings

- The high voltage system may remain powered for up to 10 minutes after the vehicle is shut off and disabled
  - Failure to shut off and disable the vehicle before performing emergency response procedures may result in serious injury or death from severe burns and electric shock
- To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component
- Wear protective ... of touching a high voltage power cable or ...
- To avoid electro... the roof of the damaged vehicle warning ... is away from it



Se...

Disable Vehicle

To shut the vehicle off, press the Engine/Power switch once or turn the ignition switch to the Lock (OFF) position.

When equipped with an Engine/Power switch, keep the electrical key transmitter outside the detection area (16 ft. or more away from the vehicle).

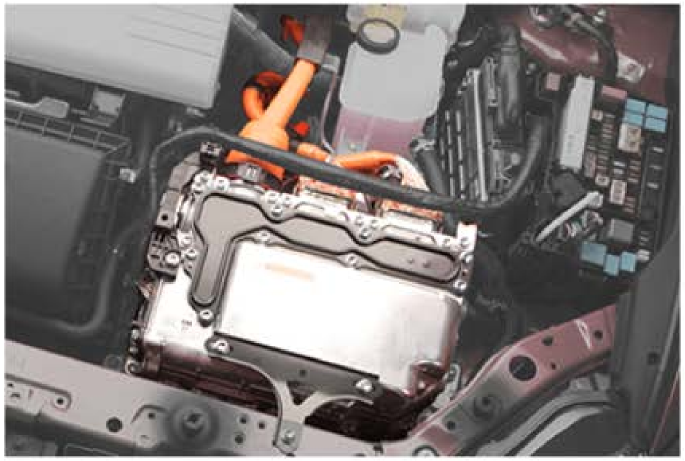
Disconnect the negative terminal of the 12 V battery. Refer to each vehicle's Emergency Response Guide or Emergency Response Quick Reference Sheet for the location of the 12 V battery.

Identification

- High voltage electrical components are contained within insulated metal covers or cases
- High voltage power cables are color-coded orange, indicating high voltage

Consult the vehicle's Emergency Response Guide/Emergency Response Quick Reference Sheet for the location of components in the high voltage system.

Refer to the Assess Vehicle Section to learn how to identify HVs, PHVs, and EVs.



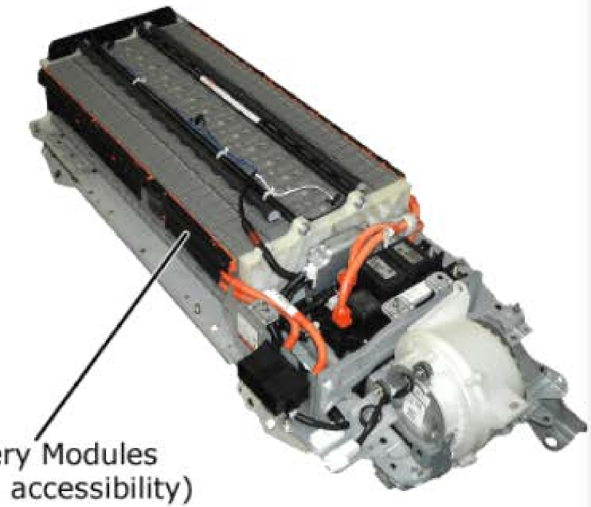
Inverter/Converter

High Voltage Battery

Nickel-Metal Hydride (Ni-MH) Battery

Most models use a nickel-metal hydride (Ni-MH) high voltage battery. Refer to the individual vehicle Emergency Response Guide/Emergency Response Quick Reference Sheet for the specific location.

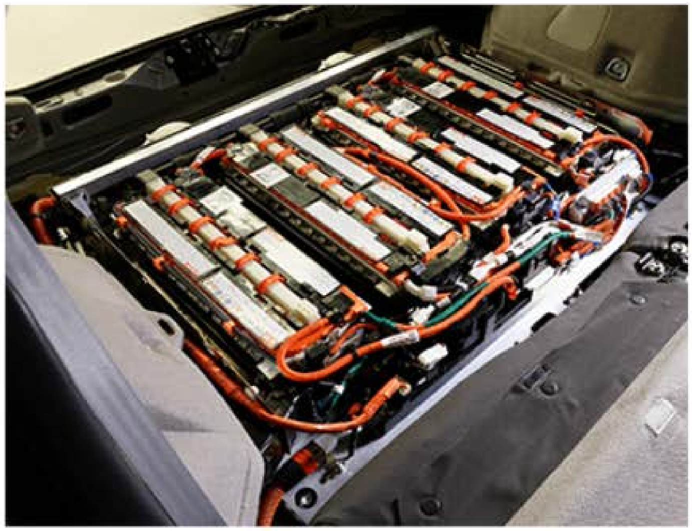
- 20 or more modules contained in a metal case
- Each module has cells connected in series to obtain high voltage (144 to 288 V)
- A catastrophic crash breaching both the metal case and a metal battery module would be rare
- Even if a module cracks, the cell plates absorb the electrolyte and it will not normally leak
- Electrolyte leakage is unlikely due to the amount of electrolyte contained within the modules
- A Ni-MH electrolyte leak is not a hazardous material incident



Battery Modules
(limited accessibility)

- Ni-MH battery electrolyte is a caustic alkaline (pH 13.5) that damages human tissues
- To avoid injury, wear appropriate protective equipment (rubber gloves and eye protection) when there is a risk of touching electrolyte
- All responders in the hot zone should wear the proper Personal Protective Equipment (PPE) for fire fighting including Self Contained Breathing Apparatus (SCBA)

Lithium ion (Li-ion) Battery



To determine the high voltage battery type and location, refer to the individual Emergency Response Guide/Emergency Response Quick Reference Sheet.

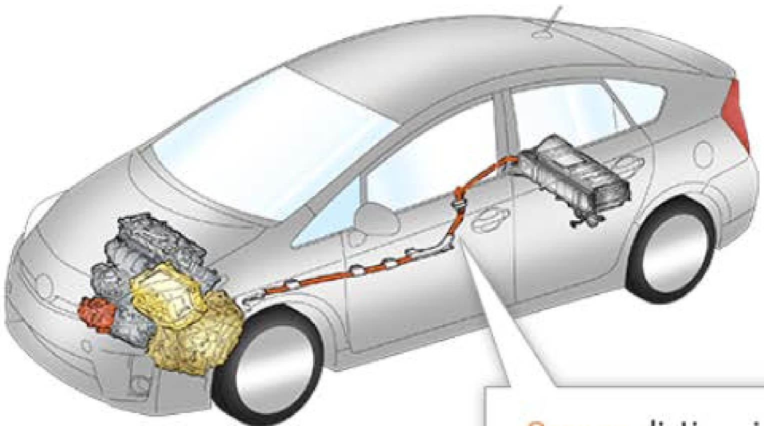
- Li-ion batteries have multiple stacks, each with 14 or more cells contained in a metal case
- Stacks are connected in series to obtain high voltage (207 V)
- A catastrophic crash breaching the metal case, battery frame, and cells would be rare
- Even if a cell is crushed or cracked, the cell separators absorb the electrolyte and leakage is unlikely
- If any electrolyte leaks, it should only be a small amount
  - Electrolyte quickly evaporates
  - A small amount can irritate the eyes, nose, throat, and skin

Warnings

- Li-ion electrolyte is flammable and damages human tissues
- Evaporating electrolyte from a burning Li-ion battery may irritate the eyes, nose, and throat
- To avoid injury from coming into contact with Li-ion electrolyte or vapor, all responders in the hot zone should wear the proper Personal Protective Equipment (PPE) for fire fighting including rubber gloves, eye protection, protective mask, or Self Contained Breathing Apparatus (SCBA)
- Keep spilled Li-ion electrolyte away from fire and ensure the area is well ventilated
- Absorb spilled Li-ion electrolyte and store the absorption material in an airtight container until properly disposed of

High Voltage Power Cable

- Connects high voltage electrical components
- Located in the engine/motor compartment and running near the centerline of the vehicle

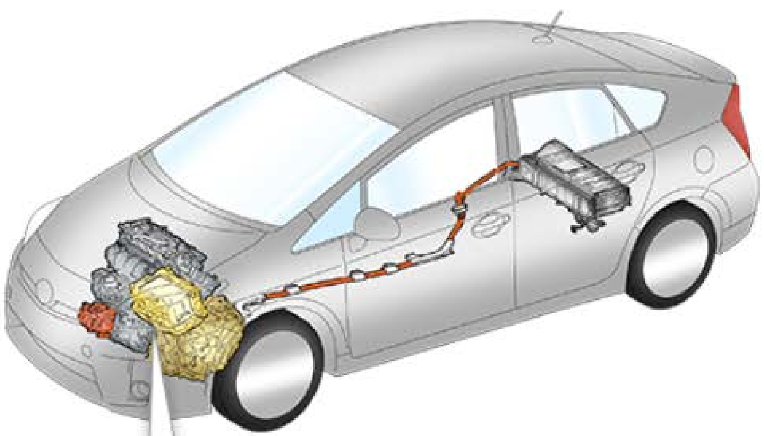


- High Voltage Battery
- Inverter/Converter
- Hybrid Transaxle
- A/C Compressor

Orange distinguishes the cable as high voltage.

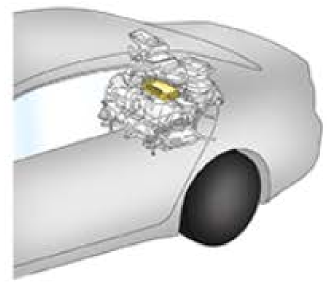
Inverter/Converter

Boosts high voltage from the high voltage battery
Changes DC to 3-phase AC to drive the electric motor



Inverter/Converter:
- Inverter
- Boost Converter
- DC-DC Converter

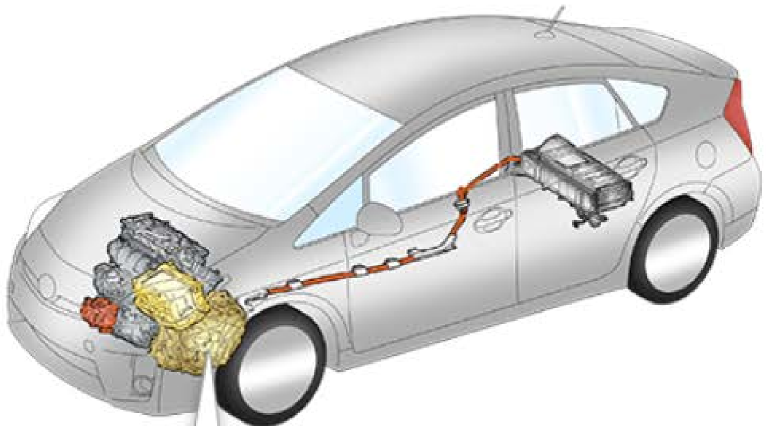
DC-DC Converter
- Steps high voltage down to approximately 14 V DC
- Charges the 12 V battery and powers accessories
- Integrated with the inverter/converter or located near the high voltage battery (depending on model)



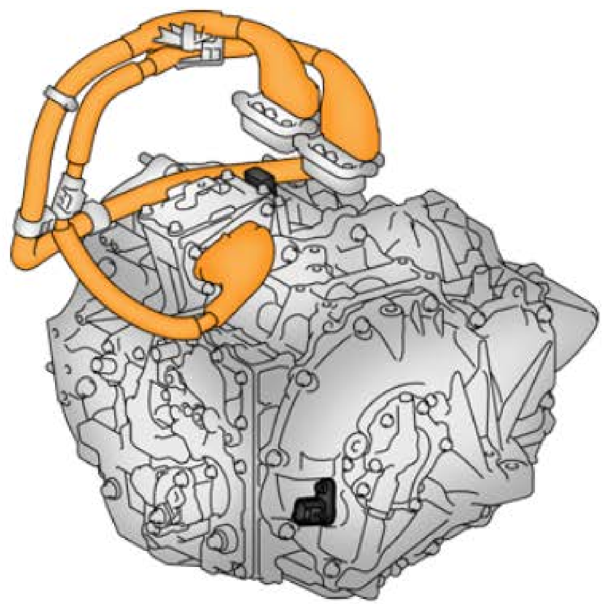
Refer to the individual vehicle Emergency Response Guide/Emergency Response Quick Reference Sheet for the location of high voltage components.

HV/EV Transmission/Transaxle

- Has an electric motor/generator that drives the vehicle's wheels and recharges the high voltage battery
- The inverter/converter powers the motor/generator with up to 650 V AC



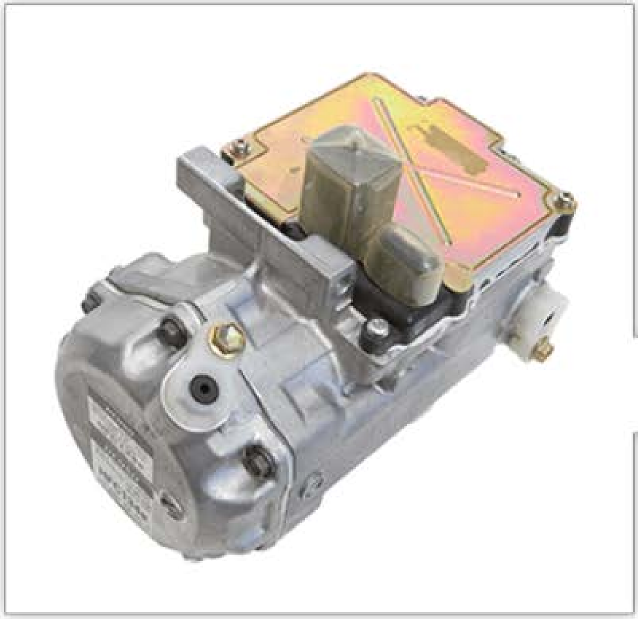
Hybrid Transaxle:
- Located in the engine/motor compartment
- Exact location depends on the vehicle layout

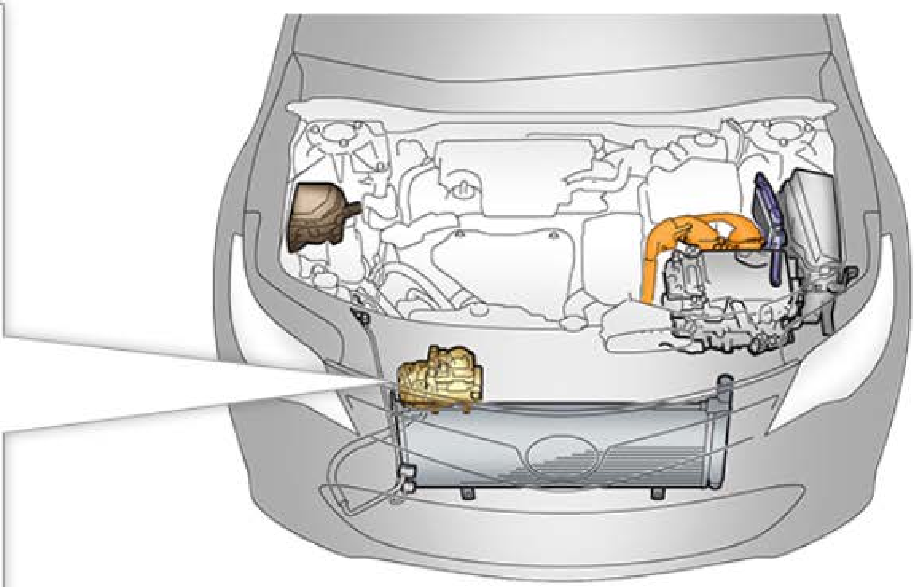


Rear Drive Motor
AWD models also have a rear transaxle with an electric motor that drives the rear wheels. The rear drive motor is located above the rear drive shafts, and it is also powered by the inverter/converter.

A/C Compressor

HVs and EVs use an electric air conditioning compressor that operates on voltages as high as 300 V. A dedicated inverter converts high voltage from the high voltage battery into 3-phase AC.





Toyota Avalon Hybrid shown

Charging Inlet

- PHVs and EVs have a charging inlet to charge the high voltage battery
- Current Toyota PHVs and EVs use SAE J1772 level 1 and level 2 protocol
- External power supply cable will be energized during charging

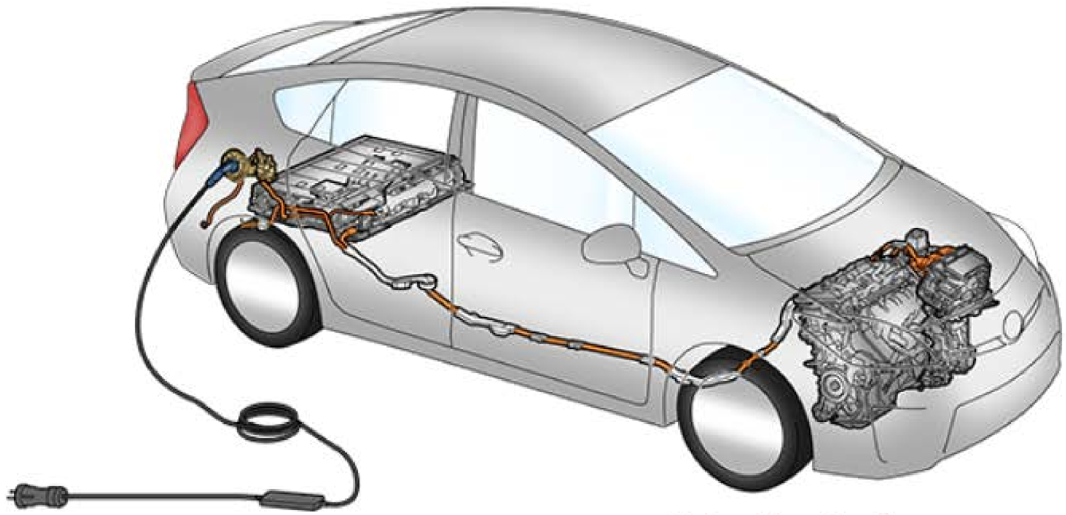
If the vehicle, charge cable, or charger is submerged in water, shut off the utility circuit supplying power to the charge cable before disconnecting it to prevent serious injury or death from severe burns or electric shock.

- If the charge cable assembly connector lock cannot be released, turn the external charger OFF, unplug it, or turn its main breaker OFF
- The charge cable assembly connector lock cannot be released during quick charging
- If charging does not stop even when the charger is turned OFF, turn its main breaker OFF

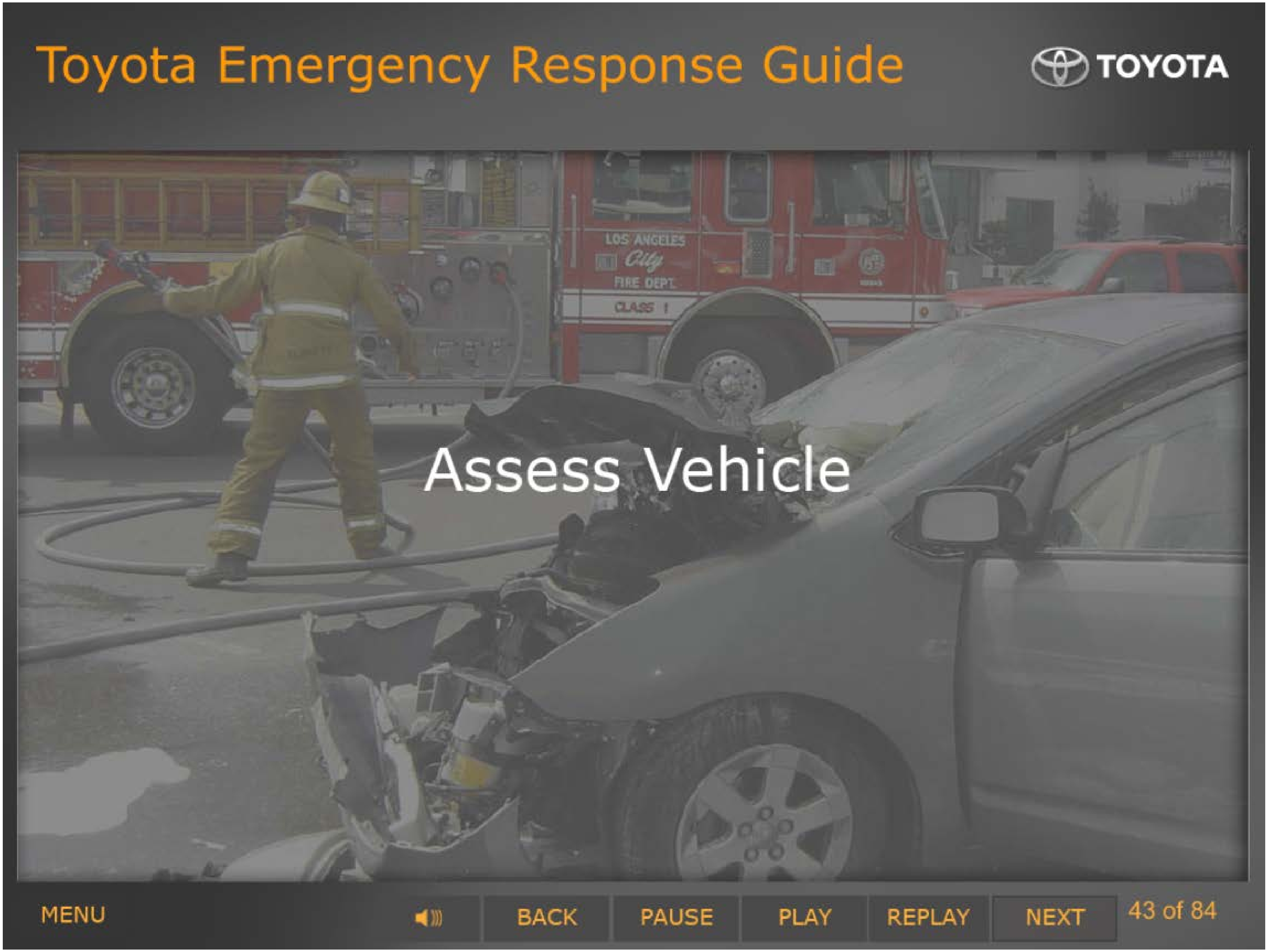
Onboard Charger

PHVs and EVs have an onboard charger that converts AC power from an external power source to DC, boosts it, and then uses it to charge the high voltage battery. Orange on-board charger cabling is energized during charging.

The onboard charger may be located in the engine/motor compartment or in the HV battery assembly. Refer to the vehicle's Emergency Response Guide/Emergency Response Quick Reference Sheet for the specific location of the onboard charger.



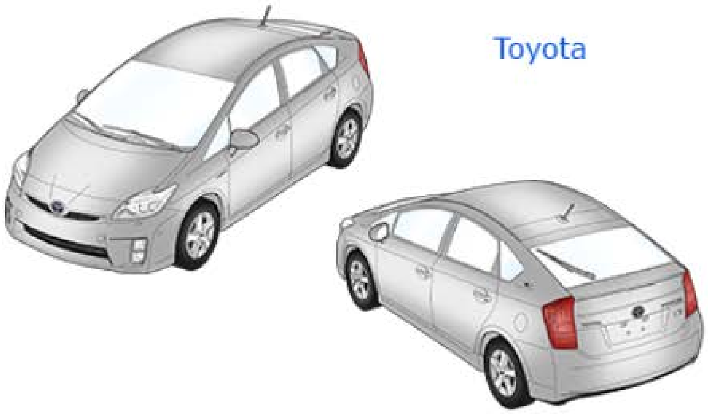
Prius Plug-in shown


Toyota Emergency Response Guide
TOYOTA
LOS ANGELES
City
FIRE DEPT.
CLASS I
Assess Vehicle
MENU
BACK
PAUSE
PLAY
REPLAY
NEXT
43 of 84

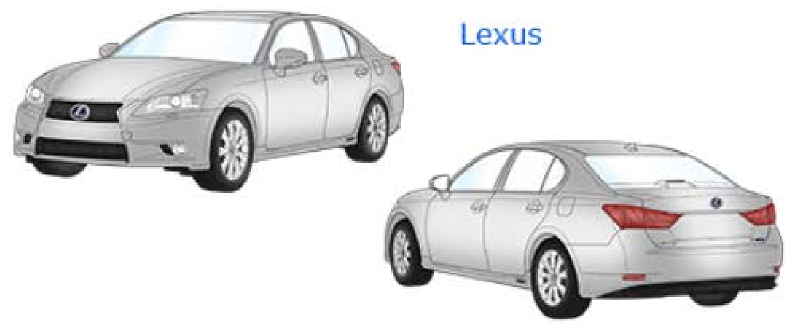
Exterior

If a vehicle uses a high voltage electrical system, badges and other exterior cues help you identify it as a hybrid or electric vehicle. The individual vehicle Emergency Response Guide/Emergency Response Quick Reference Sheet shows the specific location of badges.

Select the links to see the badges.



Toyota



Lexus

Scion

Assess Vehicle

Toyota
- Some models may have blue tinted headlamps
- PHVs and EVs have a charge inlet door (refer to the Powertrain High Voltage System section)

Lexus
- Blue tinted headlamps and taillamps

Scion

Interior

To identify a hybrid or electric vehicle from the interior, look for the following:

- Instrument cluster READY indicator (illuminated when the vehicle is ON and operational)
- Hybrid system indicator in place of a tachometer (may be blacked out if the vehicle is shut off)
- May have a "B" shift lever position

Blue tinted shift selector

Toyota Emergency Response Guide

TOYOTA

Assess Vehicle

Engine/Motor Compartment

You can identify a vehicle as an HV, PHV, or EV from the orange high voltage power cables and the cover in the engine/motor compartment.

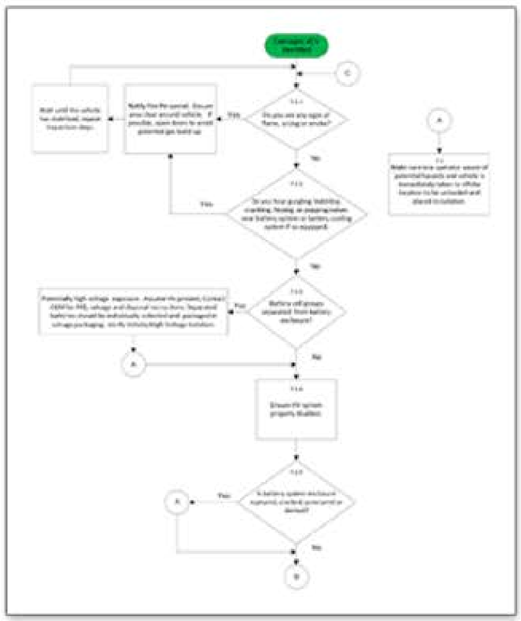
Hybrid models have an under hood label that identifies battery locations and type of high voltage battery

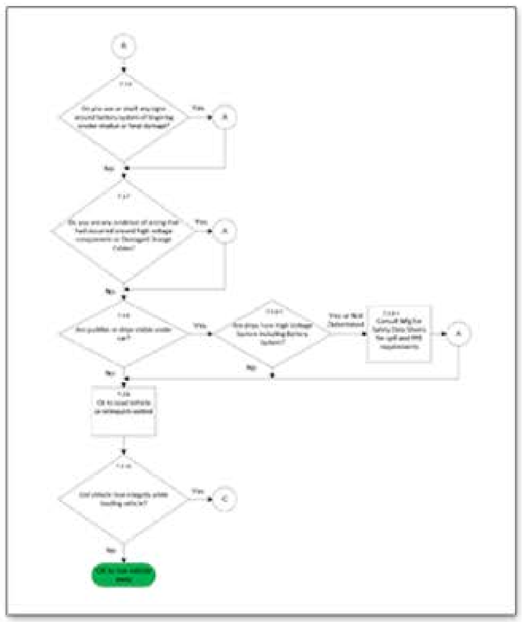
Vehicle Inspection

SAE standard J2990, "Hybrid and EV First and Second Responder Recommended Practice," includes a useful flow chart for on scene inspection of high voltage vehicles.

You may purchase this standard from SAE International by calling 1-877-606-7323 or by ordering online at http://standards.sae.org/j2990_201211/.

On Scene High Voltage Vehicle Inspection Flow Chart





SAE standards help ensure the safety, quality, and effectiveness of products and services across the mobility engineering industry.

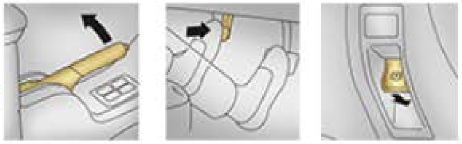
Immobilize Vehicle

Immobilize Vehicle

On arrival, immobilize the vehicle following these steps:

1. Chock the wheels and set the parking brake

The vehicle may have a lever, foot pedal, or switch-type parking brake.



2. Shift the vehicle into Park

Some models use an electronic gearshift selector:

- Press the P position switch near the gearshift selector
- This switch also sets the parking brake on some models

3. Enable Access

Before shutting the vehicle down:

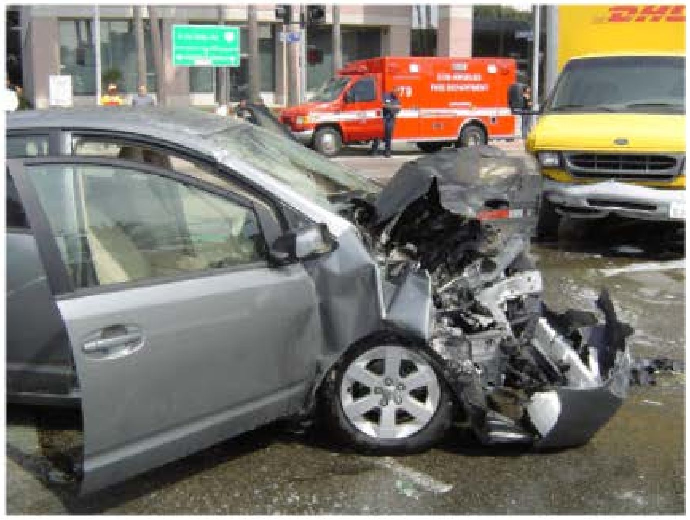
- Lower windows
- Open back door (if equipped)
- Unlock doors
- Move seats and steering wheel

Once the 12 V battery is disconnected, power controls will not operate.

- To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component
- Wear protective equipment including insulated gloves when there is a risk of touching a high voltage power cable or component


Disable Vehicle
LOS ANGELES
City
FIRE DEPT.
CLASS I

Confirm Vehicle Status



The purpose of disabling the vehicle is to shut off the fuel supply, high voltage supply, and electrical power to the SRS.

The vehicle is on if any of these conditions are met:

- Engine is running
- Ignition switch is in ACC, ON, or START position
- Meters are illuminated
- Air conditioning, audio system, or wipers are operating
- Navigation or other displays are on

Disable Vehicle

Warnings

- Never assume a vehicle is off because it is silent
  - The vehicle may be equipped with an idling stop system
- Always observe the instrument cluster for the READY indicator status to verify whether the high voltage system is on or off
- When the vehicle is equipped with a remote air conditioning system and the meters are illuminated, high voltage may be applied to the air conditioning system even though the READY indicator is off
  - Shut off and disable the vehicle and ensure the meters are off
- Failure to shut off and disable the vehicle before performing emergency response procedures may result in serious injury or death from unintentional deployment of the SRS or unintentional actuation of the seatbelt pretensioners or active headrests
- **Hint:** If the vehicle is shut off, the instrument cluster gauges will be "blacked out" (not illuminated)

Shut Vehicle Off

1. Press the Engine/Power switch once or turn the ignition switch to the LOCK (OFF) position

If equipped with an Engine/Power switch, the vehicle is shut off when all of the following conditions are met:
- Engine is not running
- Meters are not illuminated
- A/C, audio system, or wipers are not operating
- Navigation or other displays are off

Operating the Engine/Power Switch
With the brake pedal depressed, pressing the switch toggles between Stop and Start. If the brake pedal is not depressed, the vehicle will not start.

With the brake pedal released, pressing the switch toggles between Accessory, Ignition-On, and Off.

Click here to see a diagram of the ignition mode sequence.

2. When equipped with an Engine/Power switch, keep the electrical key transmitter outside the detection area (16 ft. or more away from the vehicle).

⚠ If the electrical key transmitter is in the cabin or near the vehicle, it could start unexpectedly.

3. Disconnect the 12 V battery's negative terminal.

The 12 V battery location varies. Refer to each vehicle's Emergency Response Guide/Emergency Response Quick Reference Sheet for the specific location.

⚠ Shutting off the power to the electrical system helps prevent electrical fires and keeps the vehicle from starting.

Click the links to learn more.

Ignition Mode Sequence

Brake pedal depressed:

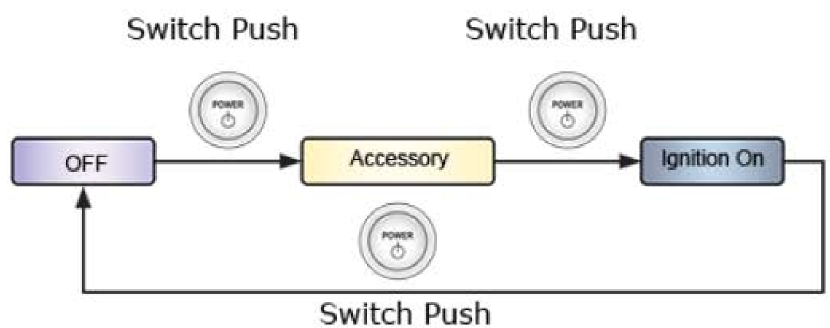
Pressing the Engine/Power switch toggles between Stop and Start.

Brake pedal released:

Pressing the Engine/Power switch toggles between Accessory, Ignition-On, and Off.

In Accessory mode, the radio and other components operate.

In Ignition-On mode, the power windows, wipers, HVAC, and SRS are operational.



12 V Battery Locations

In trunk

Under rear seat

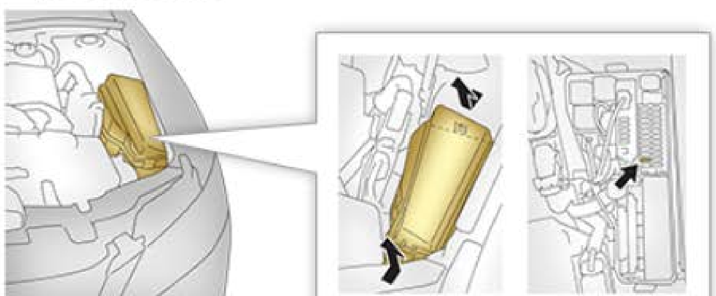
Depending on the model, the 12 V battery is located in the engine compartment, the luggage compartment, or under the rear seat.

Shut Vehicle Off – Alternate Procedure

If the ignition switch or Engine/Power switch is inaccessible or inoperative, follow this alternate procedure to disable the vehicle:

1. Open the engine compartment fuse box cover and remove the appropriate fuse.

   Refer to each vehicle's Emergency Response Guide/Emergency Response Quick Reference Sheet for the location of the fuse box.



Cover Removed

2. Disconnect the 12 V battery's negative terminal.
   Depending on the model, the 12 V battery is located in the engine compartment, the luggage compartment, or under the rear seat.

   Refer to each vehicle's Emergency Response Guide/Emergency Response Quick Reference Sheet for the specific location.

Shutting off the power to the electrical system helps prevent electrical fires and keeps the vehicle from starting.

If you can't identify the correct fuse, pull **all** the fuses until all of the following conditions are met:

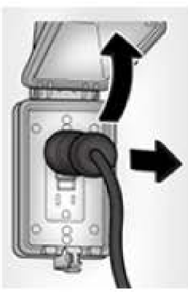
- Engine is **not** running
- Meters are **not** illuminated
- Air conditioning, audio system, or wipers are **not** operating
- Navigation or other displays are **off**

When Charging – Vehicle With Plug-in Charge System

An external power source charges the high voltage battery in PHVs and EVs. If a charge cable is connected to the vehicle's charging inlet, disconnect the cable to stop charging:

1. Push the latch release button on top of the charge cable connector and pull it away from the vehicle's charging inlet.

> ⚠ If you can't release the charge cable assembly connector lock, turn off the external power source. If the lock is still not released:
>
> - Unplug the external charger or turn the main breaker off
> - Disconnect the charge cable assembly from the charge inlet



Wall-mounted Outlet

Home Charging Station

2. Close the charging inlet cap and charging port lid.

3. Turn off the external power source by unplugging it or turning its main circuit breaker off.

> ⚠ If the vehicle, charge cable, or charger is submerged in water, shut off the utility circuit supplying power to the charge cable before disconnecting it to prevent serious injury or death from severe burns or electric shock.


LOS ANGELES
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FIRE DEPT.
CLASS I
Access Patients

Overview

- Immobilize and disable the vehicle
- Open or remove windows and doors to access patients
- Secure the necessary space by adjusting the position of the steering wheel and seats and removing the head rests
- Crib the vehicle to stabilize it
- Cut the vehicle to gain access to the patient

Overview

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Immobilize Vehicle

On arrival, immobilize the vehicle following these steps:

1. **Chock the wheels and set the parking brake**
2. **Shift the vehicle into Park**
   Some models use an electronic gearshift selector:
   - Press the P position switch near the gearshift selector
   - This switch also sets the parking brake on some models
3. **Enable access**
   Before shutting the vehicle down:
   - Lower windows
   - Open back door (if equipped)
   - Unlock doors
   - Move seats and steering wheel

Once the 12 V battery is disconnected, power controls will not operate.

Overview

- Immobilize and disable the vehicle
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Disable Vehicle

To shut the vehicle off, press the Engine/Power switch once or turn the ignition switch to the Lock (OFF) position.

When equipped with an Engine/Power switch, keep the electrical key transmitter outside the detection area (16 ft. or more away from the vehicle).

Disconnect the negative terminal of the 12 V battery. Refer to each vehicle's Emergency Response Guide or Emergency Response Quick Reference Sheet for the location of the 12 V battery.

Access Patients

Warnings

- The SRS, seatbelt pretensioners, and active headrests may remain powered for up to 90 seconds after the vehicle is shut off and disabled
  - Wait 90 seconds after shutting off and disabling the vehicle
  - Failure to shut off and disable the vehicle before performing emergency response procedures may result in unintentional airbag deployment or unintentional actuation of seatbelt pretensioners or active headrests, causing serious injury or death
- Cutting an undeployed SRS airbag, seatbelt pretensioner, or active headrest inflator may cause it to explode
- Immediately after SRS airbag deployment, seatbelt pretensioner actuation, or active headrest actuation, the components are extremely hot and may cause burns if touched
- If an SRS airbag deploys with all doors and windows closed, inflation gas may cause breathing difficulty
- If residue produced during SRS deployment, seatbelt pretensioner actuation, or active headrest actuation contacts the skin, rinse it off immediately to prevent irritation
- The high voltage system may remain powered for up to 10 minutes after the vehicle is shut off and disabled
- Failure to shut off and disable the vehicle before performing emergency response procedures may result in serious injury or death from severe burns and electric shock
- To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component

Warnings

- The SRS, seatbelt pretensioners, and active headrests may remain powered for up to 90 seconds after the vehicle is shut off and disabled
  - Wait 90 seconds after shutting off and disabling the vehicle
  - Failure to shut off and disable the vehicle before performing emergency response procedures may result in unintentional airbag deployment or unintentional actuation of seatbelt pretensioners or active headrests, causing serious injury or death
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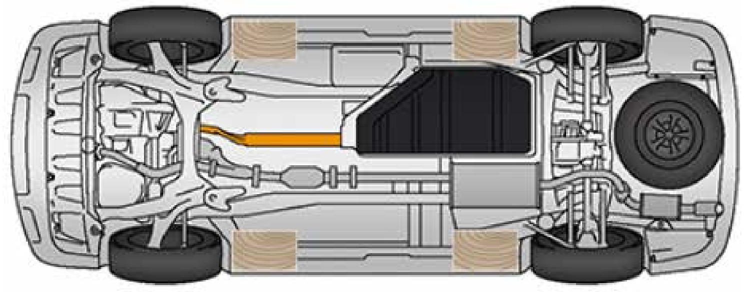
Disconnect the negative terminal of the 12 V battery. Refer to each vehicle's Emergency Response Guide or Emergency Response Quick Reference Sheet for the location of the 12 V battery.

Stabilize Vehicle

Crib at four points directly under the front and rear pillars.



Optimal cribbing points

Lexus LS400h L shown

- Cribbing under the exhaust system, fuel system, high voltage battery, or high voltage power cables may generate heat, burst air lifting bags, or damage the high voltage power cables
- This may result in a vehicle fire, crushing accident, or electrical shock, possibly leading to serious injury or death

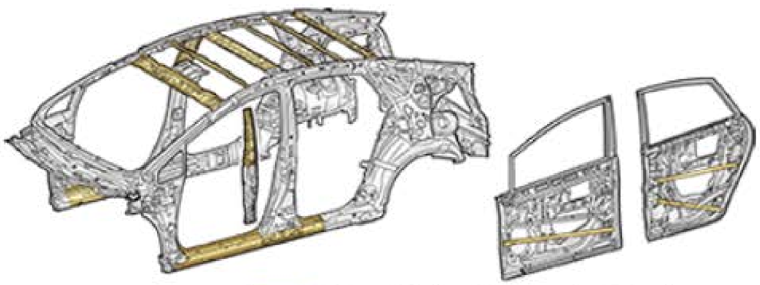
Cut Vehicle

When cutting, pay attention to the location of:

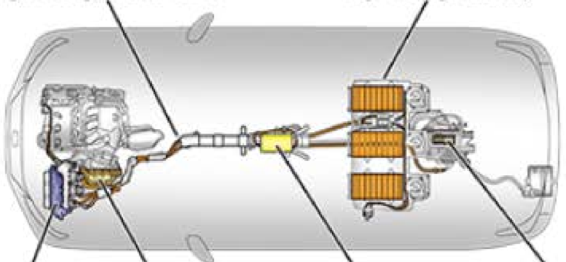
- Ultra high strength steel
- Fuel system
- SRS
- High voltage electrical system components

Note: If the SRS airbag, seatbelt pretensioners, or active headrests have already been activated, the inflator can be cut.

Consult the individual vehicle Emergency Response Guide/Emergency Response Quick Reference Sheet for locations.



Ultra High Strength Steel



High Voltage Components

To prevent serious injury from a fire caused by sparks, use a hydraulic cutter or other tools that do not produce sparks when cutting.

Vehicle Fire

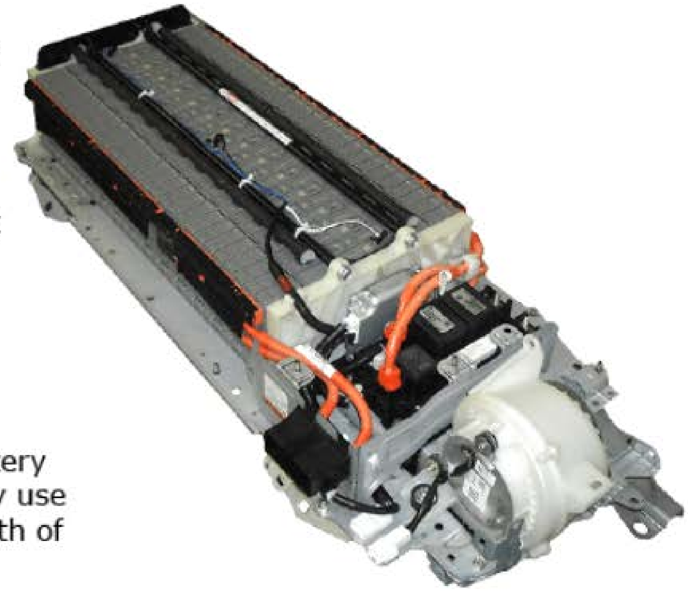
Introduction

- When attacking an HV, PHV, or EV fire, use copious amounts of water to extinguish the fire and cool the high voltage battery
- The high voltage battery is difficult to access in some vehicles
- If it is difficult to apply copious amounts of water to the high voltage battery, allow the battery to burn itself out
- Refer to the individual vehicle Emergency Response Guide/Emergency Response Quick Reference Sheet for the location of the high voltage battery

- To avoid serious injury or death from severe burns or electric shock, never breach or remove the high voltage battery assembly cover under any circumstances, including fire
- If only a small amount of water is used to extinguish a fire, a short circuit may occur in the high voltage battery, causing the fire to reignite
- Because toxic gases are by-products of combustion, all responders in the hot zone should wear the proper Personal Protective Equipment (PPE), including Self Contained Breathing Apparatus (SCBA)

Ni-MH Battery

To attack a Ni-MH battery fire, use copious amounts of water at a safe distance or let the fire burn itself out.

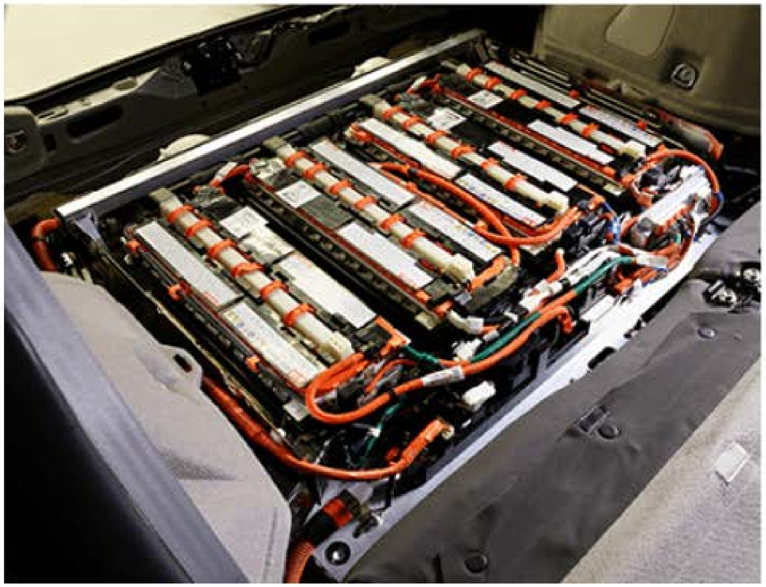


Normally, flooding a Ni-MH high voltage battery with water controls battery fires by cooling adjacent modules below the ignition temperature. Remaining modules not extinguished by water will burn out.

However, flooding the Avalon Hybrid high voltage battery pack is not recommended. The battery case design and location prevent responders from safely applying water through the vent openings. We recommend letting the Avalon Hybrid high voltage battery pack burn itself out.

Defensive Fire Attack
In a defensive attack, pull back a safe distance and allow Ni-MH battery modules to burn out. During this defensive operation, fire crews may use a water stream or fog pattern to protect exposures or control the path of smoke.

Li-ion Battery



To attack a Li-ion battery fire, use copious amounts of water at a safe distance or let the fire burn itself out.

This is particularly true for large format Li-ion batteries like those in the Prius Plug-in Hybrid and second generation RAV4 EV. It is nearly impossible to extinguish burning high voltage batteries in these vehicles.

There is a potential for delayed ignition or re-ignition of a Li-ion battery fire even after it is believed to be extinguished. This may remain an issue until the Li-ion battery is properly discharged.

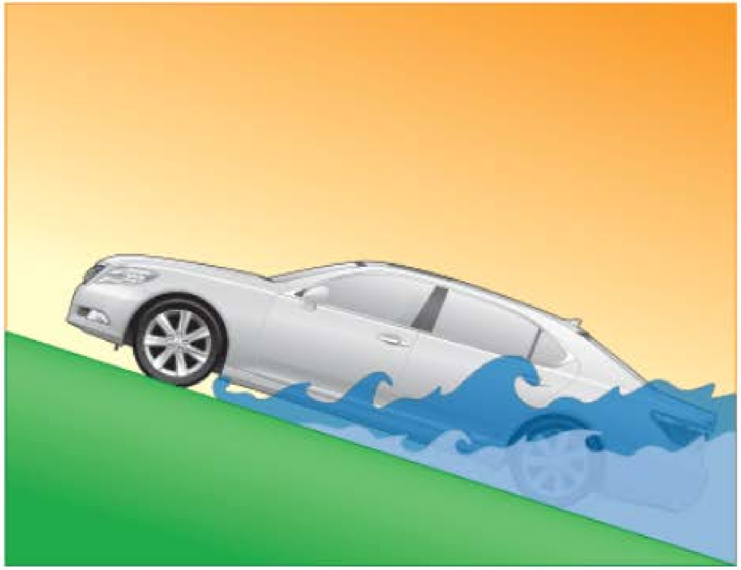
Vehicle Submersion

TOYOTA

Vehicle Submersion

Introduction

- If an HV, PHV, or EV is fully or partially submerged in water, pull it out as much as possible
- Immobilize and disable the vehicle before performing emergency response procedures
- To prevent a vehicle fire, do not turn a submerged vehicle's ignition switch to ACC or ON or set the Engine/Power switch to Ignition-On
- A submerged HV, PHV, or EV does not have high voltage potential on the vehicle body and is safe to touch
- It is safe to enter the water as the vehicle and water have the same electrical potential
- After some time has passed, electrical corrosion may cause a short circuit leading to a vehicle fire



- Touching exposed orange high voltage power cables or high voltage components may cause electrical shock due to a change in electrical potential
- To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component
- Wear protective equipment such as **insulated gloves** when there is a risk of touching high voltage power cables or high voltage components

Introduction

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Immobilize Vehicle

On arrival, immobilize the vehicle following these steps:

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   Some models use an electronic gearshift selector:
   - Press the P position switch near the gearshift selector
   - This switch also sets the parking brake on some models
3. **Enable access**
   Before shutting the vehicle down:
   - Lower windows
   - Open back door (if equipped)
   - Unlock doors
   - Move seats and steering wheel

Once the 12 V battery is disconnected, power controls will not operate.

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Disable Vehicle

To shut the vehicle off, press the Engine/Power switch once or turn the ignition switch to the Lock (OFF) position.

When equipped with an Engine/Power switch, keep the electrical key transmitter outside the detection area (16 ft. or more away from the vehicle).

Disconnect the negative terminal of the 12 V battery. Refer to each vehicle's Emergency Response Guide or Emergency Response Quick Reference Sheet for the location of the 12 V battery.

- Touching exposed orange high voltage power cables or high voltage components may cause electrical shock due to a change in electrical potential
- To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component
- Wear protective equipment such as **Insulated gloves** when there is a risk of touching high voltage power cables or high voltage components

Spills

12 V Battery Electrolyte

- Dilute sulfuric acid may irritate the skin if contacted
- Wear appropriate protective equipment such as rubber gloves and eye protection when there is a risk of touching electrolyte
- Contact the OEM for Safety Data Sheets for battery electrolyte in case of spills
- Reference Safety Data Sheets for proper Personal Protection Equipment and disposal instructions

Nickel-Metal Hydride (Ni-MH) Battery

- Even if a module cracks, the cell plates absorb the electrolyte and it will not normally leak
- Electrolyte leakage is unlikely due to the amount of electrolyte contained within the modules
- A Ni-MH electrolyte leak is not a hazardous material incident
- Refer to the Powertrain High Voltage System section for more information about nickel-metal hydride (Ni-MH) high voltage batteries

- Ni-MH battery electrolyte is a caustic alkaline (pH 13.5) that damages human tissues
- To avoid injury, wear appropriate protective equipment (rubber gloves and eye protection) when there is a risk of touching electrolyte

Lithium ion (Li-ion) Battery

- Even if a cell is crushed or cracked, the cell separators absorb the electrolyte and leakage is unlikely
  - If any electrolyte leaks, it should only be a small amount
  - Electrolyte quickly evaporates
- A small amount can irritate the eyes, nose, throat, and skin
- Refer to Powertrain High Voltage System section for more information about Lithium ion (Li-ion) high voltage batteries

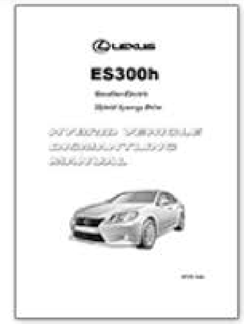
⚠

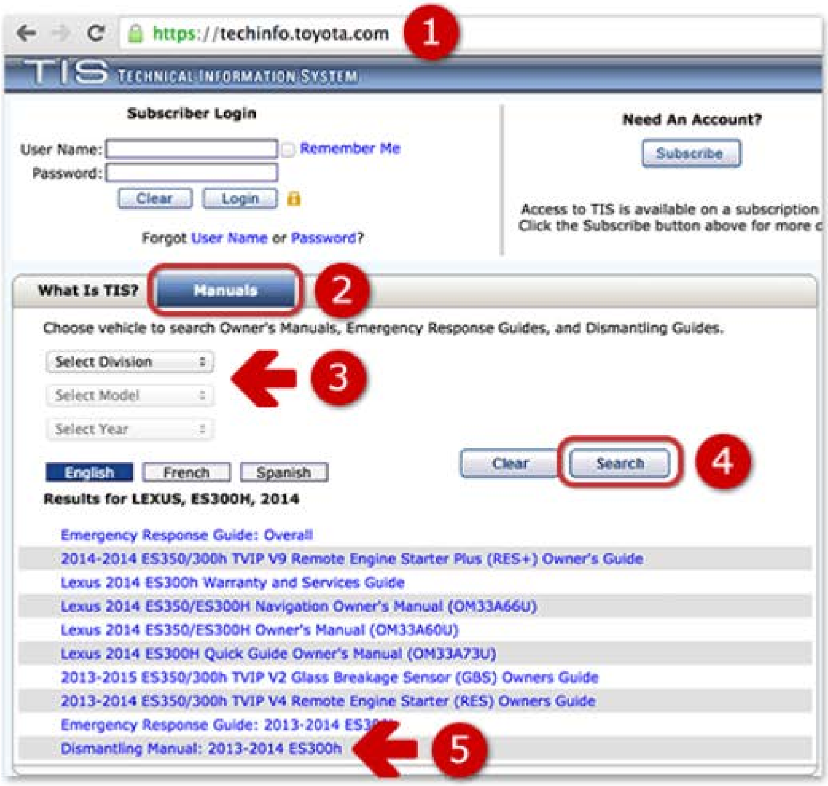
- Li-ion electrolyte is flammable and damages human tissues
- Burning Li-ion batteries may irritate the eyes, nose, and throat
- Li-ion electrolyte vapor may irritate the nose and throat
- To avoid injury by coming into contact with Li-ion electrolyte or vapor, wear appropriate protective equipment (rubber gloves, eye protection, protective mask, or SCBA) when there is a risk of touching electrolyte
- Keep spilled Li-ion electrolyte away from fire and ensure the area is well ventilated
- Absorb spilled Li-ion electrolyte and store the absorption material in an airtight container until disposed of

Second Responder Resources

Dismantling Manuals

Dismantling Manuals assist dismantlers in the safe handling of Toyota and Lexus vehicles with high voltage electrical systems.





To access the Dismantling Manuals:

1. Type techinfo.toyota.com into your browser.

   This is an open site that does not require subscriber login.

2. Click the Manuals tab.
3. Using the dropdowns, select a Division, Model, and Model Year.
4. Click the Search button.
5. A list of results will be displayed. Click Dismantling Manual to open the document in a browser window.

SAE Standards

SAE standard J2990, "Hybrid and EV First and Second Responder Recommended Practice"
Provides first and second responders with the ability to avoid hazards associated with the high voltage system, communicate hazards to other responders, and manage risks.

SAE standard J2950, "Recommended Practices for Shipping, Transport, and Handling of Automotive-Type Battery System - Lithium Ion"
Helps you identify, handle, and ship lithium-ion batteries, and provides information about U.S. and International hazardous materials (dangerous goods) transportation regulations.

You may purchase these standards from SAE International by:

- Calling 1-877-606-7323
- Ordering online at http://standards.sae.org/

Toyota Emergency Response Guide

TOYOTA

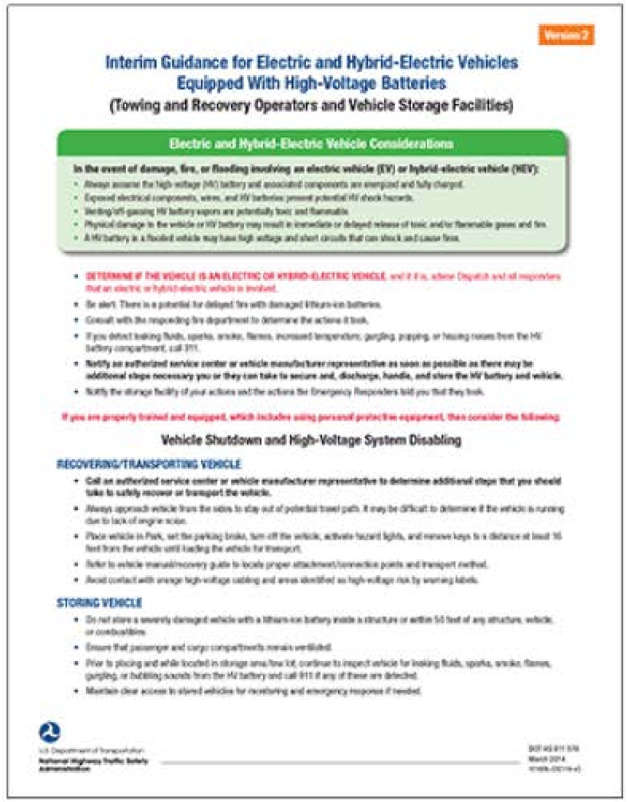
Second Responder Resources

NHTSA

The National Highway Traffic Safety Administration (NHTSA) has released three variations of "Interim Guidance for Electric and Hybrid-Electric Vehicles:"

- Emergency Responders
- Tow/Recovery/Storage
- Owners

Select the image to open the version for Tow/Recovery/Storage.


Version 2

Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High-Voltage Batteries

(Towing and Recovery Operators and Vehicle Storage Facilities)

Electric and Hybrid-Electric Vehicle Considerations

In the event of damage, fire, or flooding involving an electric vehicle (EV) or hybrid-electric vehicle (HEV):

- Notify an authorized service center or vehicle manufacturer representative as soon as possible as there may be additional steps necessary you or they can take to secure and, discharge, handle, and store the HV battery and vehicle.

If you are properly trained and equipped, which includes using personal protective equipment, then consider the following:

Vehicle Shutdown and High-Voltage System Disabling

RECOVERING/TRANSPORTING VEHICLE

- Call an authorized service center or vehicle manufacturer representative to determine additional steps that you should take to safely recover or transport the vehicle.

STORING VEHICLE

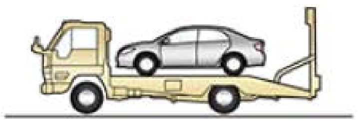
National Highway Traffic Safety Administration

March 2014

Towing

Towing

Preferred Method



Tow all HVs, PHVs and EVs on a flat bed with all four wheels off the ground:
- Before loading the vehicle, disconnect the 12 V battery's negative terminal
- Refer to each vehicle's Emergency Response Guide/Emergency Response Quick Reference Sheet for towing information and the location of the 12 V battery

Only front-wheel drive vehicles may be towed with the rear wheels on the ground.

Consult with the responding fire department on the actions it took.
First responders **must** inform tow operators of HV, PHV, and EV hazards during transit and storage:
- **High voltage**
  - To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component
  - Wear protective equipment such as insulated gloves when there is a risk of touching high voltage power cables or high voltage components
- **Potential for the high voltage battery to re-ignite after a vehicle fire**
- **Leaking high voltage battery electrolyte**
  - Wear appropriate protective equipment
    - Ni-MH battery: rubber gloves and eye protection
    - Li-ion battery: rubber gloves, eye protection, protective mask, or Self Contained Breathing Apparatus (SCBA)

Alternate Method

Use this alternate towing method only when towing with all four wheels on the ground is unavoidable:

1. Release the parking lock

   Move the shift lever from P to N while pressing and holding the lock release button.

If equipped with a P position switch, you can't release the parking lock if the 12 V battery is disconnected.

- Use wheel dollies to move the vehicle

2. Unlock the steering wheel
   Press the Engine/Power switch until in Ignition-On mode or turn the ignition switch to any position other than LOCK.

If equipped with the electrical key transmitter, the steering wheel can't be unlocked if the 12 V battery is disconnected

- Use wheel dollies to move the vehicle

3. Tow the vehicle in a forward direction at a low speed (under 20 mph) only for a short distance (up to 50 miles)

⚠

Make sure the vehicle is in "Ignition-On" mode.

- If the vehicle is in "Off" mode, the steering wheel may lock, making steering inoperative

Towing with all four wheels on the ground may damage the:

- Transmission when exceeding the speed or distance limit, or when the vehicle being towed is facing backward
- High voltage electrical system
- Idling stop system (if equipped)

Storage

Before Storing

Before storing a wrecked HV, PHV, or EV:

- Disconnect the negative 12 V battery terminal
- Drain fuel and oil
- Remove the service plug

Refer to the vehicle's Dismantling Manual for service plug location and removal steps.

Once you remove the service plug, place it in a secure location.

Only certifed Hybrid Technichians should handle high voltage battery packs.

If a vehicle was submerged

Select the link to learn more

- To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component
- The service plug is a high voltage component
- Wear protective equipment including **insulated gloves** when there is a risk of touching a high voltage power cable or component
- Touching the service plug without appropriate protective equipment may result in serious injury or death from severe burns and electric shock from the high voltage electrical system

Before Storing

Before storing a wrecked HV, PHV, or EV:

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- Drain fuel and oil
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Refer to the vehic
removal steps.

Once you remove

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If a vehicle was su

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If a Vehicle was Submerged:

- Drain the water
- Disconnect the 12 V battery and the high voltage battery service plug
- Store in an outdoor location, at least 50 feet away from other vehicles, buildings, and combustibles
  - Electrical corrosion may cause a short circuit leading to a vehicle fire
- Do not turn the ignition switch to ACC or ON or set the Engine/Power switch to Ignition-On

- To prevent serious injury or death from severe burns and electric shock, do not touch, cut, or breach any orange high voltage power cable or high voltage component
- The service plug is a high voltage component
- Wear protective equipment including **insulated gloves** when there is a risk of touching a high voltage power cable or component
- Touching the service plug without appropriate protective equipment may result in serious injury or death from severe burns and electric shock from the high voltage electrical system

Storing

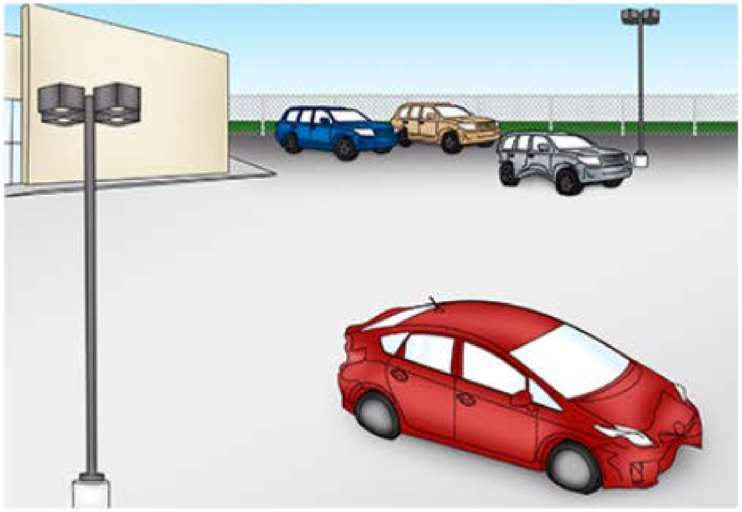
Li-ion Batteries

Vehicles with a Li-ion battery must be stored outdoors, at least 50 feet away from other vehicles, buildings, and combustibles. Always assume the high voltage battery is energized and fully charged.

After some time has passed, a short circuit due to impact or electrical corrosion in the high voltage battery may cause a fire. Call 911 if electrolyte fluid appears to be leaking from the high voltage battery, if you observe sparks, smoke, or flames, or hear gurgling, bubbling, popping, or hissing sounds.

Ni-MH Batteries

Fire will largely consume most Ni-MH batteries. Pay particular attention to the large format Ni-MH battery in the first generation RAV4 EV. If this battery smolders, store it at least 50 feet away from other vehicles, buildings, and combustibles, and monitor it closely.



Select the icons to print each warning sign

Inspecting Lithium ion (Li-ion) Batteries

Li-ion batteries require special handling to help avoid battery re-ignition after a fire has been extinguished on a Plug-in Hybrid Vehicle with a Lithium ion high voltage battery.

- To determine the high voltage battery type and location, refer to the individual Dismantling Manual
- Read the warning label on the high voltage battery cover

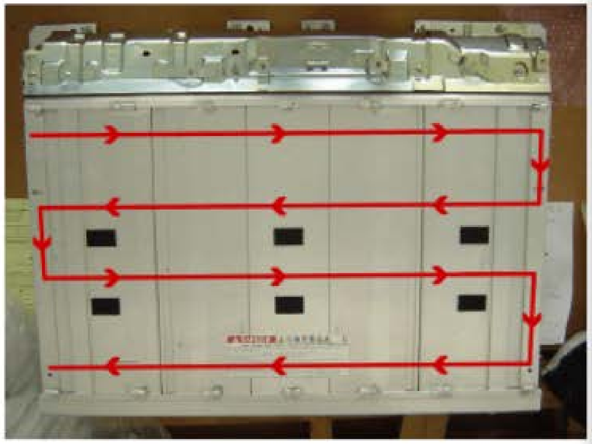
Procedure
If accessible, inspect the Lithium-ion battery for thermal runaway:

- Hold thermometer approximately 12-18 inches above the battery case and scan in the pattern shown
- Scan to the edges of the battery case
- Record the highest temperatures
- Repeat the procedure after approximately 1 hour

Recorded high temperatures should have changed **towards** ambient temperature, or remain **near** ambient.

If temperatures are changing **away** from ambient, move the battery to a safe area, preferably outside. It may have to be completely discharged by authorized recovery personnel using specialized equipment.

This procedure requires you to handle a damaged vehicle. Specialized training, tools, and protective equipment are required to perform these steps. Contact Toyota or authorized service personnel for proper procedures and resources.



Use an infrared thermometer:

- Capable of accuracy within ± 4°F
- Distance to spot ratio ≥ 10:1
- Capable of temperature readings from -4°F to +212°F

Lithium-ion Battery Warning Label

Recycling High Voltage Batteries

- Follow the warning label on the high voltage battery cover when recycling
- Only certified Hybrid Technicians should handle high voltage battery packs
- For information about recycling, contact:
  - Toyota/Lexus dealer
  - Toyota customer assistance (800) 331-4331
  - Lexus customer assistance (800) 255-3987

Ni-MH Battery Warning Label

Vehicle Storage

Shipping

Li-ion

- A Li-ion high voltage battery that has been removed from the vehicle is a Class 9 hazardous material and must be packed and shipped accordingly

- Transportation regulations for shipping Li-ion batteries is provided in SAE standard J2950, "Recommended Practices for Shipping, Transport, and Handling of Automotive-Type Battery System - Lithium Ion"

- Failure to follow current international, federal, and local hazardous materials transportation regulations may result in fines and/or penalties

Ni-MH

- Ni-MH high voltage batteries are not hazardous materials; shipping them as such is a DOT violation

To identify Li-ion and Ni-MH high voltage batteries, refer to the individual Emergency Response Guide/Emergency Response Quick Reference Sheet and the warning label on the battery cover

Toyota Emergency Response Guide

TOYOTA

Conclusion