INTRODUCTION TO FUEL CELL VEHICLES

Instructor Guide

Instructor Guide
January, 2018

LOS ANGELES TRADE-TECH
LATTC
A Community College

TWI
Transportation Workforce Institute

INTRODUCTION TO FUEL CELL VEHICLES

Course Outline
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Course Outline

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Course Overview

This 24-hour course covers Hydrogen Fuel Cell Vehicle Technology at the introductory level. It includes the history of using hydrogen gas as a fuel, the properties of hydrogen, considerations of safety and hazards, hydrogen vehicle fuel systems, and fuel cell vehicle diagnostics and troubleshooting. This course is aimed at hydrogen fuel cell technicians and first responders.

I. Learning Outcomes and Objectives

Course Learning Outcomes

- Participants will understand the design, operation, maintenance, diagnosis and repair of fuel cell vehicles
- Participants will be able to service and maintain fuel cell vehicles
- Participants will be able to safely work in an environment where hydrogen is used as a fuel

Learning Objectives

Upon completion of the course, participants will be able to:

1. Identify historical and current uses for hydrogen as a fuel
2. Discuss advantages of hydrogen as a fuel source
3. Name at least three properties of hydrogen
4. Select appropriate safety attire for working in an environment with hydrogen fuel
5. List two ways to detect a hydrogen leak
6. List several hydrogen combustion methods
7. Follow proper procedures in case of a hydrogen emergencies and first responder procedures
8. First responders will be able to safely and effectively deal with hydrogen fuel cell vehicle emergencies
9. Identify the parts of a fuel cell system
10. Name at least two major pieces of hardware one might find in a hydrogen fuel cell system
11. Diagnose a fuel cell problem using the TIS system

II. Course Agenda

Day 1

Module 00: Introduction	
10 Min	• Recommended Course Materials • Lab Requirements ○ Personal Equipment and Attire ○ Personal Protective Equipment (PPE) ○ Tattoo and Health Disclosure
Module 01: History of Hydrogen Gas as a Fuel	
1.25 Hours	• Discovery and Use • Why Consider Hydrogen as Fuel? • Infrastructure and Demand • Production
Module 02: Hydrogen Gas Safety & Service Procedures	
1.25 Hours	• First Responder Procedures • Properties of Hydrogen • Safe Work Practices • Hydrogen Leaks Module continues…
Lunch	

Lab 01: Hands-on Activities	
1.5 Hours	**Safety Concerns, Emergency Precautions, & Special Equipment** • High voltage rescue and tooling – Intro & demonstration • HV measuring and testing equipment and tooling – Procedure demo

Lab 01: Hands-on Activities	

2 Hours	**Hydrogen Fuel Cell Introduction and Familiarization**
	• Dash Board and Cluster
	    ○ Lamps, symbols and alarms
	    ○ Dashboard control and management
	    ○ Center consul and controls
	• FCV Safety areas and points of concern - HV circuits & high-pressure gas
	• High voltage power and hydrogen systems identification, distribution & layout
	• Turning ON/OFF vehicle
	• Vehicle familiarization and system operation modes

1.5 Hours	**Vehicle Compartments and Access Panels** • Front, passenger cabin and trunk • Undercarriage design, deflection panels and streamlining

Day 2

Module 02: Hydrogen Gas Safety & Service Procedures (continued)	
1.25 Hours	• Hydrogen Flames • Hydrogen Explosions • Electrostatic Discharge
Module 03: Fuel System	
1.75 Hours	• Fuel System Layout • Fuel Cell Stack
Lunch	

Lab 02: Hands-on Activities	
1.5 Hours	**Vehicle Operation** • Noise and feel • Forward, neutral, reverse and park operation • Acceleration and regenerative braking
1.5 Hours	**Onboard Diagnostics** • Software identification • Toyota TIS System intro and demonstration – Connection and access • Positive communication and pairing
1.5 Hours	**TIS Operation** • TIS main menu and contents • System selection • Real-time data monitoring

Day 3

Module 04: Toyota Mirai Fuel Cell	
1.5 Hours	• Fuel Cell Technological Innovations • Toyota's New FC Stack Structure • Fuel Storage and Safety
Module 05: Diagnostics and Troubleshooting	
1.5 Hours	• Techstream
Lunch	

Lab 02: Hands-on Activities	
5 Hours	**Advanced Testing Diagnostics** • Using TIS efficiently along with Smartborad technology • System wiring read and schematic understanding • Diagnostic trouble code and faults – DTCs • TIS navigation and module selection • System testing and output logic comprehension – demonstration • Using wiring diagrams together with TIS for correct diagnosis

III. Course Information

COURSE NAME: Introduction to Fuel Cell Vehicles

APPROVED: TBD

CLASS TIME: 24 Hours

PREREQUISITES: None

TRAINING LOCATION: TBD
TARGET CLASS SIZE: 20-25

TARGET AUDIENCE: Fuel Cell Vehicle Technicians and Emergency Personnel

CERTIFICATE(S): None

TRAINING AIDS AND EQUIPMENT:

- ☑ Smartphone, Tablet, or Laptop
- ☑ PowerPoint Presentations
- ☑ Personal safety equipment
- ☑ Maintenance reference documentation
- ☑ Vehicle Keys (Crew, operating, and maintenance keys)
- ☑ Set of maintenance tools
- ☑ Compact flashlight
- ☑ Laboratory/shop equipment as determined by activity

HANDOUTS:

- ☑ Exercise Handouts
- ☑ Participant Handouts

PARTICIPANT EVALUATION METHODS:

- Written Final Assessment TBD
- Practical Skill Assessment TBD

RESOURCES & LAB EXERCISES

Introduction to Fuel Cell Vehicles
January, 2018

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Resources &
Lab Exercises

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Instructions for Hands-on Exercises

Use the activities in this section to guide your hands-on practice with the instructor. Your instructor may modify the duration or content of the exercises to fit the circumstances of your class. This document also includes links to useful resources.

Links for Resources

1. **Online**
    a) **U.S. Department of Energy**
        - http://bit.ly/2EfKqdb - USDOE Hydrogen Quiz; "How much do you know about hydrogen?

    b) **Videos**
        - http://rsc.li/2DSUoRC - Visual hydrogen atom (1:21)
        - http://rsc.li/2Dufkkp - Hydrogen properties (7:15)
        - http://bit.ly/2DnALAg - Toyota Fuel Cell System (3:23)

    c) **Toyota Motor Corporation**
        - http://toyota.us/2npcIKy - Toyota Information System TIS (Requires Acct & login setup)
        - http://toyota.us/2EkBK5C - Mirai FCV Mayor Tech Specs (Req Acct Login)

2. **Text Resources**
    - http://bit.ly/2roGEvk -Hydrogen fuel cell Toyota Mirai cruises 300 miles
    - http://bit.ly/2ru0CVE -Toyota Mirai - A Preview of future propulsion
    - http://bit.ly/2nqYXuO - Toyota Mirai could run your home in an emergency

Lab 1 Exercises

Complete the following exercises according to the directions given by your instructor.

1. **Safety Concerns, Emergency Precautions and Special Equipment**
   a. High voltage rescue and tooling – Intro & demonstration
   b. HV measuring and testing equipment and tooling – Procedure demo

2. **Hydrogen Fuel Cell Vehicle introduction and familiarization**
   a. Dash Board and Cluster
      - Lamps, symbols and alarms
      - Dashboard control and management
      - Center consul and controls
   b. FCV Safety areas and points of concern - HV circuits & high-pressure gas
   c. High voltage power and hydrogen systems identification, distribution & layout
   d. Turning ON/OFF vehicle
   e. Vehicle familiarization and system operation modes

3. **Vehicle Compartments and Access Panels**
   a. Front, passenger cabin and trunk
   b. Undercarriage design, defection panels and streamlining

Lab 2 Exercises

Complete the following exercises according to the directions given by your instructor.

1. **Vehicle Operation**
   a. Noise and feel
   b. Forward, neutral, reverse and park operation
   c. Acceleration and regenerative braking

2. **Onboard Diagnostics**
   a. Software identification
   b. Toyota TIS System intro and demonstration – Connection and access
   c. Positive communication and pairing

3. **TIS Operation**
   a. TIS main menu and contents
   b. System selection
   c. Real-time data monitoring

Lab 3 Exercises

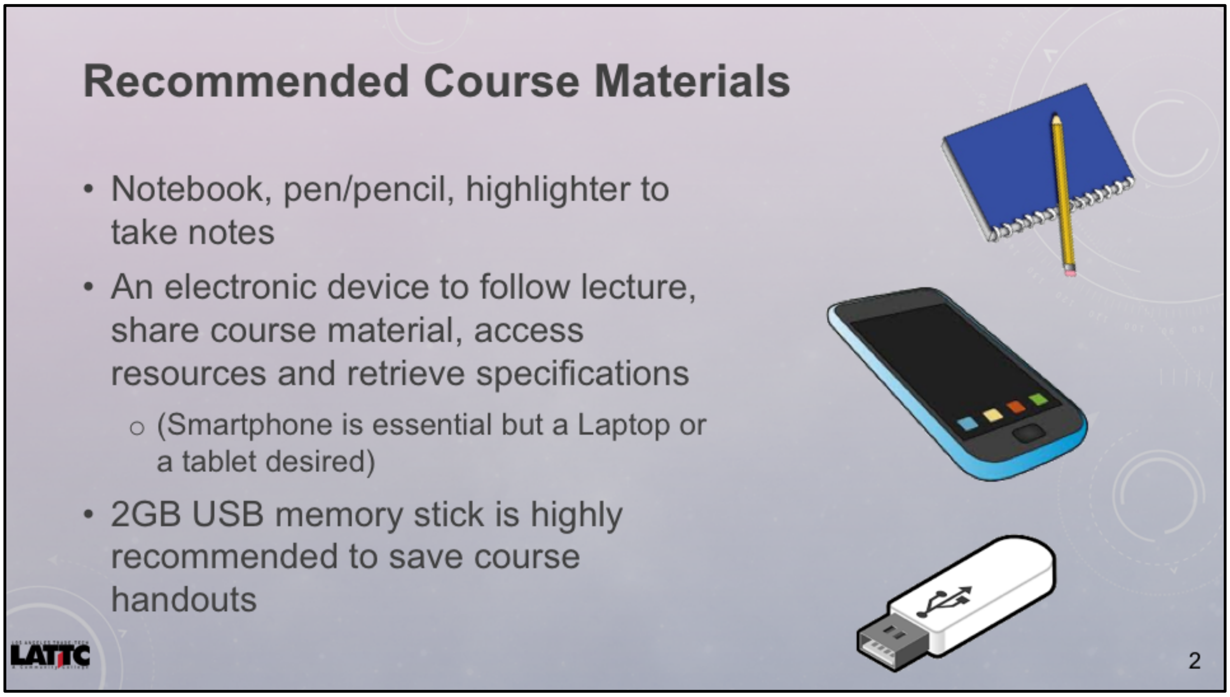
1. **Advance Testing – Diagnosis**
    a. Using TIS efficiently along with Smartborad technology
    b. System wiring read and schematic understanding
    c. Diagnostic trouble code and faults – DTCs
    d. TIS navigation and module selection
    e. System testing and output logic comprehension – demonstration
    f. Using wiring diagrams together with TIS for correct diagnosis

INSTRUCTOR NOTES

Introduction to Fuel Cell Vehicles
January, 2018

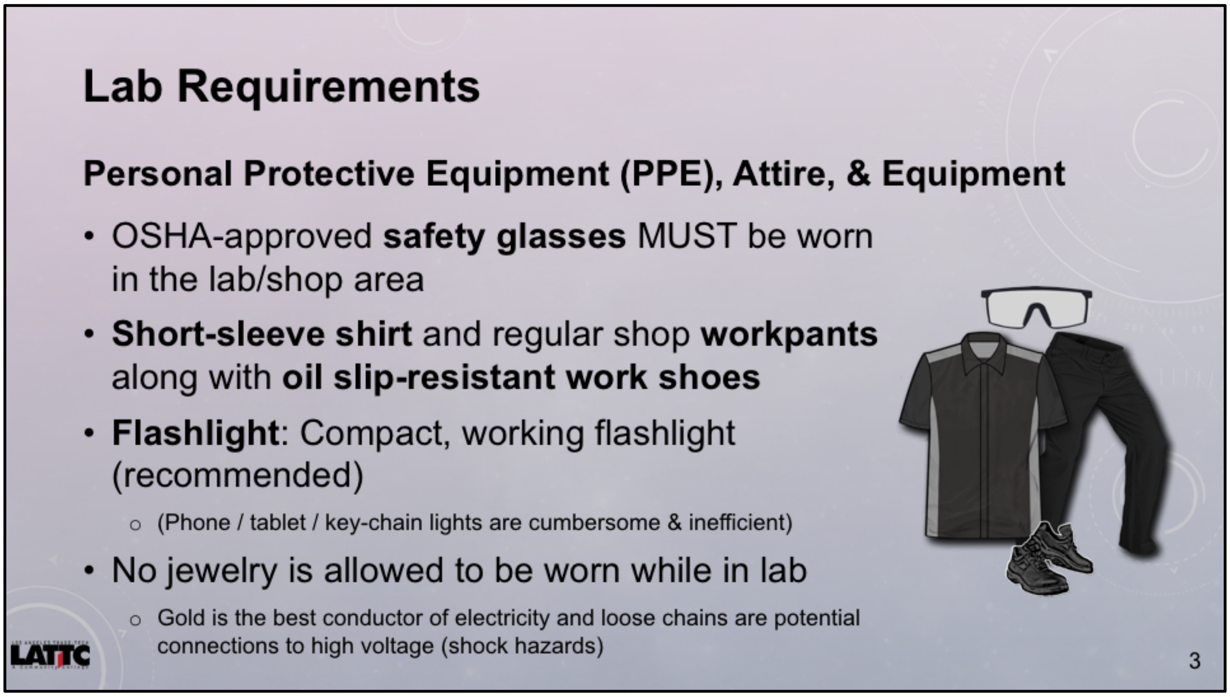
Instructor Notes

"—When human beings have curiosity and are willing to take a chance, that is the power to help shape a better world. Who knows? We might fail. The pioneer always faces threats. But we need people who are brave enough to challenge the status quo."
- Katsuhiko Hirose (Product GM – Toyota Fuel Cell Development Group)

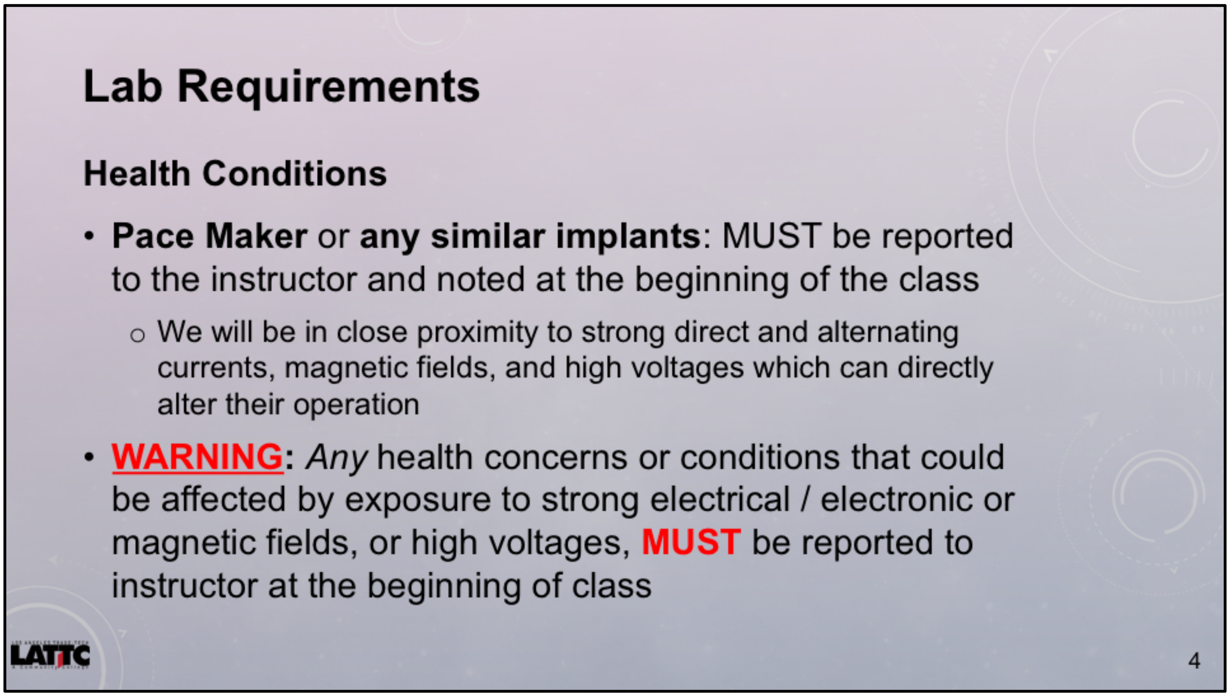


Welcome to “Introduction to Fuel Cell Vehicles” and Advanced Technologies Course! “Old-school” and “New-school” class instruction practices, procedures and learning methods are employed during this course as appropriate. Good-old chalkboard, high accuracy diagnostic and safety equipment along with new advanced learning technologies and learning management platforms are utilized, applied, manipulated and evaluated for institutional effectiveness on concept understanding and retention.

- Introductions – Class participants
- Announce locality internet/Wifi connectivity/connections details and share with the class participants for inclusion
- Printed materials are kept at a minimal for ease of access efficiency and environmental responsiveness



- OSHA-approved safety glasses MUST be worn any time during and when in the lab/shop area
- A good and compact working flashlight is recommended to take observations during lab activities (Cell/tablet and/or key-chain type lights are cumbersome and inefficient)
- Short-sleeve shirt and regular shop workpants along with oil slip-resistant work shoes are required during lab activities
- No jewelry is allowed to be worn while in lab. Gold is the best conductor of electricity and loose chains are potential connections to high voltage (shock hazards)



- If you have a Pace Maker or any similar implants, it MUST be reported to the instructor and noted at the beginning of the class. We will be in very close proximity to strong direct and alternating current magnetic fields and high voltages which can directly alter their operation

Lab Requirements

Body Art

- **Tattoo ink (Body Art):** Conducts electricity more easily than plain skin. If you have tattoos, especially on your hands and arms, please notify the instructor at the start of the class
  - Ink typically made with Iron Oxides (FeO_2) – the same as car paint!

Source: Muffet

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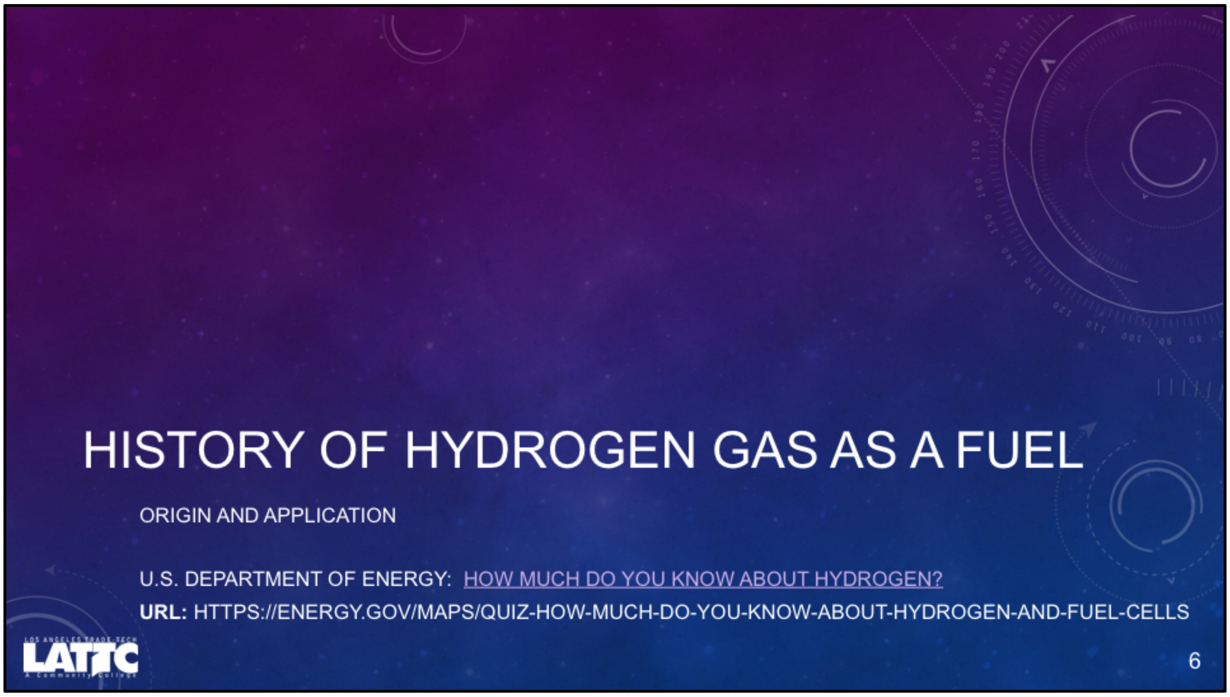
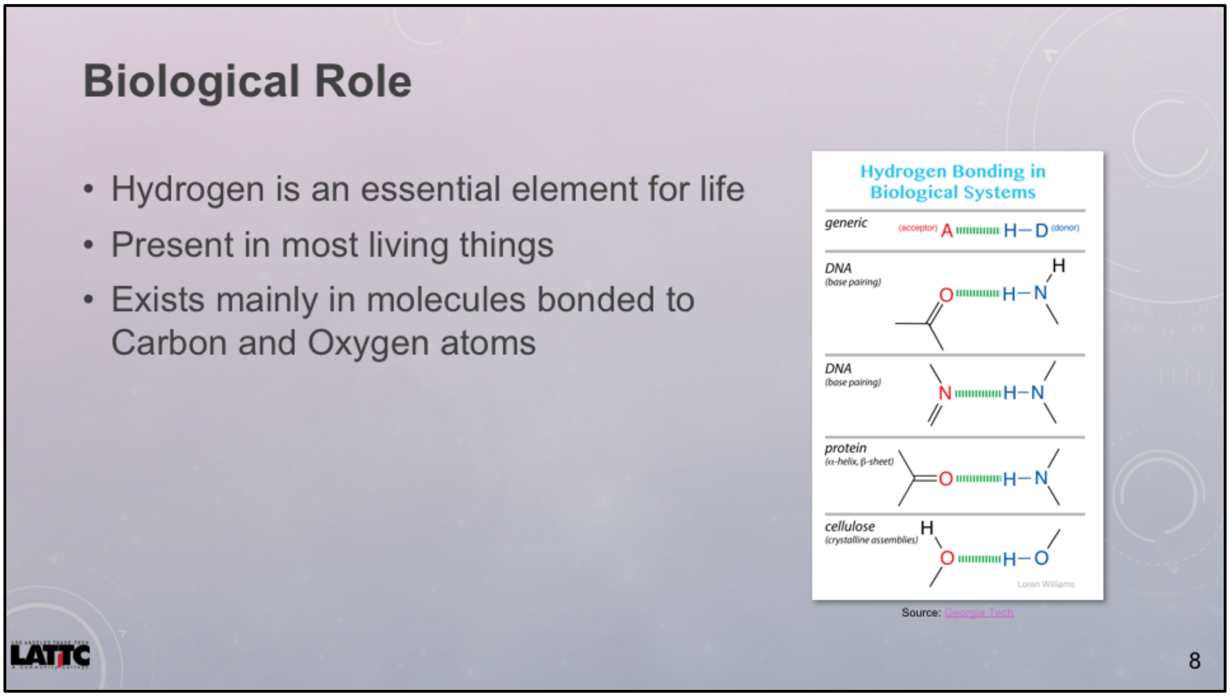
Various types of tattoo ink chemical elements such as iron oxide, mirror that of automobile paints. It can instantly become an electrical circuit because of their higher conductivity compared to highly-resistive natural plain skin. If you have any of these specifically on your hands and arms, the instructor also needs to be notified at the start of the class.

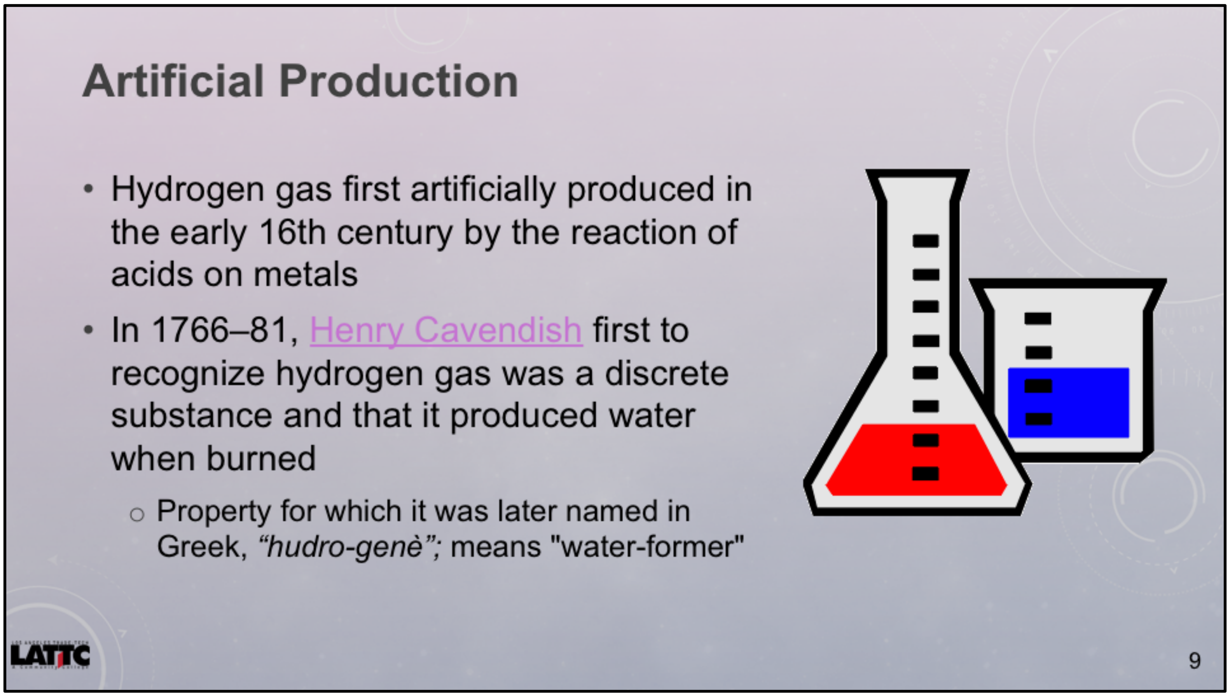


- Introduce and apply online U.S. Department of Energy quiz to students: Quiz: How much do you know about Fuel Cells?
- **URL:** https://energy.gov/maps/quiz-how-much-do-you-know-about-hydrogen-and-fuel-cells
- We all think we know… Well, this is why you are here

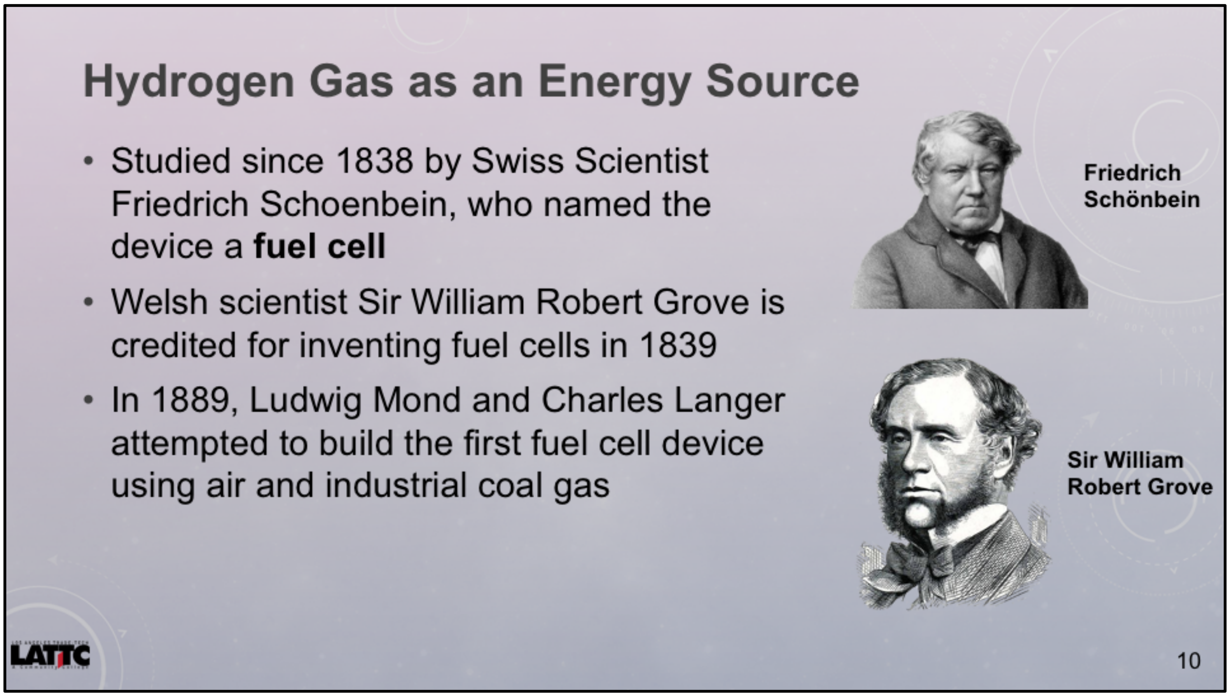
Where do we get Hydrogen Gas?



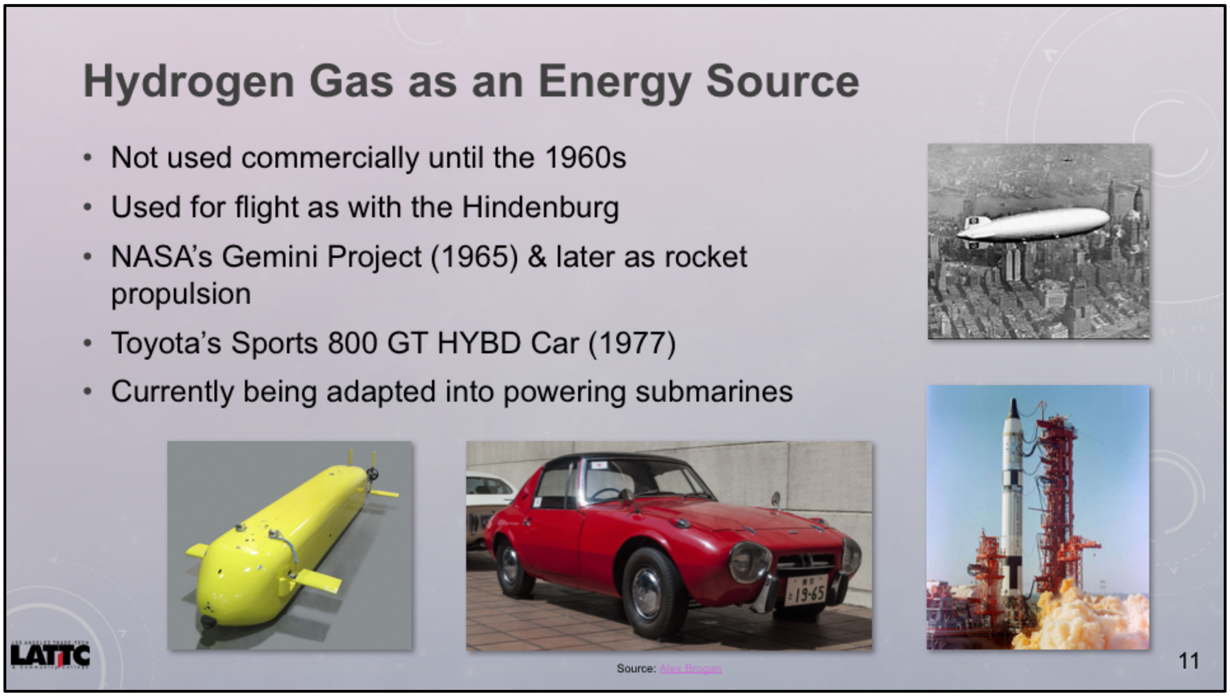
Although it is essential for life, hydrogen itself does not play a particular active role. It remains bonded to carbon and oxygen atoms, while the chemistry of life takes place at the more active sites involving, for example oxygen, nitrogen and phosphorous.



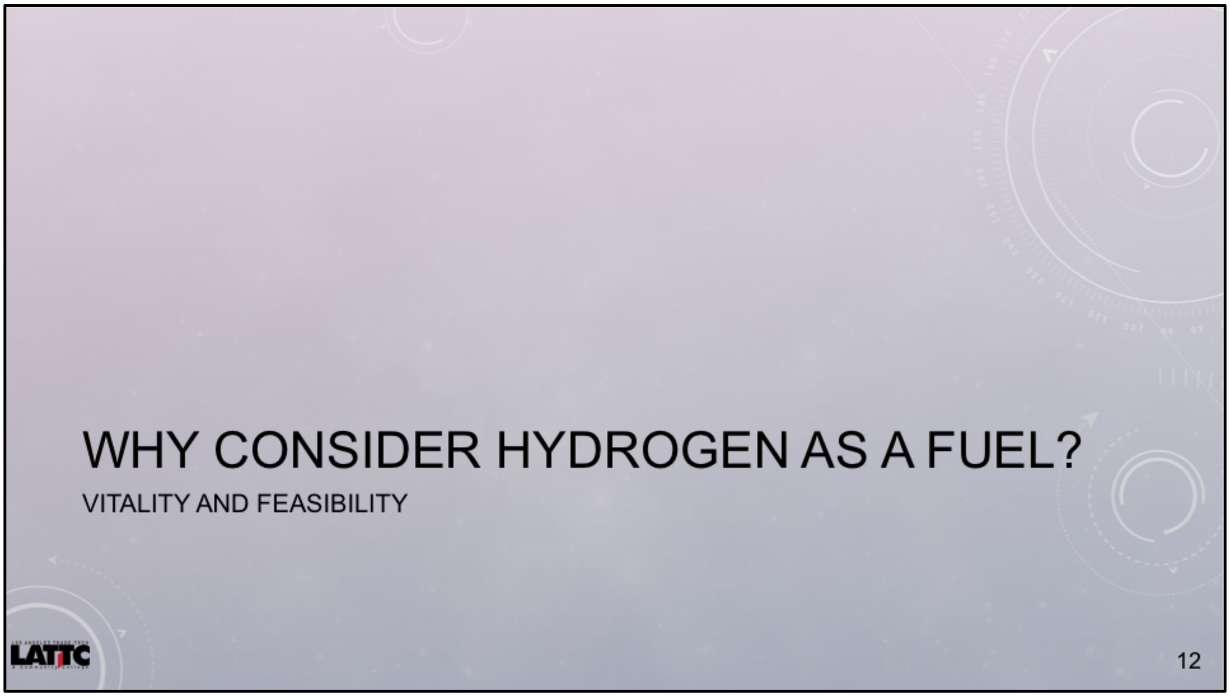
Hydrogen gas was first artificially produced in the early 16th century by the reaction of acids on metals. In 1766–81, Henry Cavendish was the first to recognize that hydrogen gas was a discrete substance and that it produced water when burned, the property for which it was later named in Greek, *“hudro-genè”;* means "water-former".



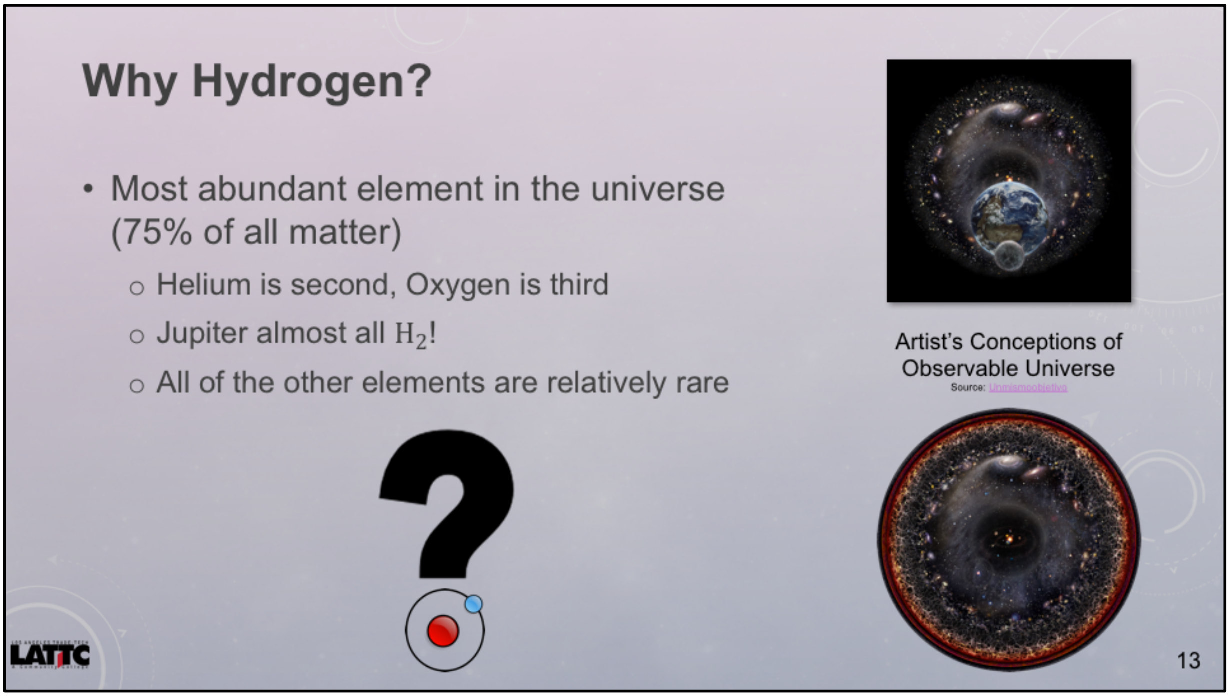
Hydrogen-gas as a possible energy source, has been studied since 1838 by Swiss Scientist Friedrich Schoenbein. They named the device a fuel cell. Welsh scientist Sir William Robert Grove is credited for inventing fuel cells in 1839. As a derivative from this consensus and in 1889, Ludwig Mond and Charles Langer attempted to build the first fuel cell device using air and industrial coal gas.



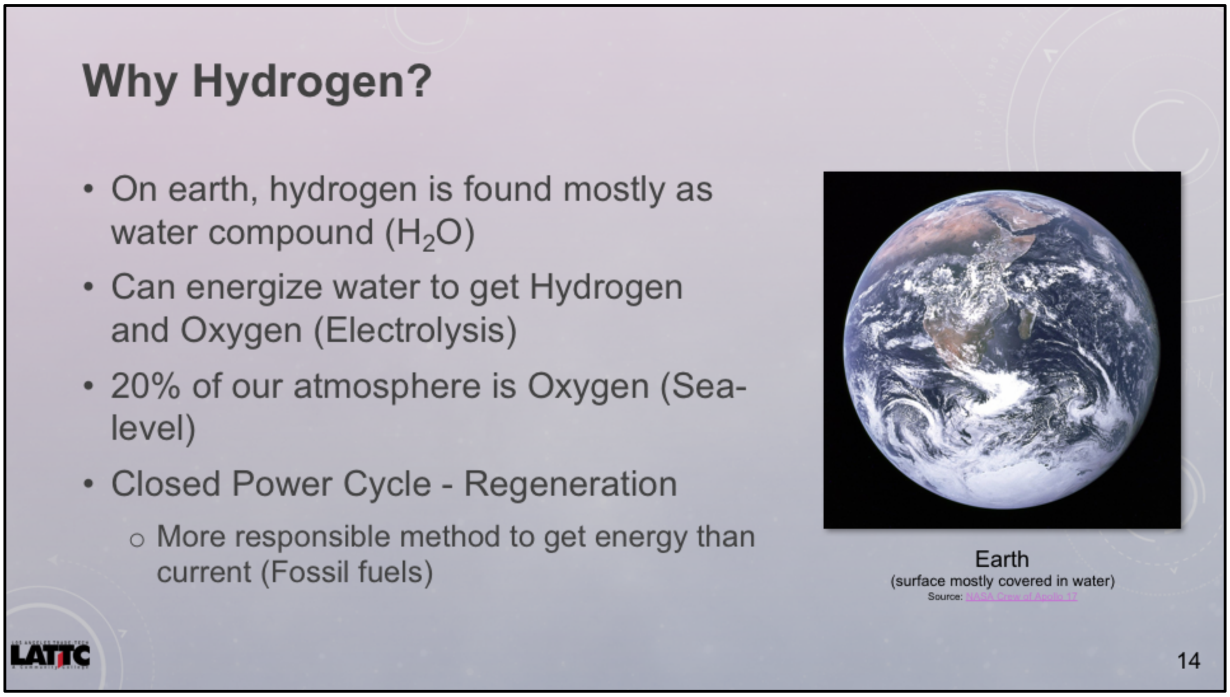
- The technology wasn't used commercially until the 1960s. Ever since, hydrogen has been used and applied in various applications and uses such as for flight as with The Hindenburg as well as with NASA's Gemini Project (1965) and later as rocket propulsion
- Toyota's sports 800GT hybrid concept car developed in the through the 1960s and was their first production sports car. It used a gas turbine engine to spin a generator that power an electric motor
- Currently, this technology is being adapted into powering submarines



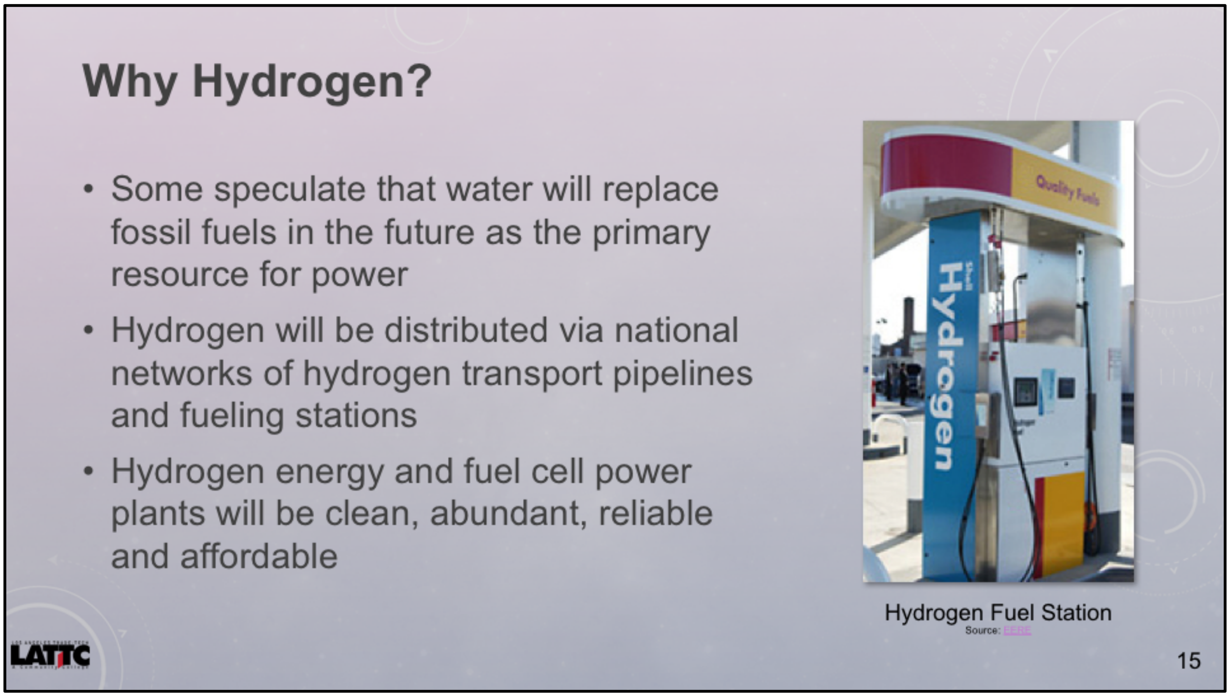
- It is abundant throughout the universe and harnessable on earth
- Fossil-free and an evironmently clean source to generate electricity
- Has substantial potentials



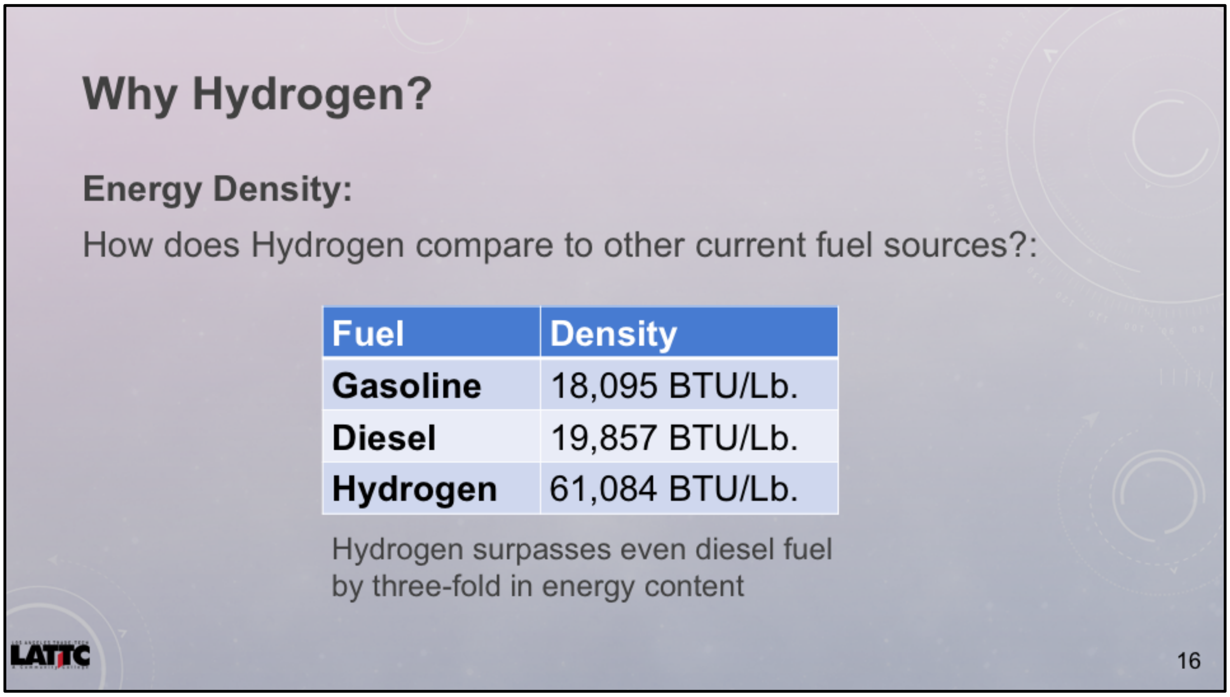
If ¾ of the universe is hydrogen and oxygen constitutes a good percentage as well, shouldn't we consider them as fuel to support space travel?



- By running electricity through water we get them apart ("Charging" the water)
- We can combine them again through a fuel cell to reform water and harness electricity
- Harnessing the electricity invested to split them, we can start the cycle again (Closed cycle)



As an energy source, it holds the potential to become an important component along with other renewables currently in place, as a viable solution to our future energy needs.



- As we can clearly see above, hydrogen surpasses even diesel fuel three-fold in energy content
- It takes a large volume of hydrogen gas (192cf) to make one pound of weight (1 Lb.) for this linear comparison (70°F - sea level)
- Therefore the high energy content…


HYDROGEN DEMAND AND
INFRASTRUCTURE
ENERGY SECTOR OUTLOOK
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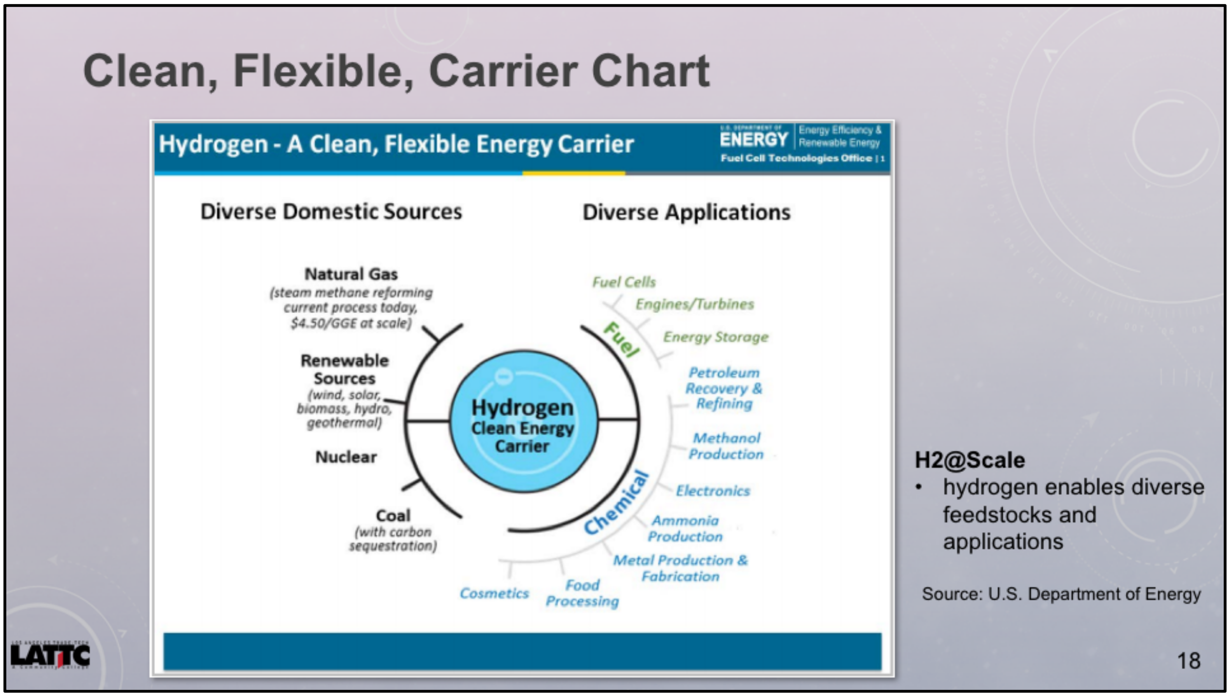
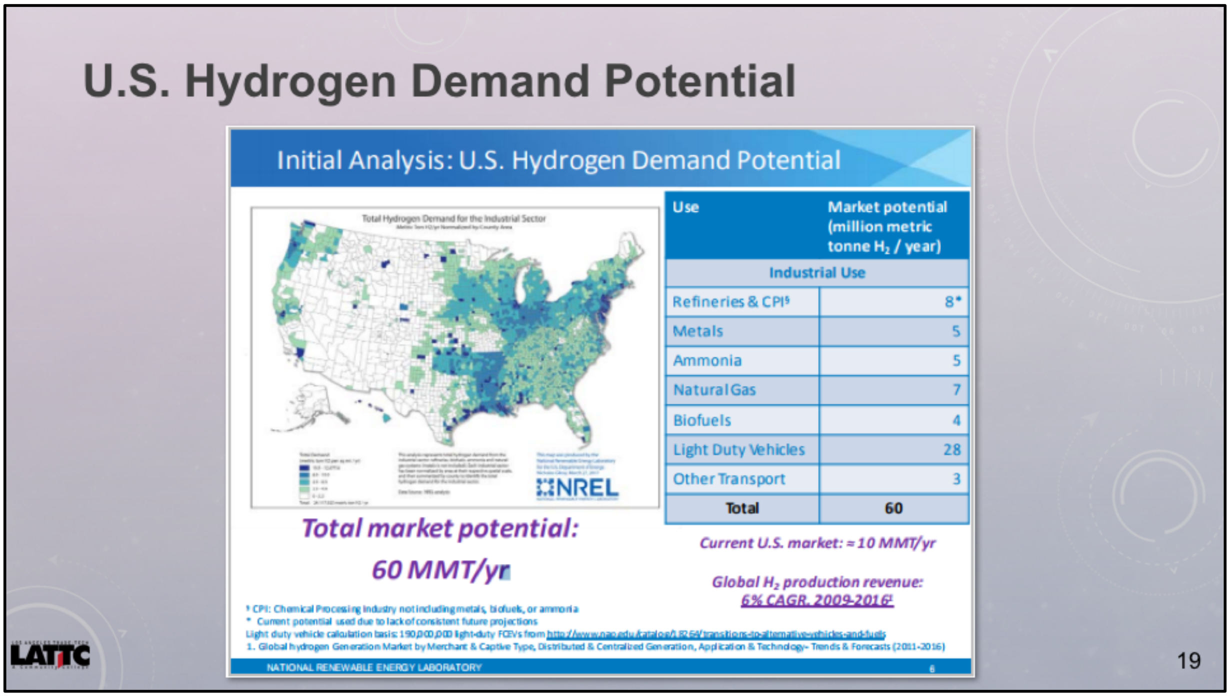
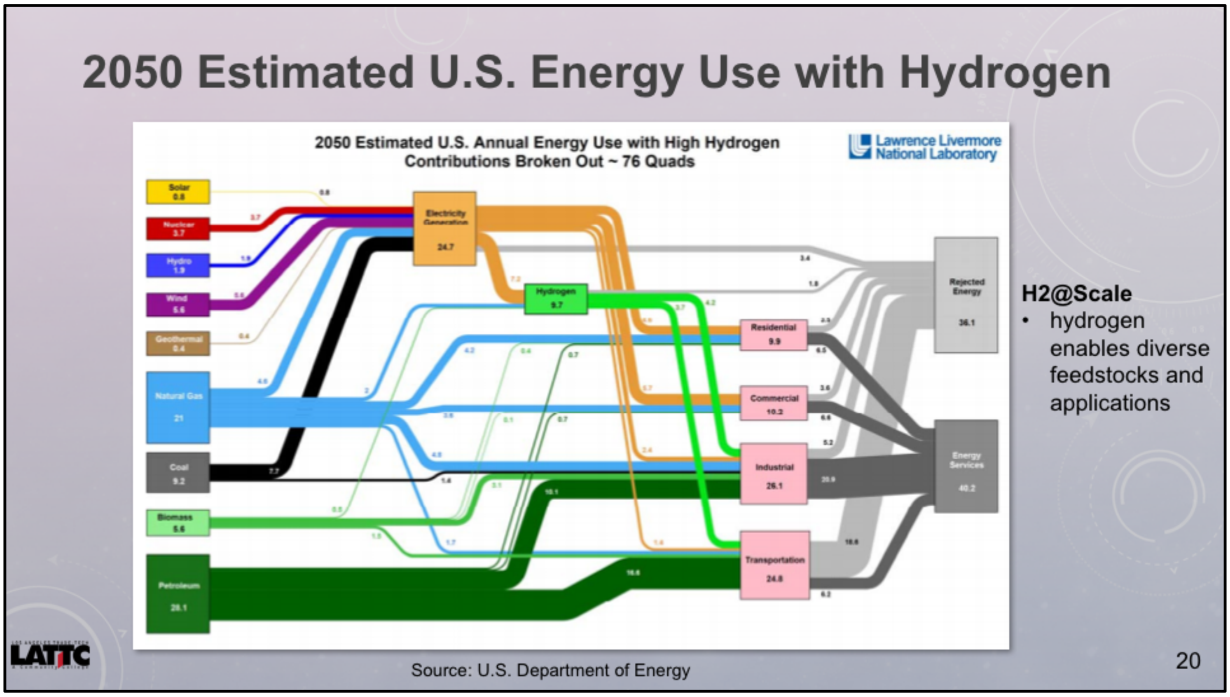


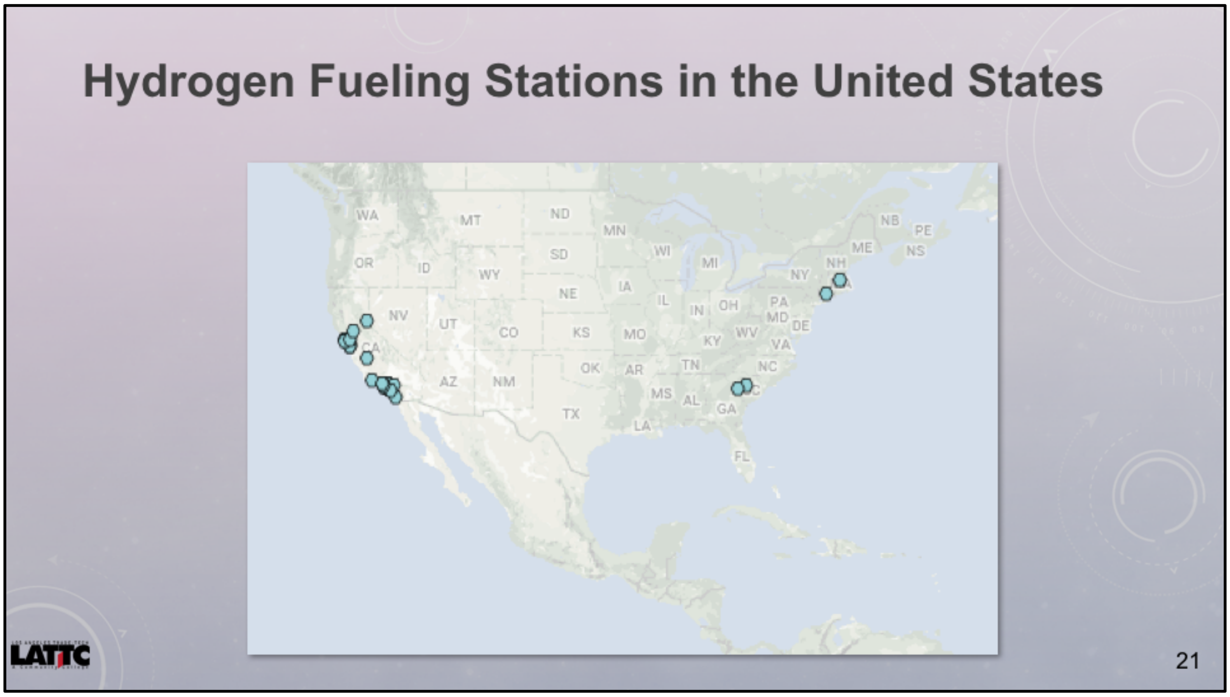
Hydrogen offers good flexibility across for many energy mediums.



Good market growth outlook.

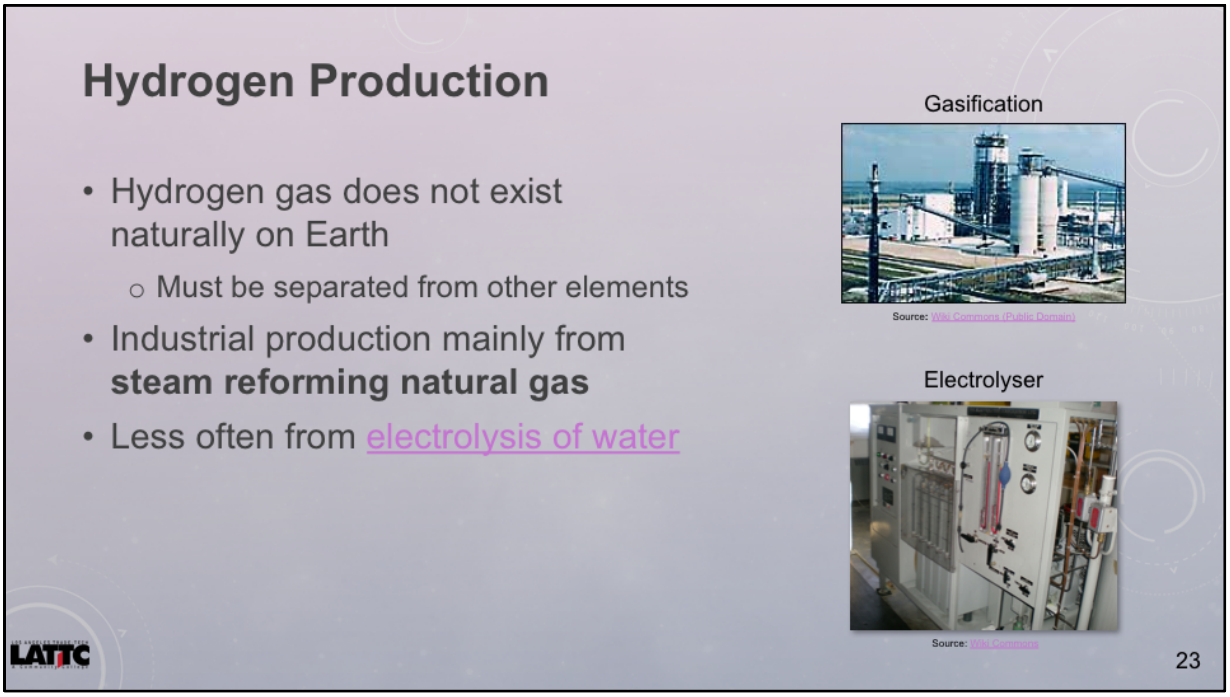


The inclusion of hydrogen into our existing energy sector spectrum, easily comes onboard into our modern way of life as a growing energy commodity.



- This slide shows the locations of hydrogen fueling stations in the United States as of January 2018
- Note that the stations are on the east and west coasts with none in the middle of the country

How do we get hydrogen?



Hydrogen GAS does not naturally exist by itself in our planet.

Hydrogen Production

- Hydrogen is a standard industrial chemical commodity today
- 10 million metric tons produced per year in the U.S.
  - Most used near the site of its production
- Largest uses:
  - Fossil fuel processing (e.g., hydrocracking)
  - Ammonia production, mostly for fertilizer market

Fluid Catalytic Cracker

Source: Valero Energy Corporation/TX

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- Hydrogen currently use for petroleum refining and fertilizer production
- Fuel Cell platforms currently used in transportation, residential and other applications will soon create and surpass them both, as the main sector consumer for hydrogen
- Infrastructure will grow right along and just as fast


HYDROGEN GAS SAFETY AND SERVICE PROCEDURES
FIRST RESPONDER PROCEDURES, PROPERTIES, SAFE WORK PRACTICES & HAZARDS
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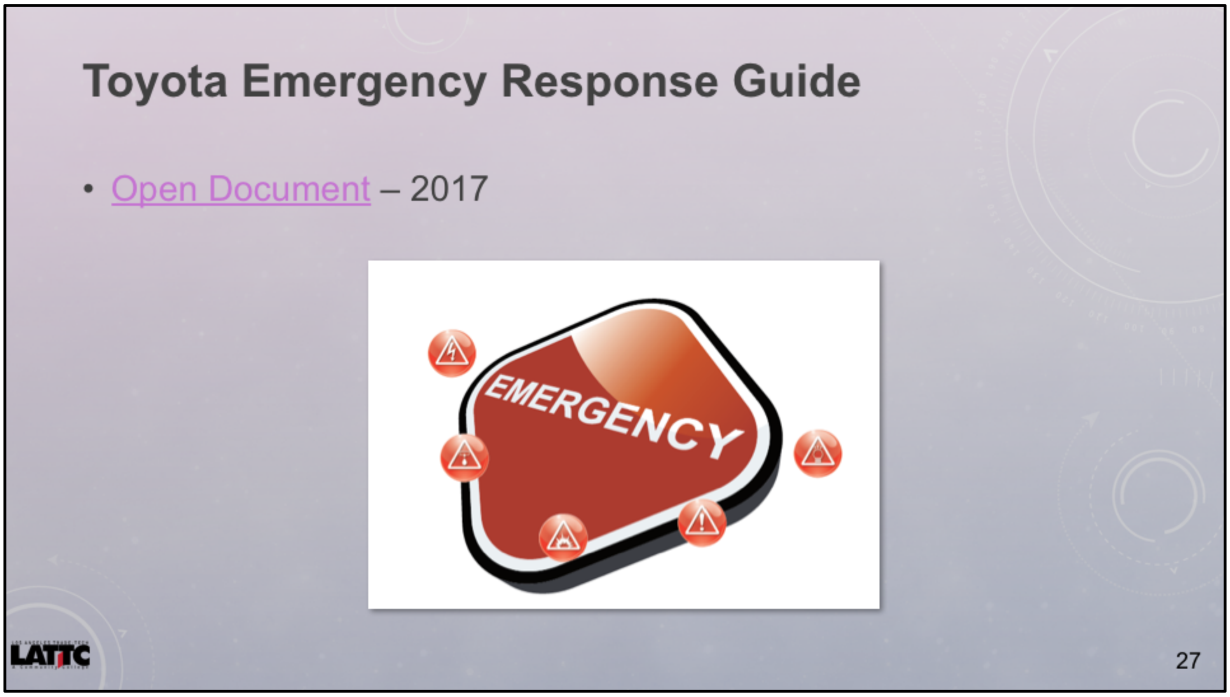
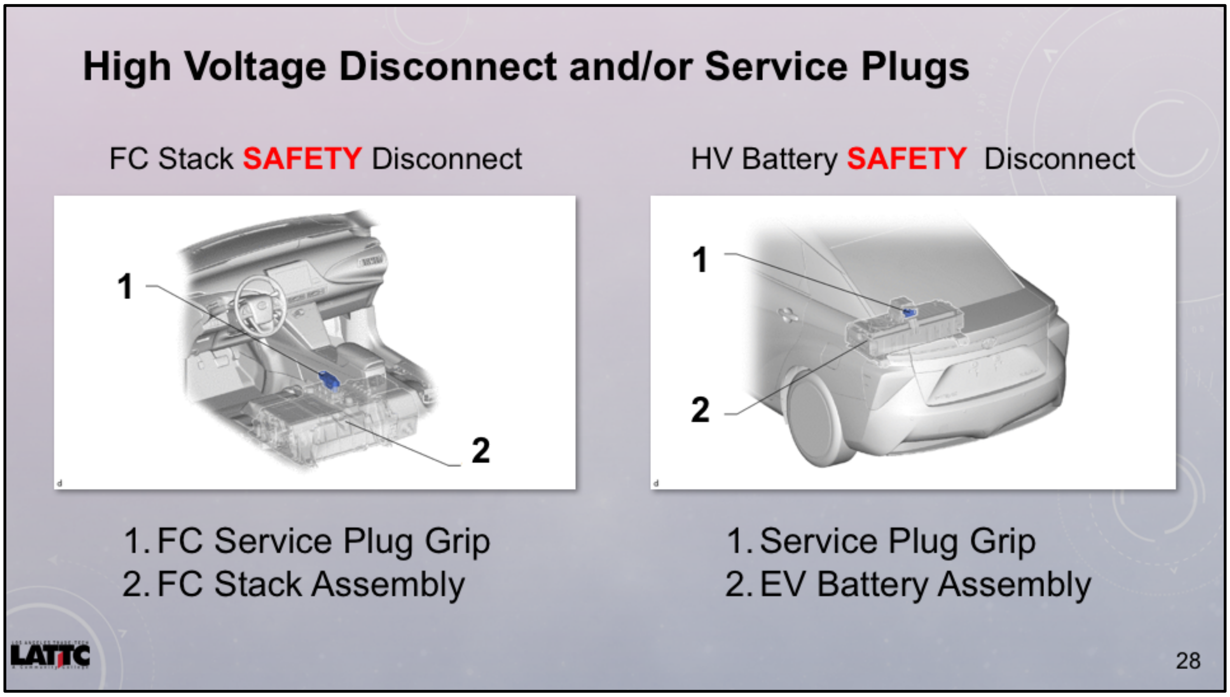
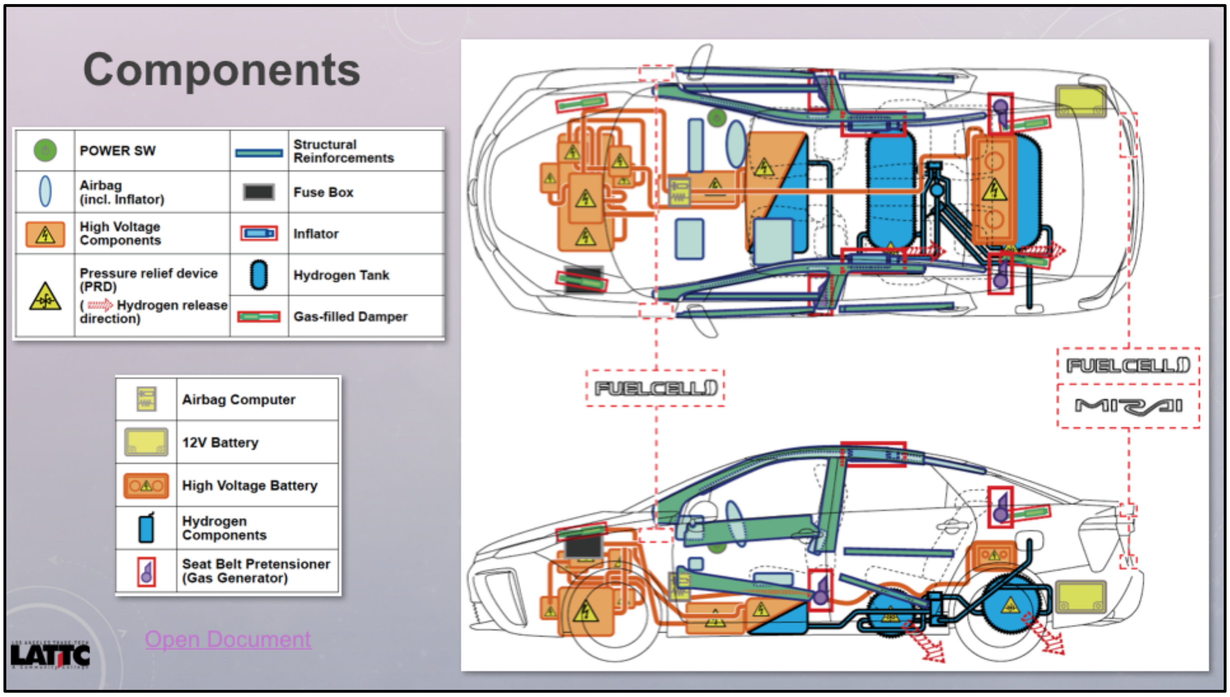
Having ample knowledge about the hazards and dangers which you may be encountered with when responding to emergencies about high pressure hydrogen gas, is imperative. Hydrogen-fueled vehicles pose a unique hazard to emergency personnel responding to emergencies different than that of conventional vehicles. Understanding what they are, where they are, how they behave and what to do about it, takes specialized instruction and preemptive training.



Toyota addresses the importance of vehicle safety and vehicle system de-power. The Emergency Response Guide stipulates in detail all aspects which may be encountered in the event of an emergency. It is highly recommended for the technician servicing the vehicle to read it hole and follow the recommended procedures.

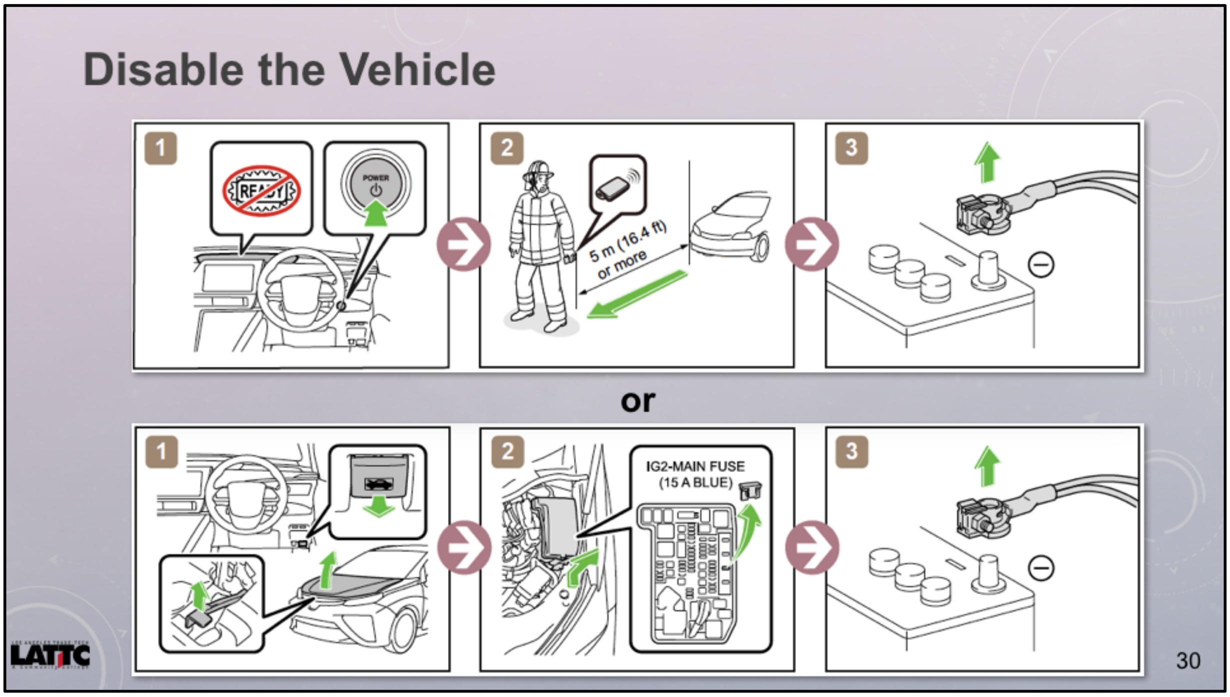


There are **two bright orange, HV safety plugs** in the Mirai FC vehicle. These safety plugs may be cumbersome and challenging not only to be removed but to get access to them by first responders and their equipment. Rather than designate them as an emergency procedure point for emergency personnel, Toyota recommends to disconnect the **12v battery** and remove a **specific fuse** instead (coming up on following slides). However, it **is important to note** their location and removal procedures **for technicians to de-power** the vehicle's high voltage systems for repairs.

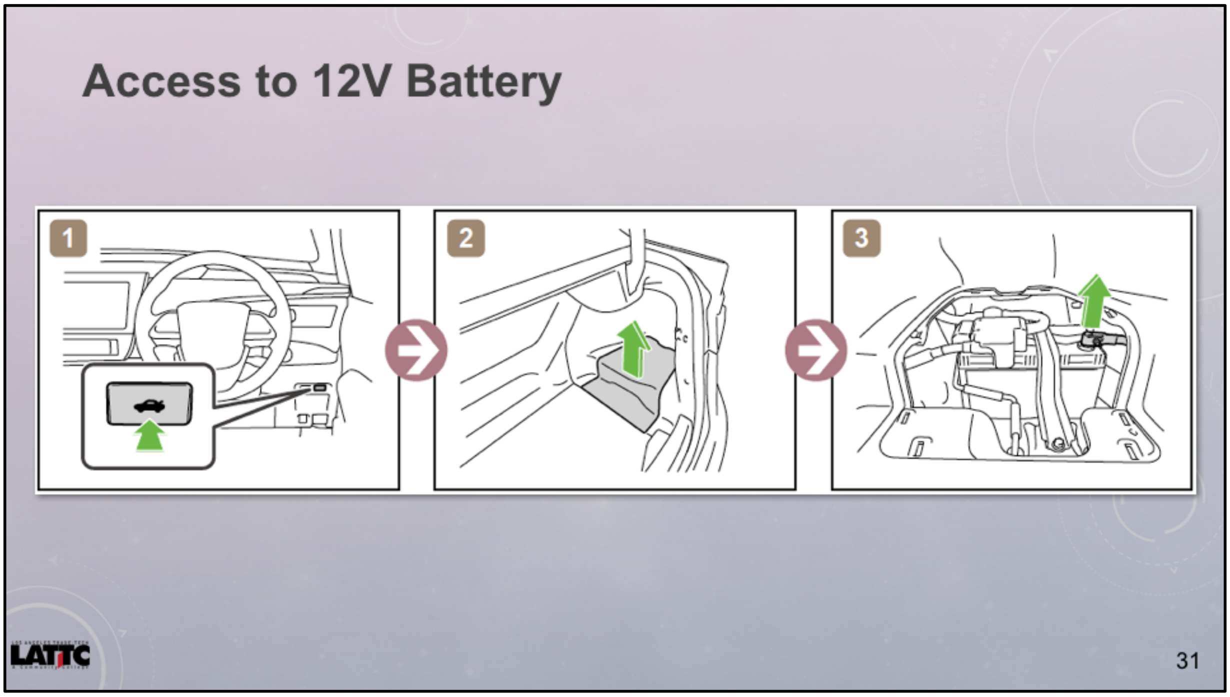


This is a "Quick" component reference guide which applies to the 2017 Toyota Mirai Fuel Cell Vehicle specifically. Always research the information to the areas to be worked on PRIOR to any engagement by using the appropriate manufacture's maintenance manual.

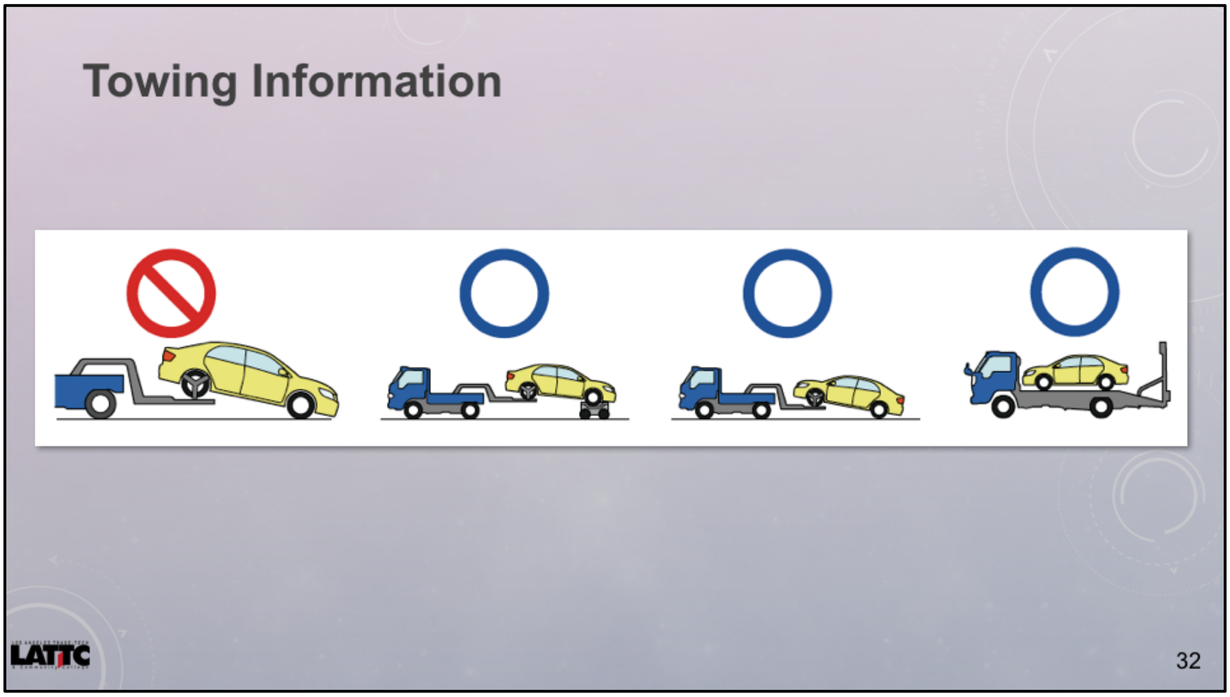
- Note the location of components and their related systems
- Note the adjacent components an take care of the recommendations by the OEM
- Note the **PRDs discharge direction** angled towards the road and rear of vehicle



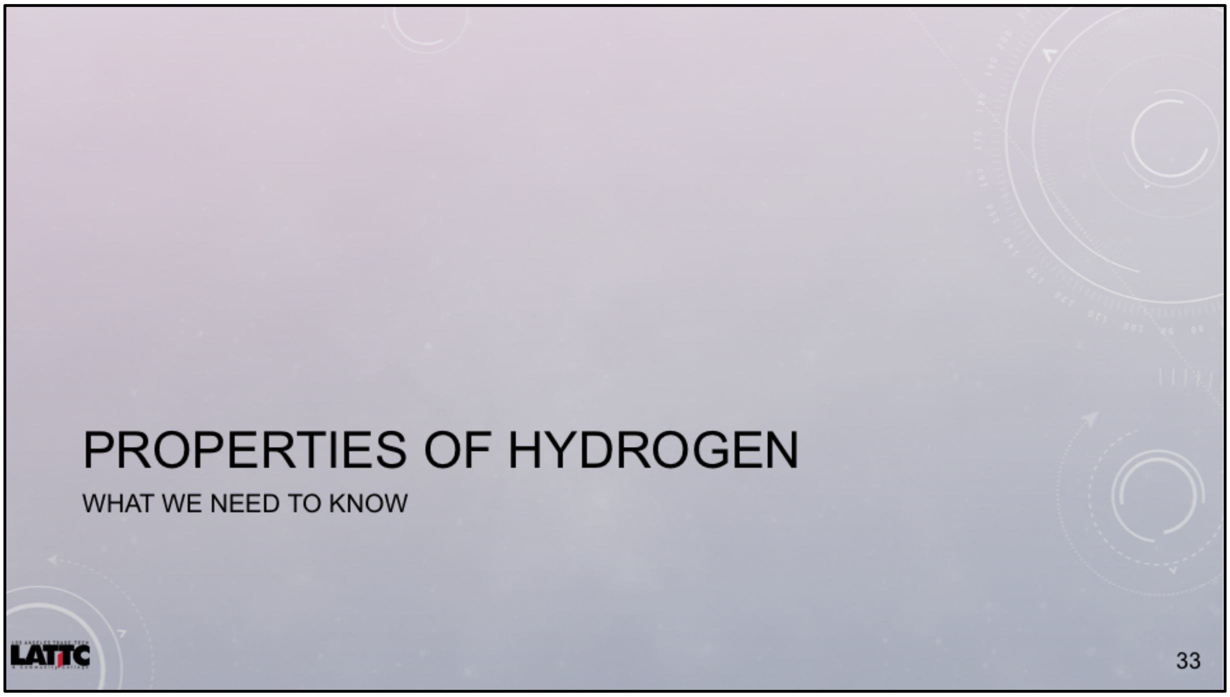
Follow the specific steps which are listed above to disable the vehicle. Make sure you clearly understand and interpret the meanings of these images correctly.



The 12 volt system or "Auxiliary power system" can be disabled by disconnecting the 12 volt auxiliary battery NEGATIVE cable from the rest of the vehicle. Make sure you insulate the terminal to prevent unintended and accidental reconnection.



When the vehicle becomes inoperative and a “Tow” is the best choice, make sure to understand why the manufacturer is recommending the procedure process. The traction wheels, need to be kept from rotating when the vehicle is off. Powerful magnets in the traction motor can generate high voltages which can damage sensitive electrical and electronic equipment. Follow the OEM’s recommended towing procedures.


PROPERTIES OF HYDROGEN
WHAT WE NEED TO KNOW
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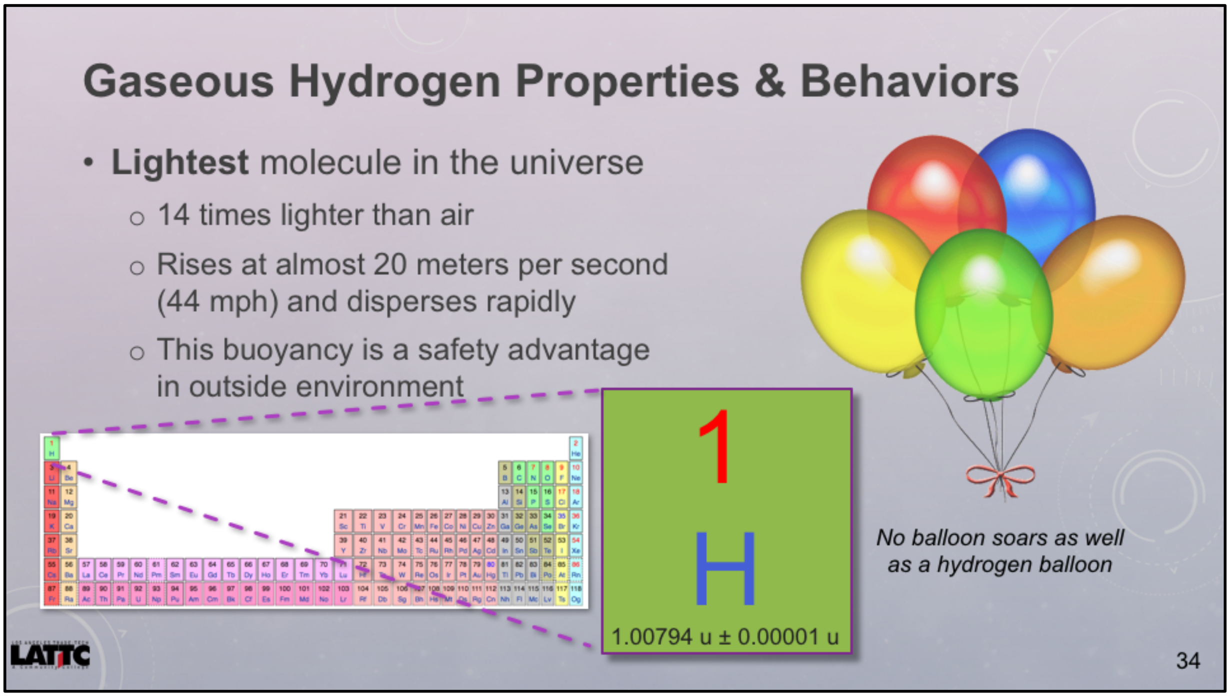
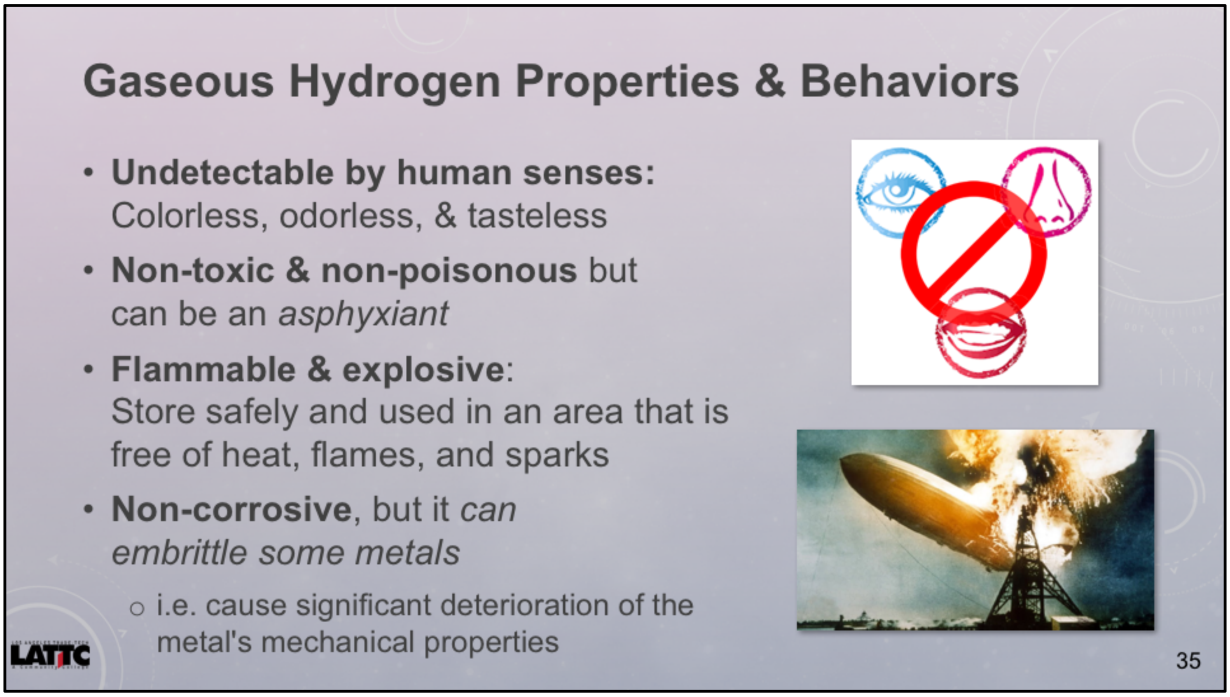


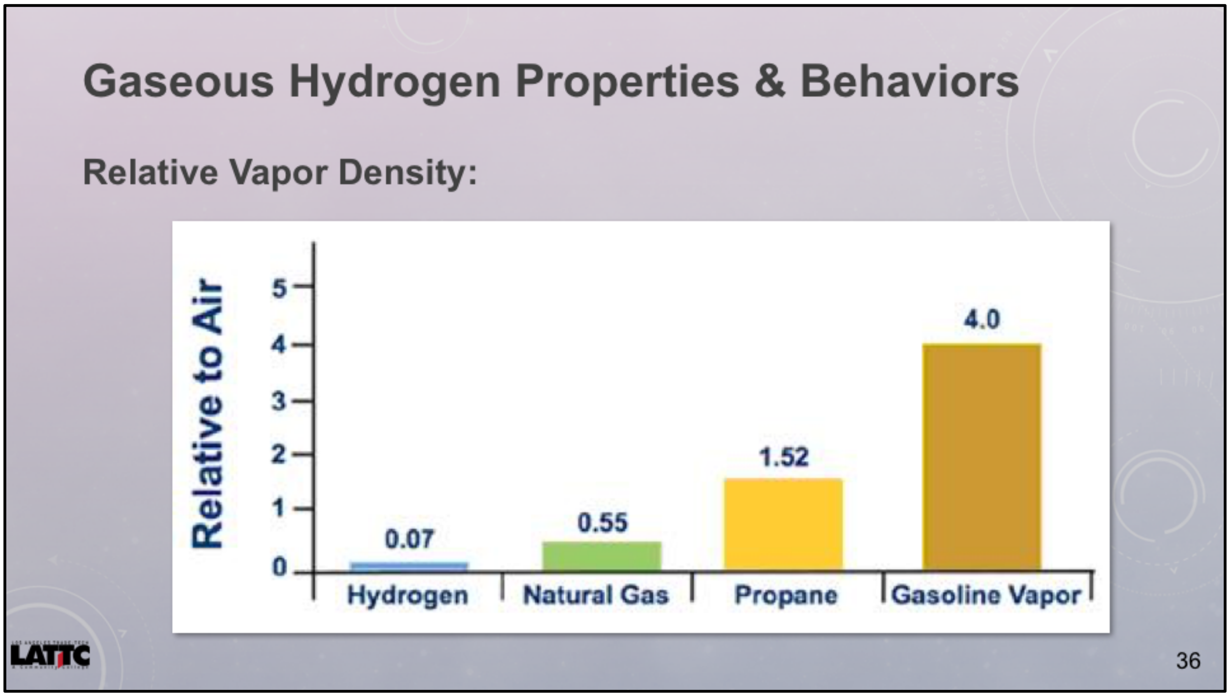
The storage and use of hydrogen poses unique challenges due to its ease of leaking as a gaseous and buoyancy that must be accounted for to ensure safe operation. Some basic properties and behaviors of gaseous hydrogen are highlighted on this page:

- 14 times lighter than ambient air
- Will move directly upwards (Vertical) at a fast rate of accent (Speed)
- Production, storage and maintenance facilities MUST be designed and equipped under specific guidelines to meet hydrogen gas safety standards (i.e. ventilation and leak-detection systems)



Some basic properties and behaviors of gaseous hydrogen are highlighted on this page:

- We are generally UNAWARE of its presence!
- It can displaced the air we need to breathe!
- Wide flammability range of combustible fuel-air mixture ratios of 4% to 75% concentration with ambient air!
- Electrostatic Charge arresting methods are imperative for safe working procedures and handling!
- Flowing hydrogen from a high-psi chamber to a lower-psi one, will cause an refrigeration effect which weaken metals (Embrittling)



Some basic properties and behaviors of gaseous hydrogen are highlighted on this page:

- Air has a value of 1 RVD (Relative Vapor Density)
- Hydrogen is less dense than air and hence will rise. The lower the density of the gas the faster it rises
- As we can see above, propane and gasoline are denser than air therefore they sink to the ground hence the automobile garage vents location close to the floor in residences and such


SAFE WORK PRACTICES
WORKING WITH HYDROGEN
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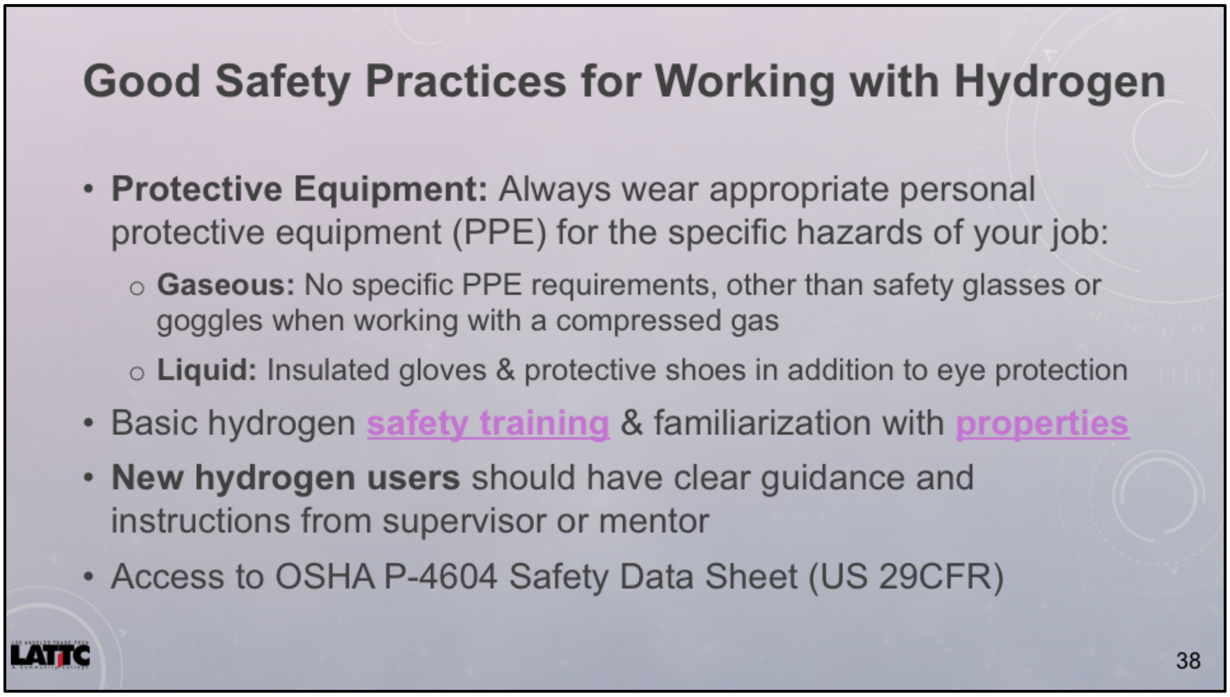
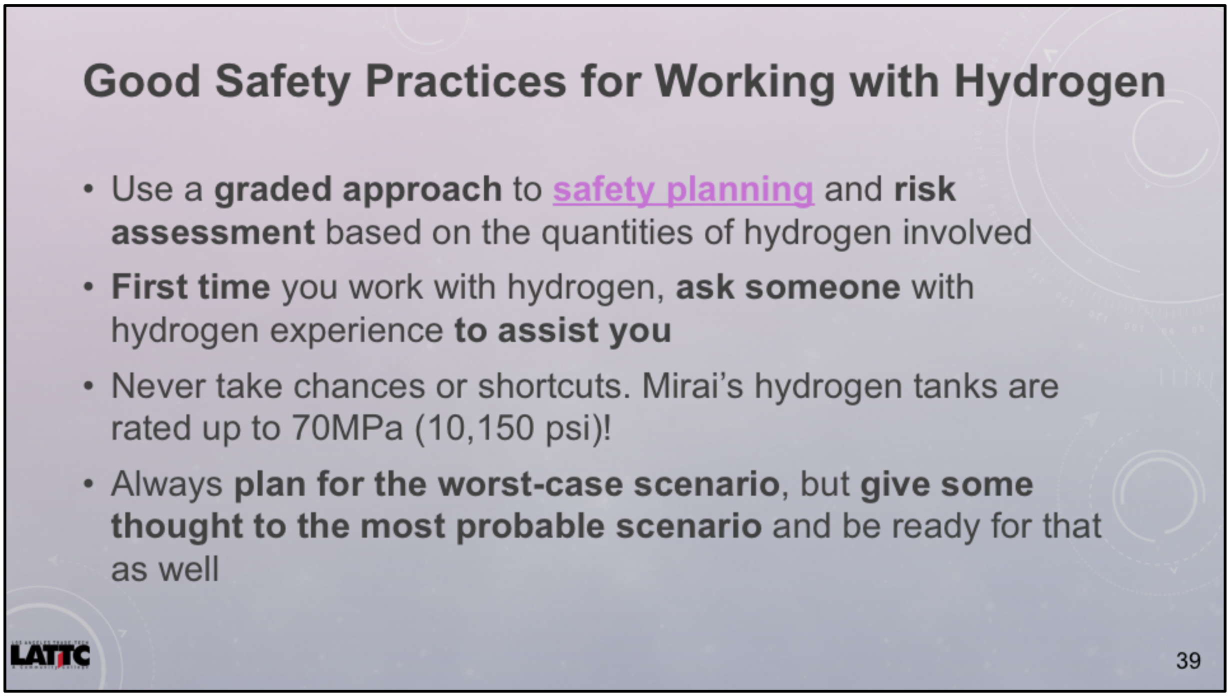


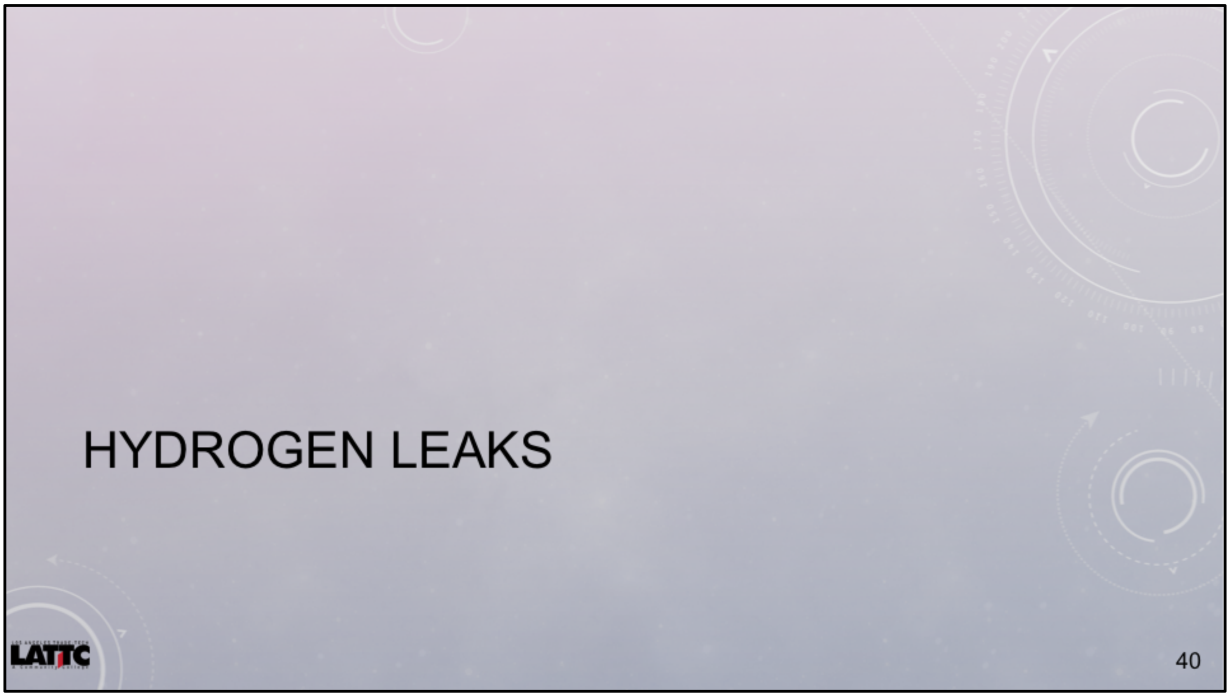
Good Safety Practices for Working with Hydrogen are highlighter here:

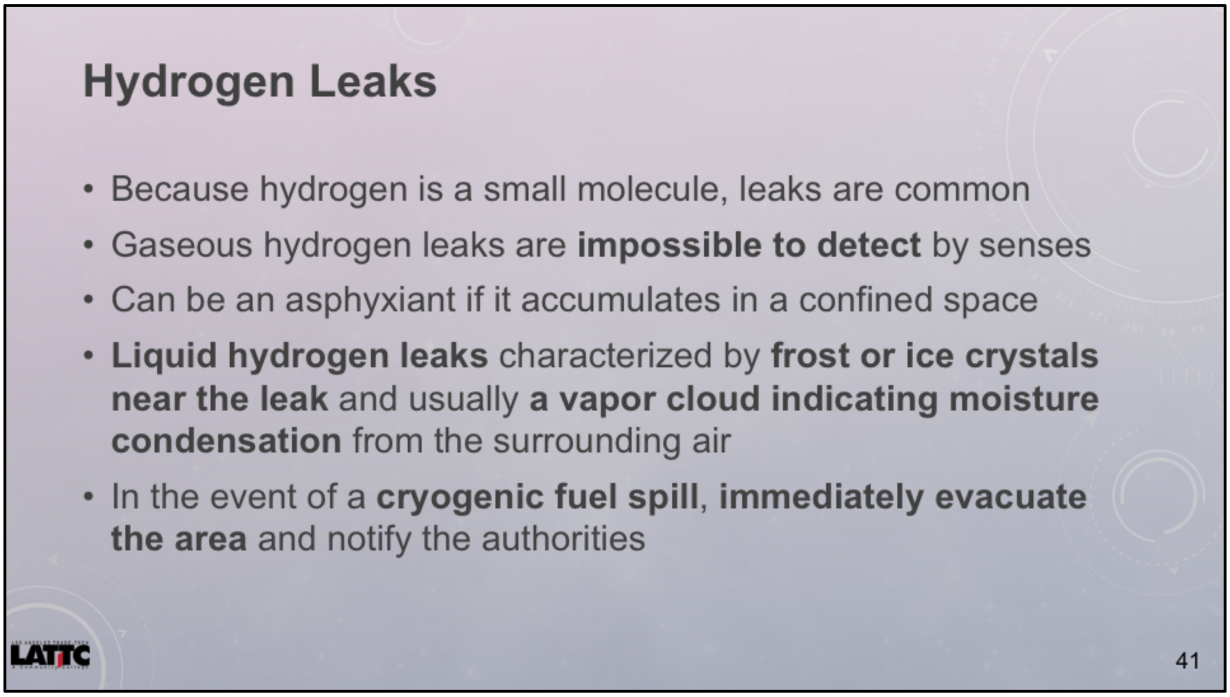
- Always wear appropriate personal protective equipment (PPE) for the specific hazards of your job
- Anyone working with high pressure hydrogen gas should have been provided with some basic hydrogen safety training (see Safety Culture) and should be familiar with the basic properties of hydrogen (see Facility Design)
- New hydrogen users should have clear guidance and instructions from their supervisor or mentor on the required training and approvals necessary before working with hydrogen. Ask for clarification of any unclear guidance, instructions, or responsibilities



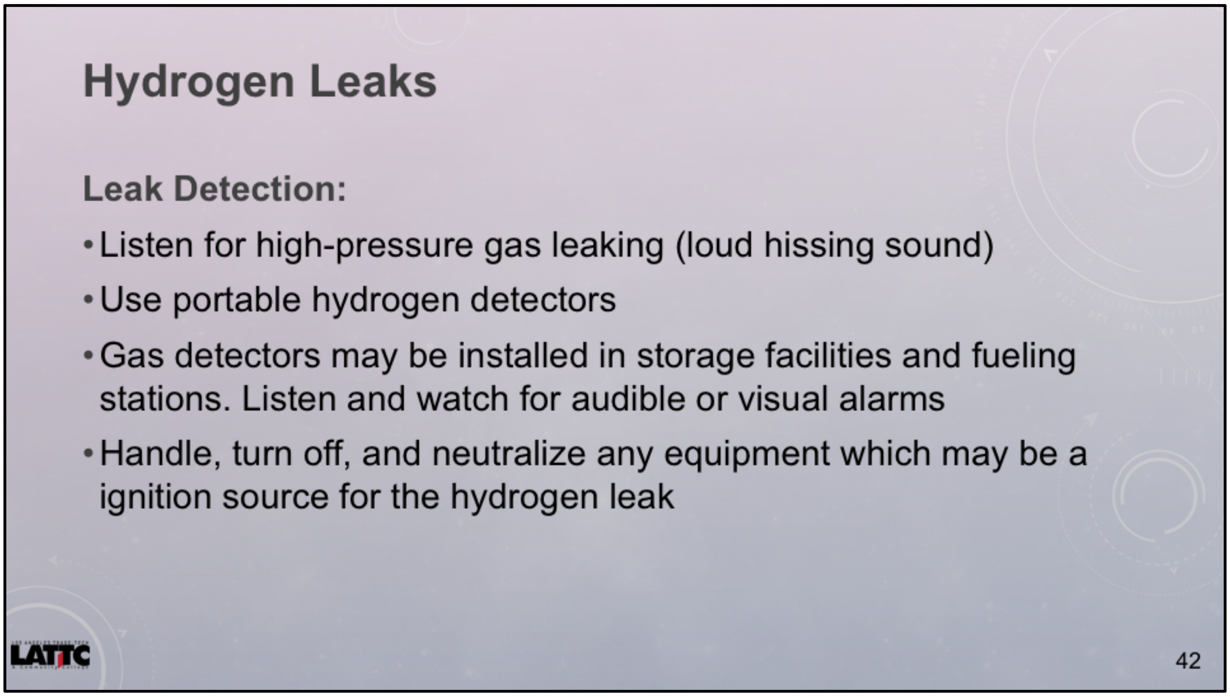
Good Safety Practices for Working with Hydrogen are highlighter here:

- Regardless of what kind of project you are working on, you should use a graded approach to safety planning and risk assessment based on the quantities of hydrogen involved (see Safety Planning)
- **70MPa** = 10,150 psi
- The first time you work with hydrogen, you should ask someone with hydrogen experience to assist you. You should never take chances or shortcuts
- Always plan for the worst-case scenario, but give some thought to the most probable scenario and be ready for that as well


HYDROGEN LEAKS
40



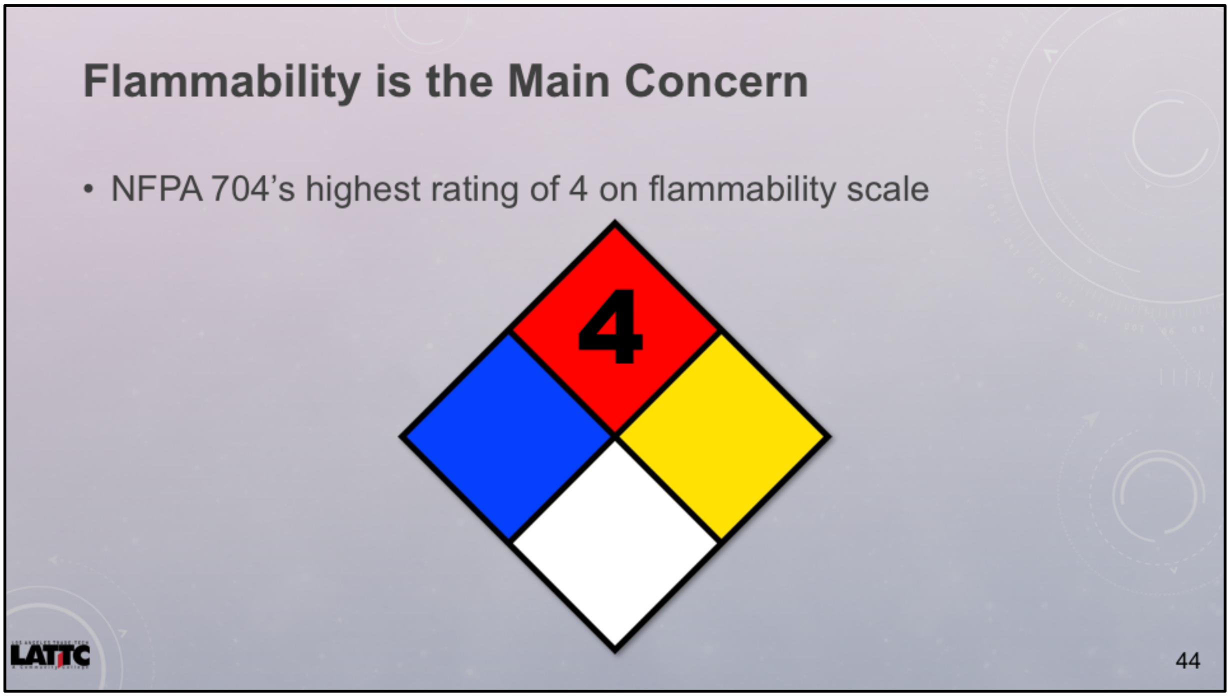
- Because hydrogen is such a small molecule, leaks are common
- The only human sense which could be use to detect a compressed hydrogen gas leak, may only be audible (Hissing noise) and visual (Frost). Remember, hydrogen is colorless, odorless, and tasteless
- If hydrogen accumulates in a confined space in sufficient concentrations, it is an asphyxiant (like any other gas except oxygen)
- Liquid hydrogen leaks are characterized by frost or ice crystals near the leak and usually a vapor cloud indicating moisture condensation from the surrounding air
- In the event of a cryogenic fuel spill, immediately evacuate the area and notify the authorities
- Cryogenic fuels are fuels that require storage at extremely low temperatures in order to maintain them in a liquid state (Liquid hydrogen temp: -423°F, -253°C or 20 K)



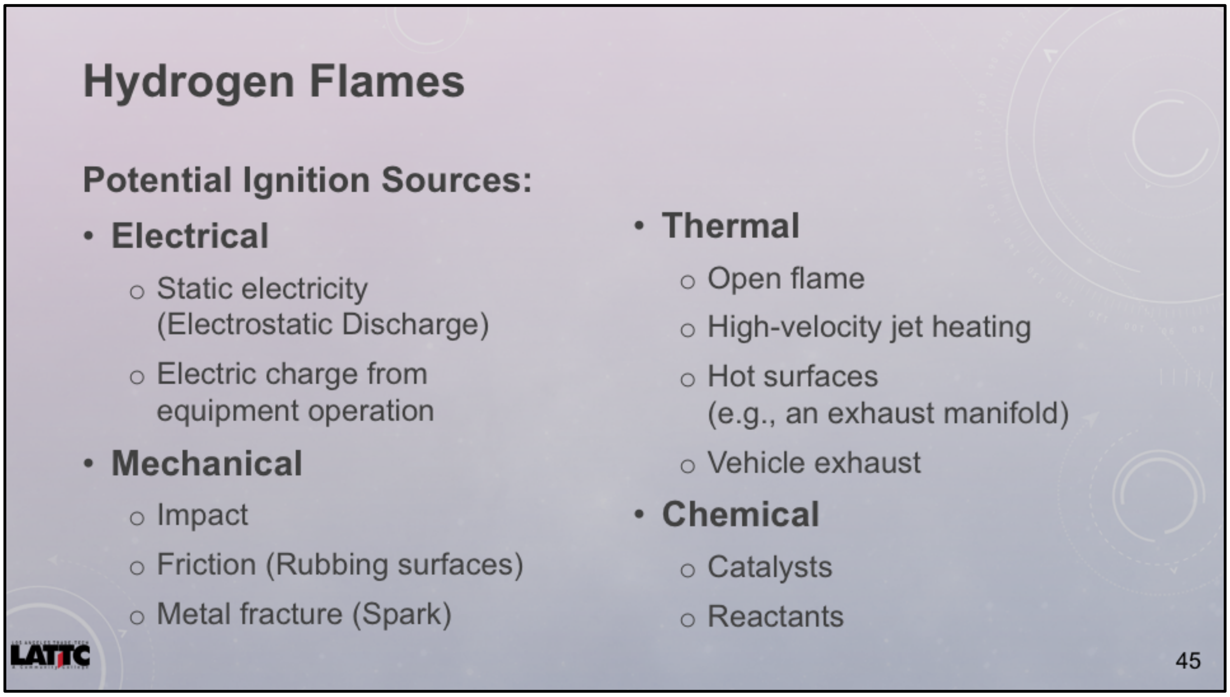
Leaking hydrogen constitutes a high personal SAFETY priority and HAZARD concern, and must be addressed with extreme caution.

- Hydrogen Leak Detection (Sniffers, sensors and hand-held testers)
- Listen for high-pressure gas leaking (loud hissing sound)
- Use portable hydrogen detectors
- Gas detectors may be installed in storage facilities and fueling stations. Listen and watch for audible or visual alarms
- Leak detecting systems and equipment must be employed anywhere compressed hydrogen gas is used or worked on
- If a hydrogen leak is suspected, ventilate the area, disable potential ignition sources in close proximity specially if they are located directly above of the suspected leak area (i.e. celling heaters, high-temp lighting, etc.)

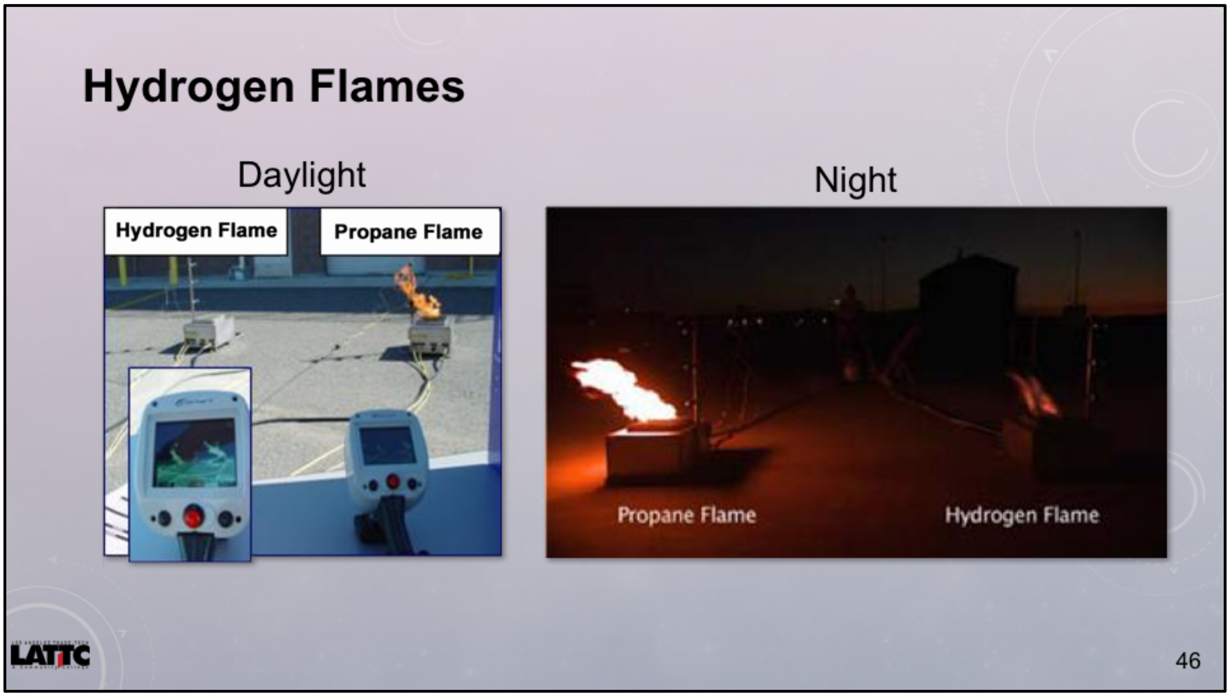
Hydrogen flames are very different than carbon ones. They emit a lot less smoke thus are hard to identify.



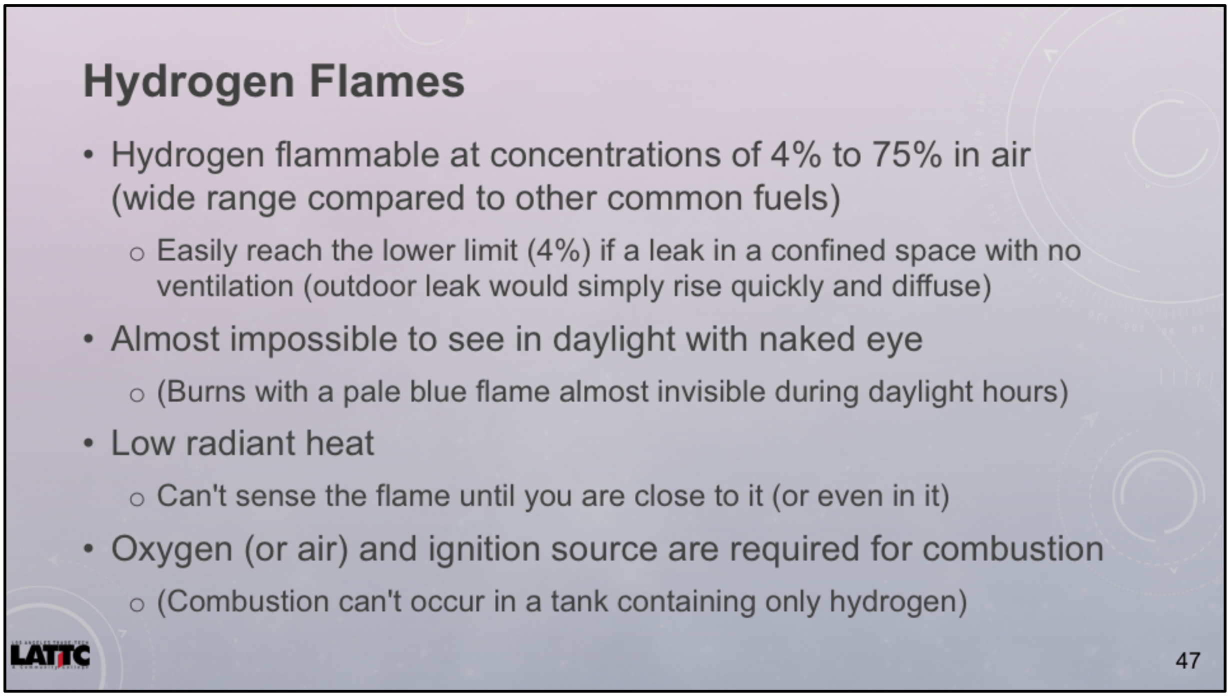
- The main concern in working with hydrogen is flammability
- Hydrogen possesses the NFPA 704's highest rating of 4 on the flammability scale because it is flammable when mixed even in small amounts with ordinary air
- Hydrogen gas and normal air can ignite at as low as 4% air due to the oxygen in the air and the simplicity and chemical properties of the reaction
- However, hydrogen has no rating for innate hazard for reactivity or toxicity
- Liquid hydrogen poses additional challenges due to its increased density and the extremely low temperatures needed to keep it in liquid form
- BLUE: Heath Hazard, RED: Flammability Hazard and YELLOW: Stability hazard. Highest DANGER number level is 4 (Range is 0 to 4), which can be place on any color according to the hazard at hand



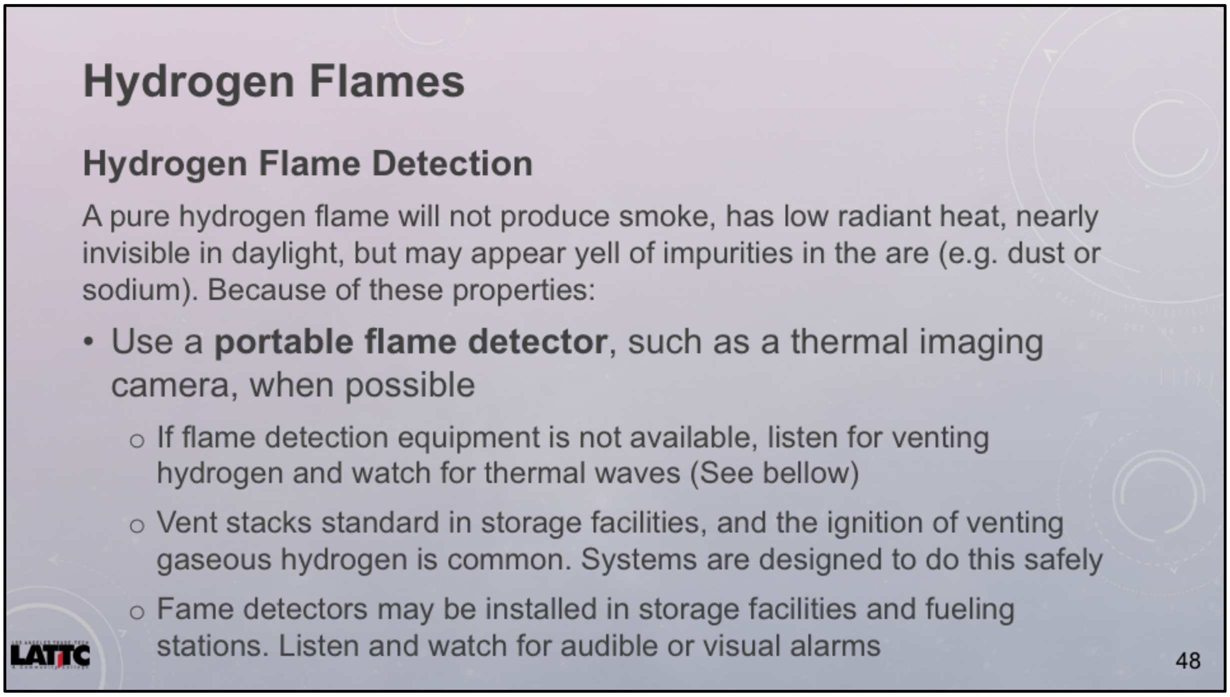
- Always evaluate potential ignition sources BEFORE working with compressed hydrogen gas
- There may also be other additional ignition sources present at your site in addition to the ones mention above



BE AWARE: Because hydrogen does not derive from fossil fuels (Contains no carbon), it burns quite clean with almost no visual smoke and forms water (Ironic). It is nearly impossible to see a hydrogen flame with the naked eye specially in daylight. Thermal imaging equipment MUST be used to identify any hydrogen fires (Combustion).



- Hydrogen flammability at very low concentrations (4%)
- The hydrogen concentration could easily reach the lower flammability limit (4%) if there were a leak in a confined space with no ventilation. An outdoor leak would simply rise quickly and diffuse
- Hydrogen fires have low radiant heat, so you can't sense the presence of a flame until you are very close to it (or even in it)
- Combustion can't occur in a tank that contains only hydrogen. The three RADICALS are not present=No fire (Fuel+Oxygen+ignition). Concentrations of pure hydrogen (99.5%-100%) will not ignite (Too rich)



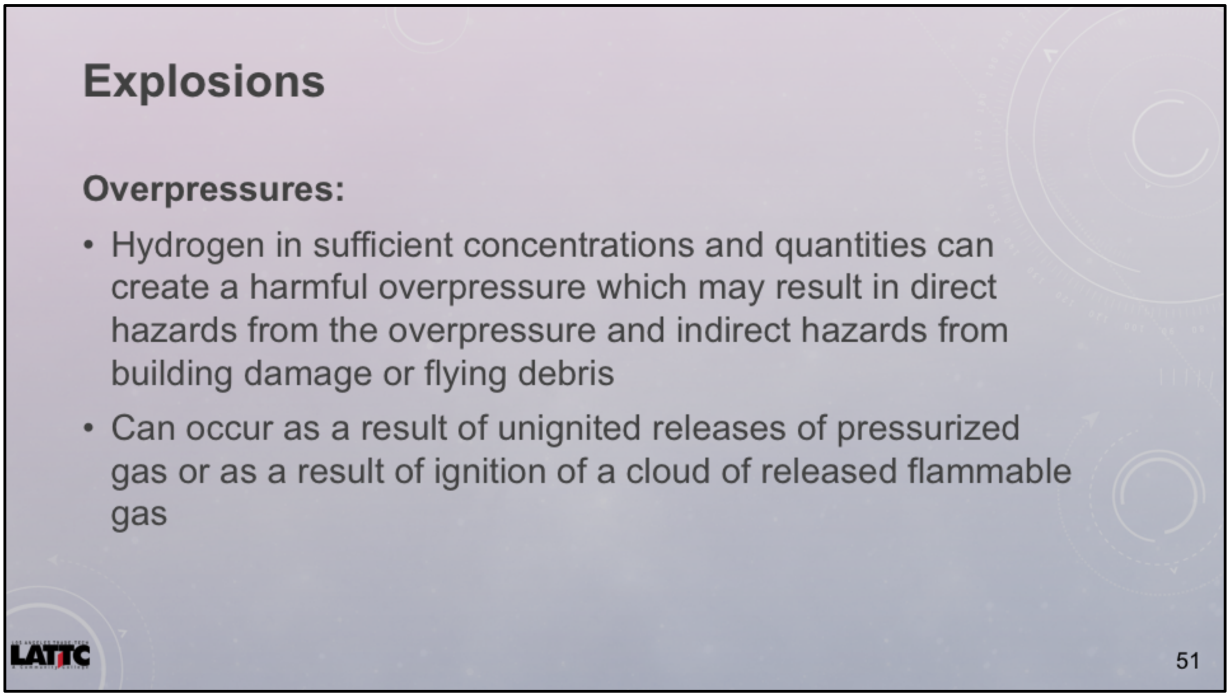
Hydrogen Flame Detection:

- Hydrogen burns with a pale blue flame that is nearly invisible in daylight. The flame may appear yellow if there are impurities in the air like dust or sodium
- A pure hydrogen flame will not produce smoke
- Hydrogen flames have low radiant heat. Unlike a hydrocarbon fire, you may not feel any heat until you are very close to the flame
- Because of these properties, use a portable flame detector, such as a thermal imaging camera, when possible. If flame detection equipment is not available, listen for venting hydrogen and watch for thermal waves
- Note that vent stacks are standard in storage facilities, and the ignition of venting gaseous hydrogen is common. Systems are designed to do this safely
- Fame detectors may be installed in storage facilities and fueling stations. Listen and watch for audible or visual alarms

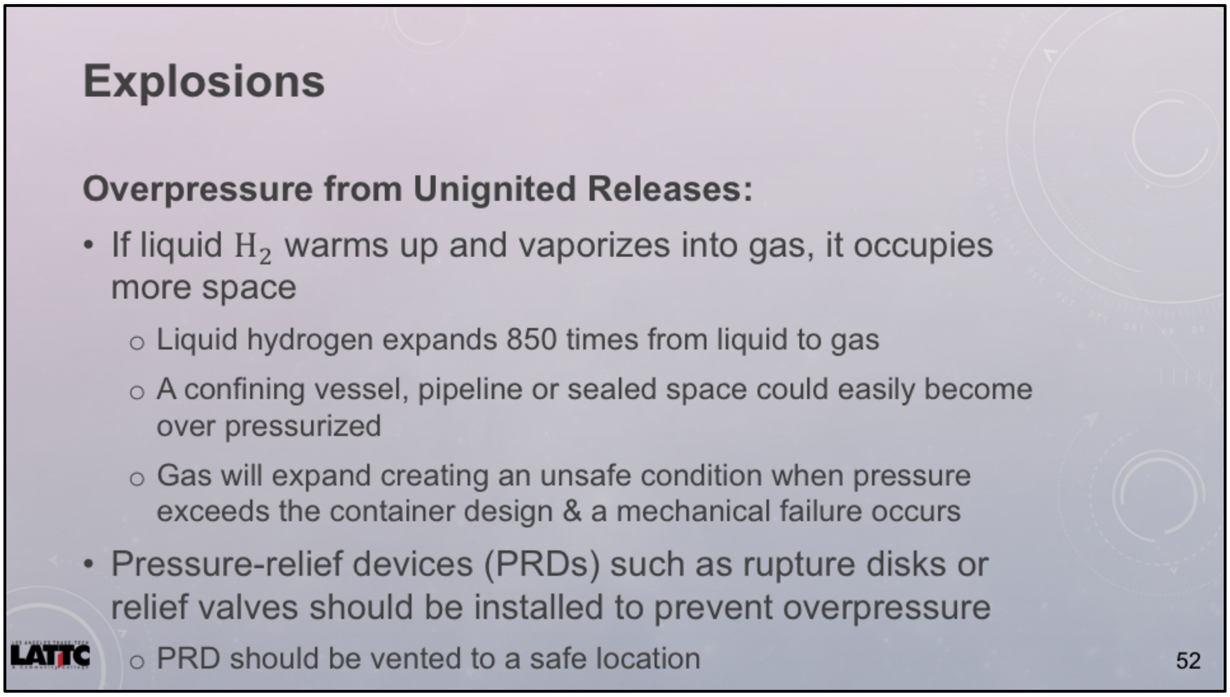
Hydrogen Flame Detection:

- Because of these properties, use a portable flame detector, such as a thermal imaging camera, when possible. If flame detection equipment is not available, listen for venting hydrogen and watch for thermal waves
- Note that vent stacks are standard in storage facilities, and the ignition of venting gaseous hydrogen is common. Systems are designed to do this safely (They are also grounded to the ground- Ground strap)
- Flame detectors may be installed in storage facilities and fueling stations. Listen and watch for audible or visual alarms

Hydrogen gas explosions are extremely DANGEROUS because of their sudden and violent expansion. This happens the moment the surrounding air-fuel ratio comes into flammable parameter. Again, hydrogen concentrations from 4% to 75% hydrogen gas with air, are ready to ignite!

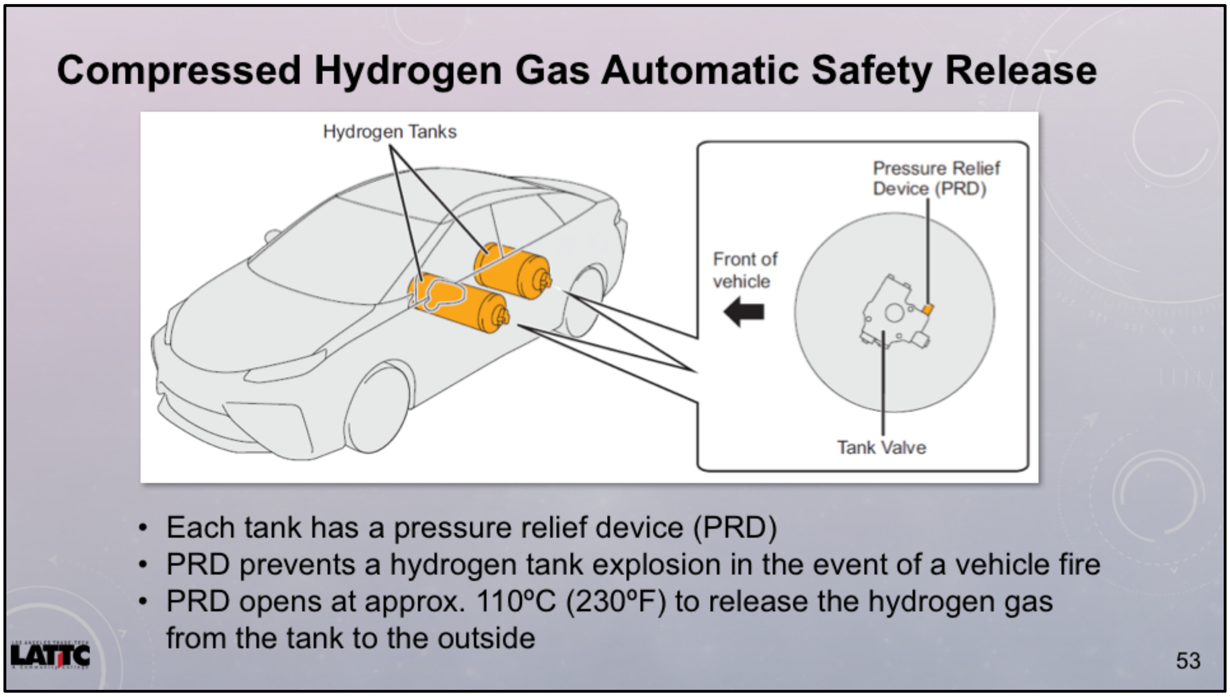


Hydrogen in sufficient concentrations and quantities can create a harmful overpressure which may result in direct hazards from the overpressure and indirect hazards from building damage or flying debris. Overpressures can occur as a result of unignited releases of pressurized gas or as a result of ignition of a cloud of released flammable gas.



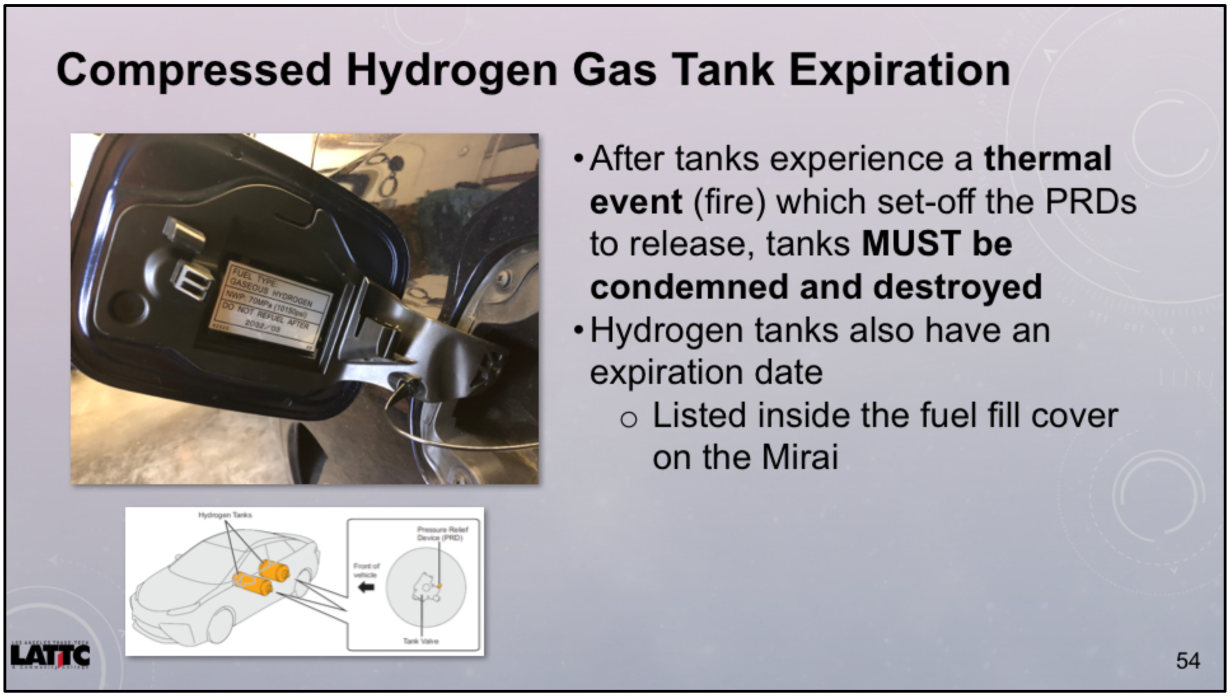
Overpressure from Unignited Releases:

- As with any cryogenic fluid, if it is warmed and vaporizes into a gaseous state, it occupies significantly more space
- If a pressurized gas container is heated the gas will expand creating an unsafe condition
- Pressure-relief devices (PRDs) are installed onto hydrogen gas tanks to handle this risk. In the even that a PRD has opened, it will stay in this mode and will empty the entire container until equalizes with atmospheric pressure
- Even after there is no more release (equal pressure), there is STILL 100% hydrogen gas occupying the void in the "empty" tank. This residual hydrogen gas in the tank needs to be "pushed-out" (Purged) by filling the tank with water or other volume-occupying, non-igniting fluid
- PRD's release manifold is plumbed to vent towards a safe direction and exit to the atmosphere in a safe location



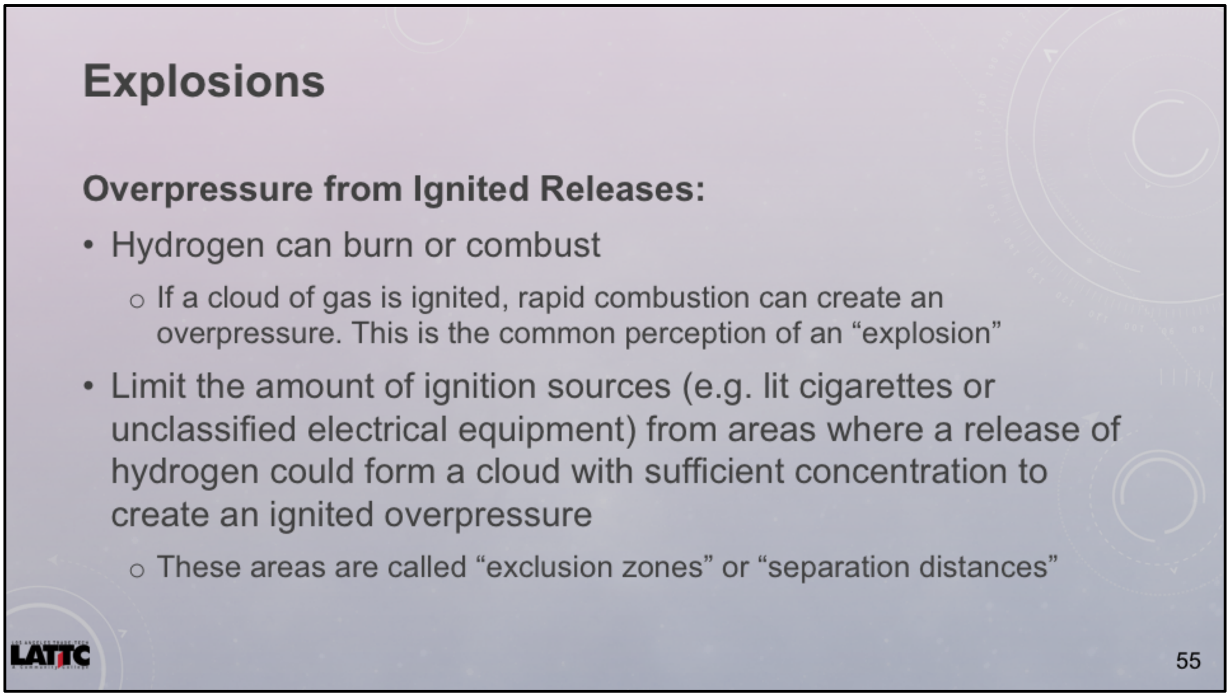
Hydrogen Tanks and Pressure Relief Device:

- Each tank is equipped with a pressure relief device (PRD) in order to prevent an explosion when the temperature of the hydrogen reaches above normal levels due to a vehicle fire. The pressure relief device will open at approximately 110℃ (230°F) to release the hydrogen gas in the tank outside of the vehicle
- PRDs are designed to **open** at specific temperatures and venting the **ENTIRE** container (unusable)
- After tanks experience a **thermal event** (fire) which set-off the PRDs to release, tanks **MUST be condemned and destroyed**



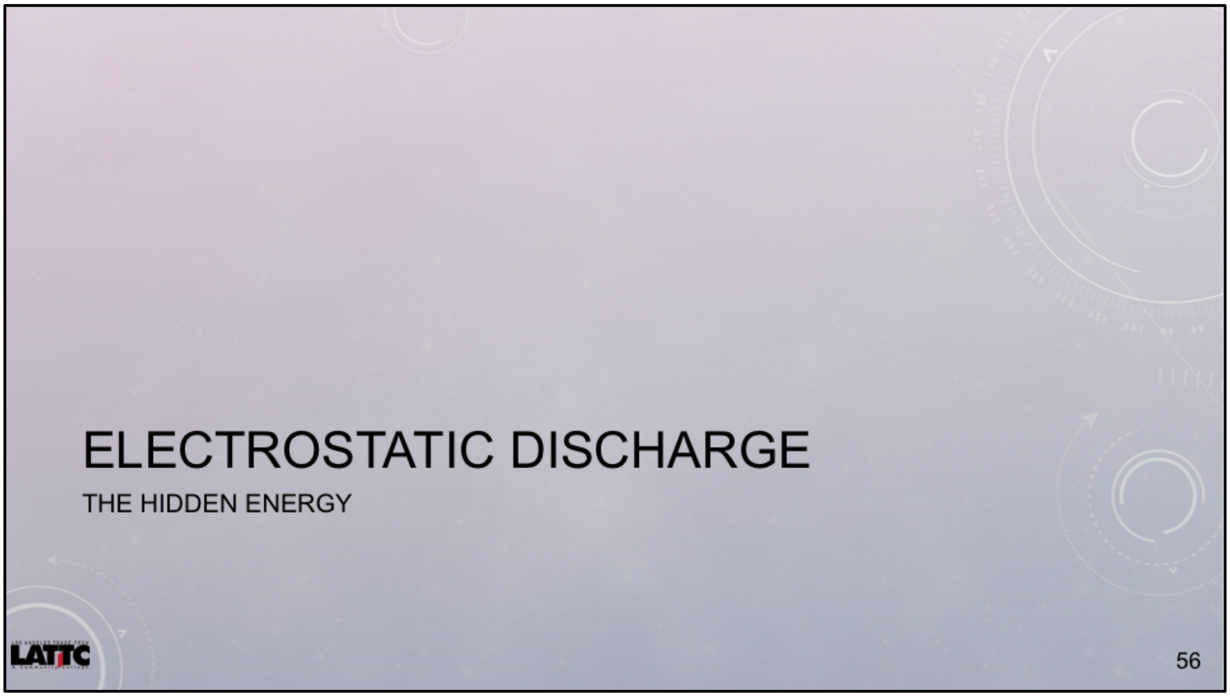
Hydrogen Tanks and Pressure Relief Device:

- After tanks experience a **thermal event** (fire) which set-off the PRDs to release, tanks **MUST be condemned and destroyed**
- Hydrogen tanks also have an expiration date
    - Listed inside the fuel fill cover on the Mirai

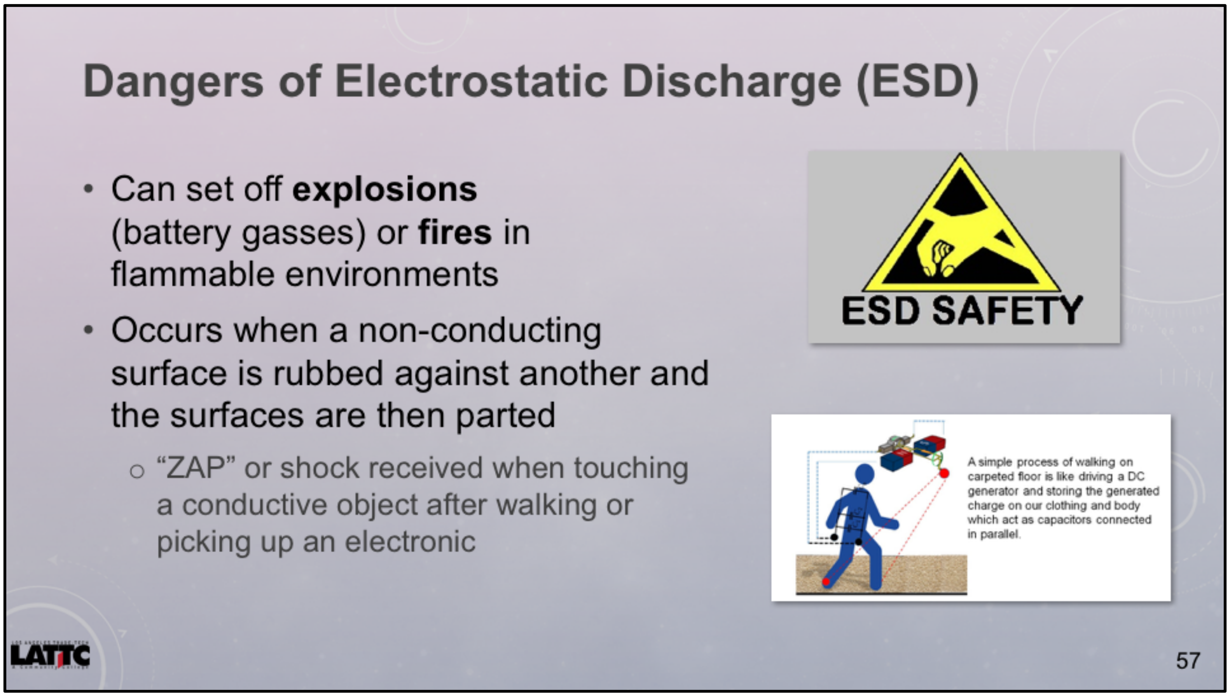


Burning VS. Combustion (Differences):

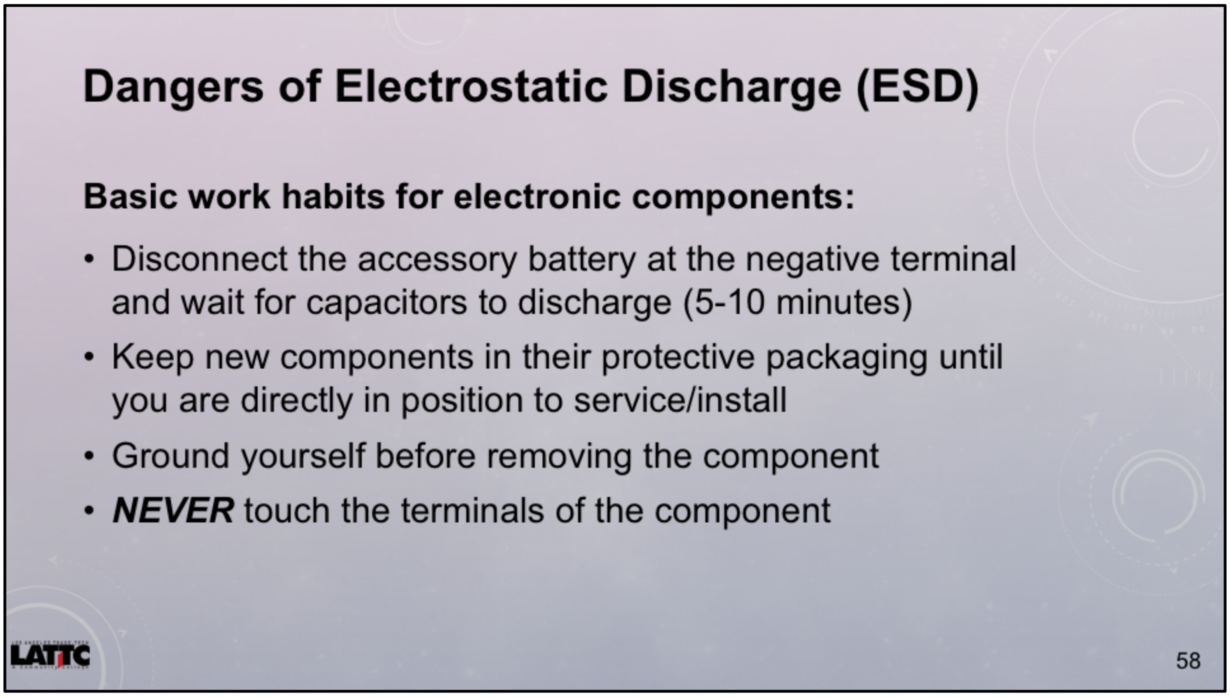
- BURNING: “To set something on fire”
  - Always creates a flame
  - Forms a low amount of heat
  - Always produces light
- COMBUSTION: “Chemical reaction that involves the oxidation of a fuel”
  - May or may not create a flame
  - Forms a high amount of energy
  - May or may not form light as an energy form



Hiding like a thief, ignition by ESD sources are ignored with relative frequency. However, they always surprise all of us with a “Zap”! Sometimes, we even hear the actual discharge spark or “crack”. Unfortunately by this time, it is done/over (Discharged).

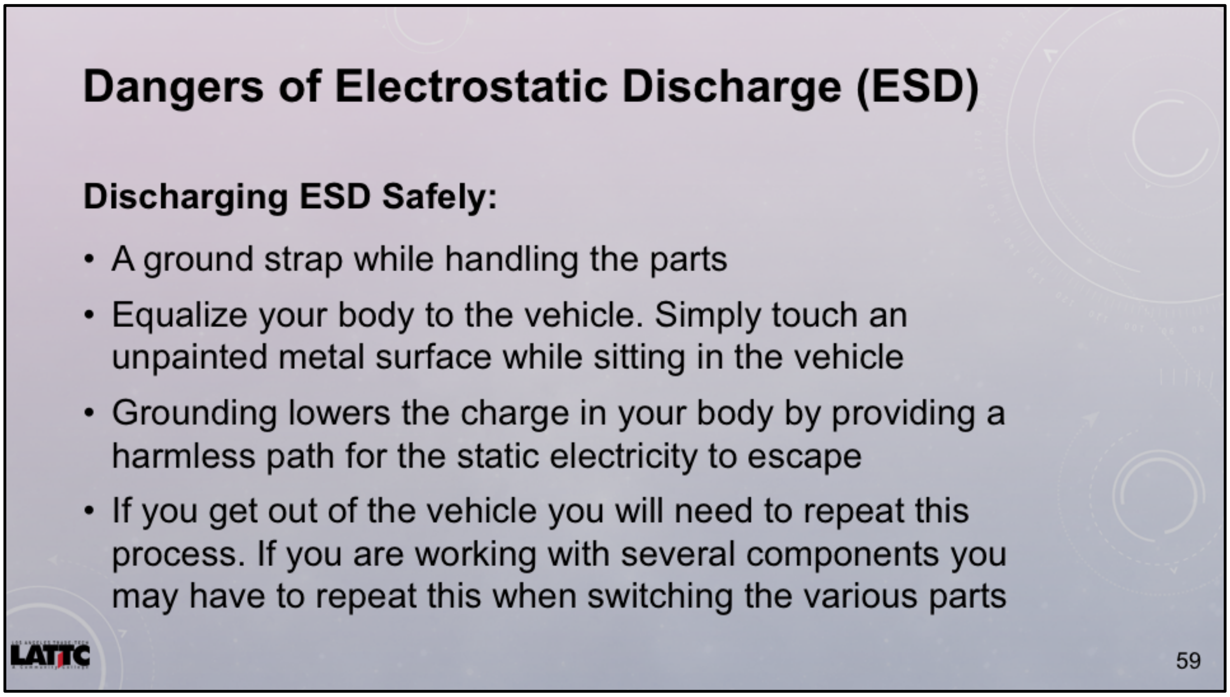


Electrostatic discharge (ESD) occurs when a non-conducting surface is rubbed against another and the contacted surfaces are then parted
ESD can **damage** or destroy **sensitive** electronic components, erase or alter magnetic media, or set off **explosions** (battery gasses) or **fires** in flammable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



Basic work habits for electronic components:

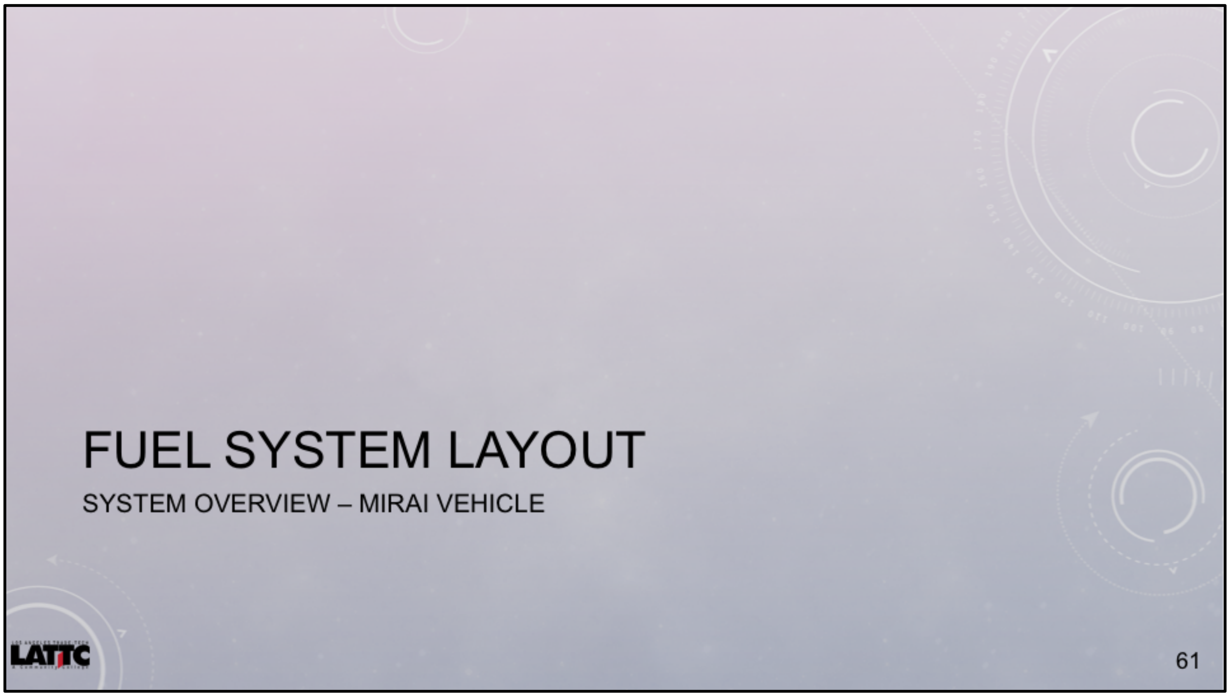
- Disconnect the accessory battery at the negative terminal and wait for capacitors to discharge. (most modern vehicles have SRS/air bag systems that require at least 5-10 minuets to discharge, check with the approximate information for the vehicle you are working on)
- Keep the new component in its 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:

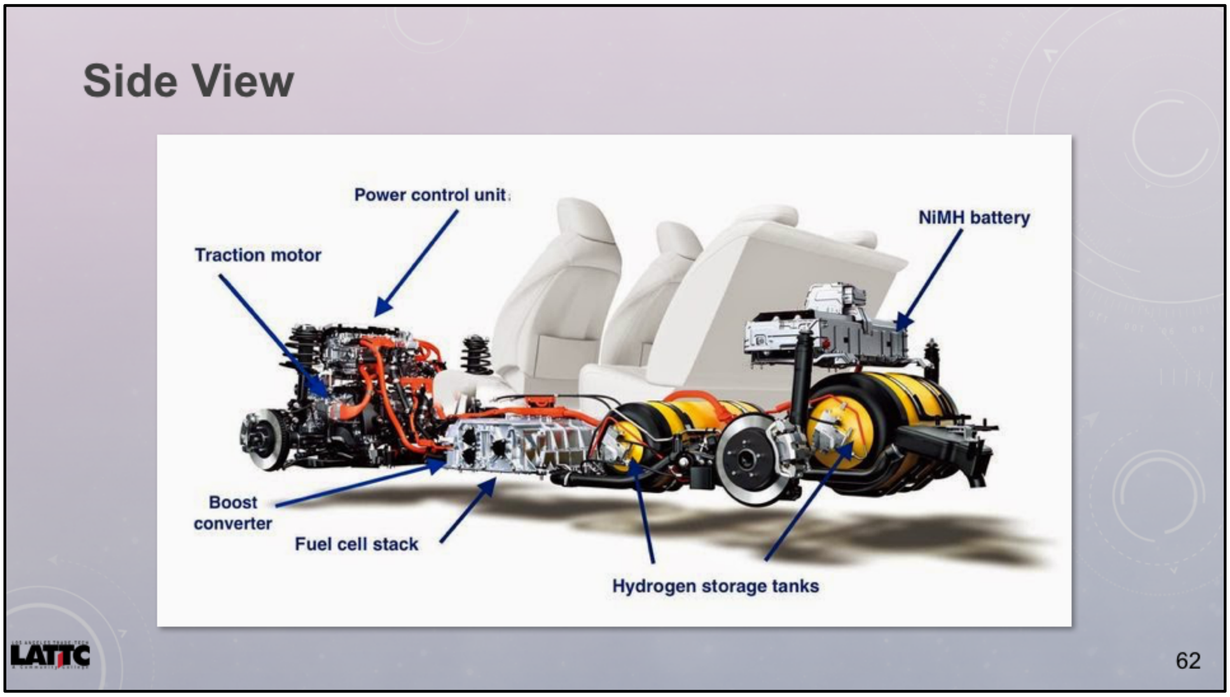
- There are several ways to do this depending on the manufactures instructions and the components manufacture. In some cases you will need a simple ground strap while handling the parts. Most commonly you will need to equalize your body to the vehicle. This can be accomplished by simply touching an unpainted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


FUEL SYSTEM
LAYOUT, FUEL CELL STACK, DIAGRAMS, & FUEL STORAGE
LATTC
60

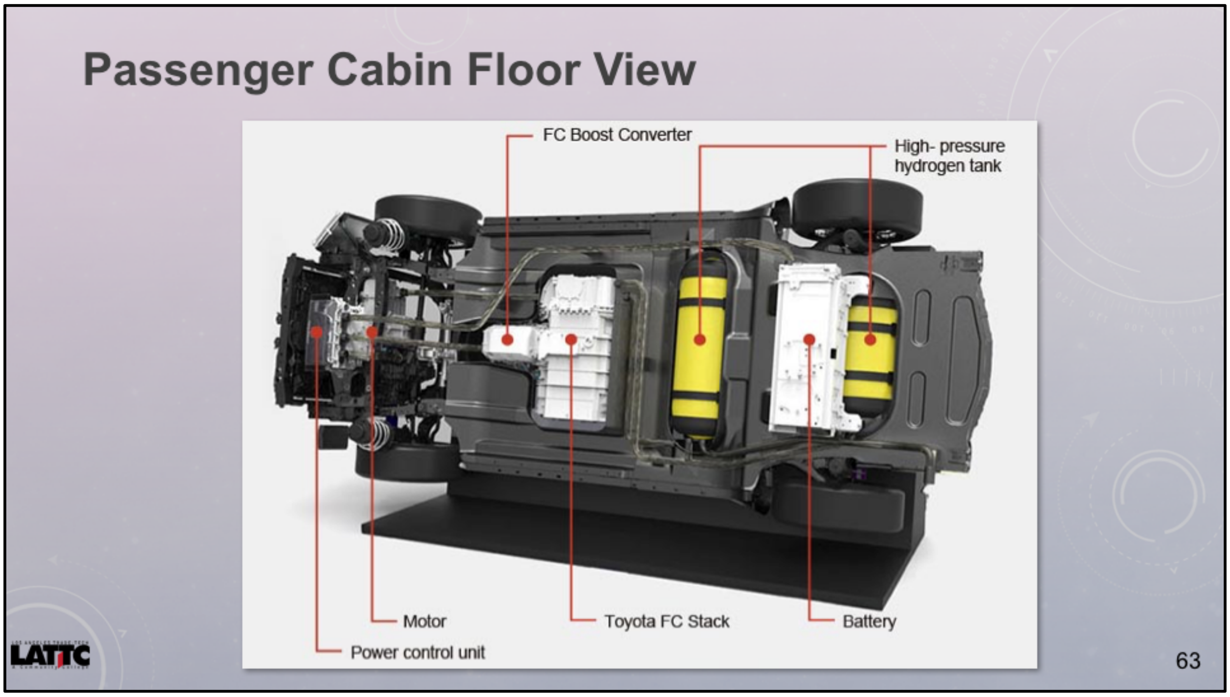


Highly pressurized hydrogen gas is used as fuel to supply the vehicle's fuel cell stack as the energy source for the vehicle operation. The fuel system stores, delivers and controls the safety release of gas if a over-pressurization event ever takes place.

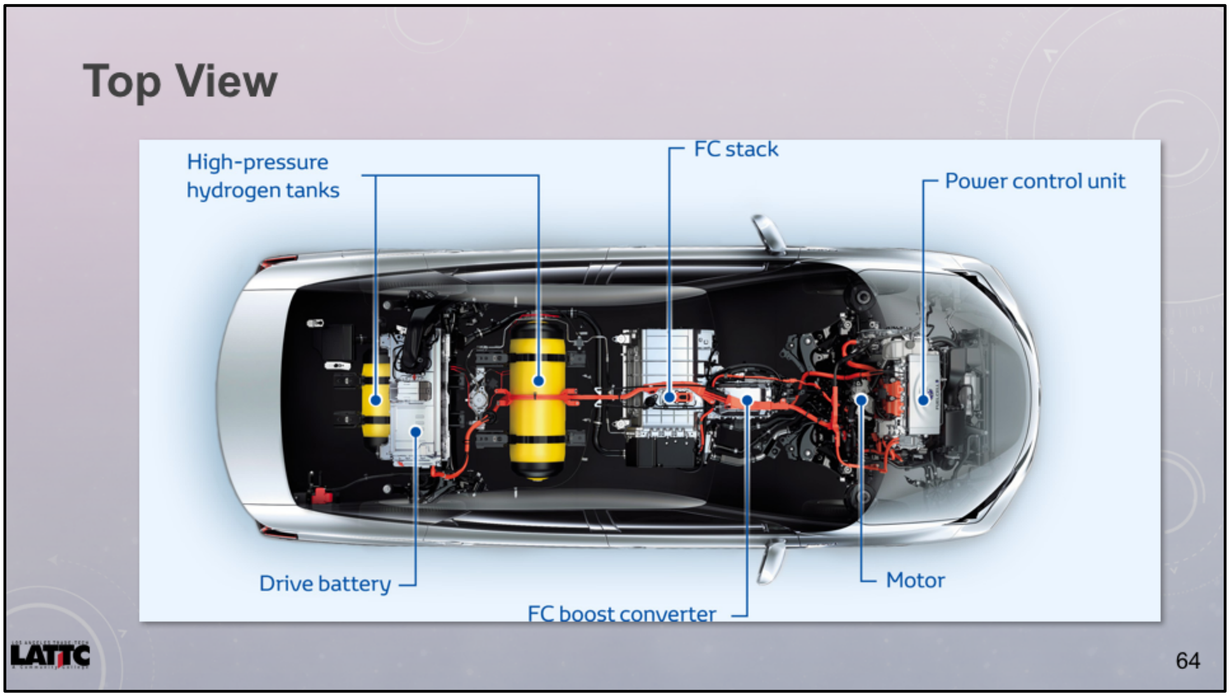
- High pressure hydrogen storage cylinders (2)
- High pressure regulator is used to step the cylinder tank pressure (~5,000 psi) down to 145↔218 psi



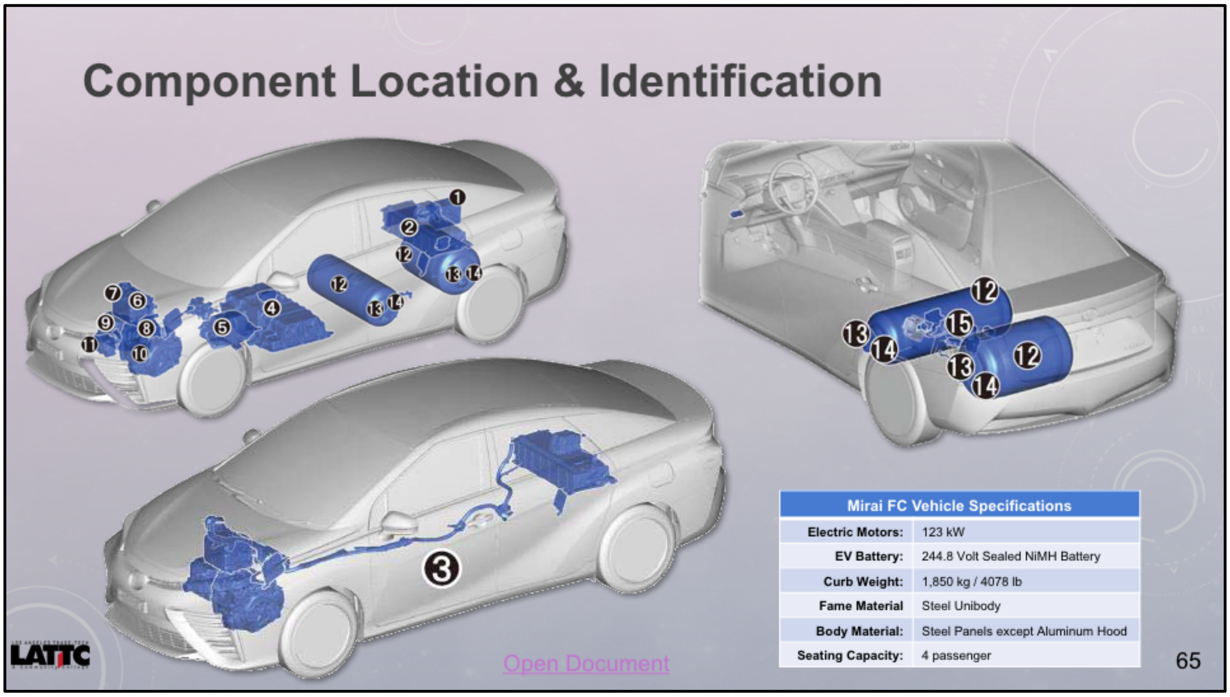
Mayor vehicle components other than the power control unit, are hidden away from view. Familiarized yourself with what they are and their locations.



Removing the body-shell and carpet off the vehicle, the view looking at the passenger floor from above, clearly show us how some of the system components protrude through the vehicle's floor.



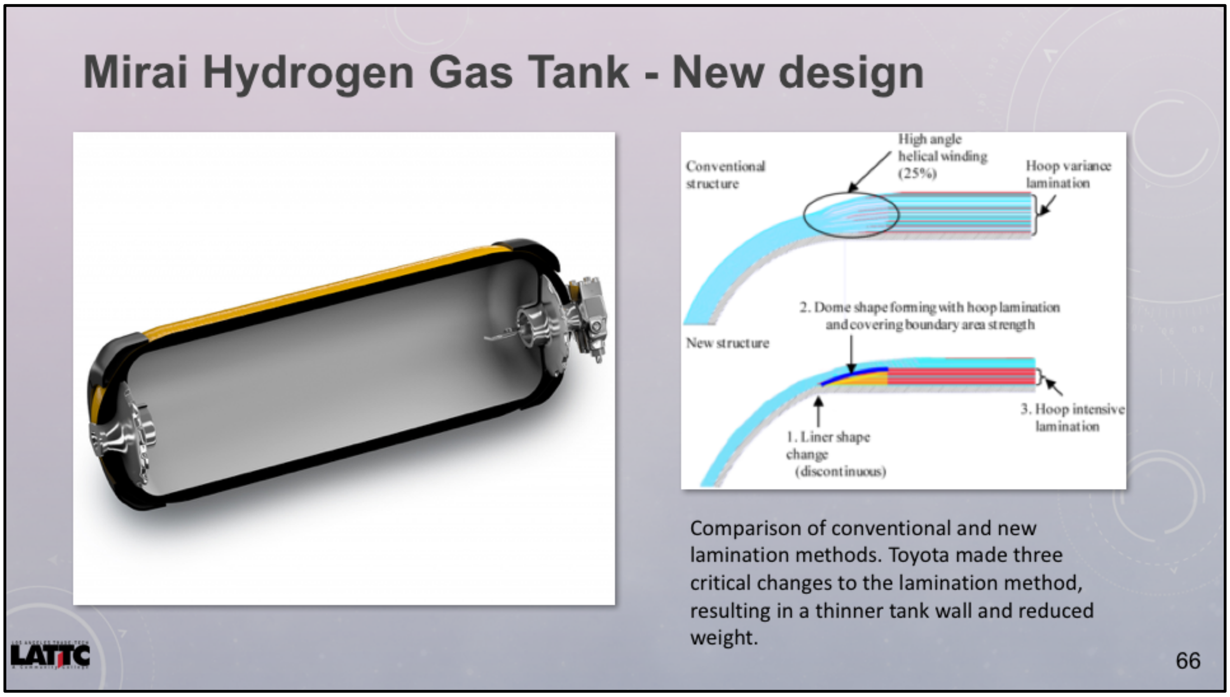
In this see-through body image, take note on the different size and configuration of the **high-pressure**, hydrogen-fuel cylinder tanks and bright orange, **high-voltage** power cables.



INDEX:

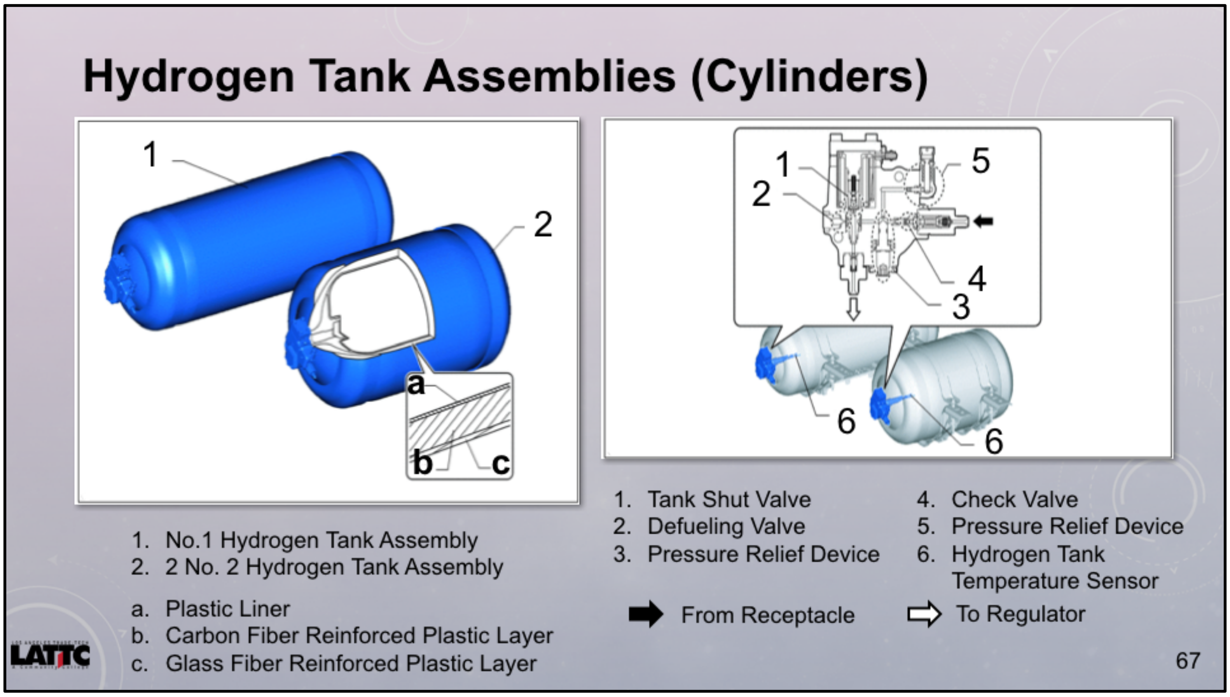
1. **12v Aux battery:** Conventional, Lead-Acid 12v battery (truck area).
2. **EV Battery:** 244.8 Volt Nickel Metal Hydride (NiMH) battery pack consisting of 34 low voltage (7.2 Volt) modules connected in series.
3. **HV Power cables:** 244.8v↔650v.
4. **FC Stack Assy:** Generates electrical energy by causing a chemical reaction.
5. **FC Converter Assy:** Boosts the voltage of the electrical energy generated in the FC stack assembly to a maximum of DC 650 Volt.
6. **Inverter with Converter Assy:** 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.
7. **DC-DC Converter:** Steps down the voltage and supplies the auxiliary 12v power for conventional vehicle loads (i.e. lights, ignition, widows, etc.).
8. **FC Cooling Water Pump with motor Assy:** 3-phase, 340vAC, water pump motor cools the FC stack assembly and the air compressed by the air compressor.
9. **FC Air Compressor Assembly:** Provides supercharged air to he FC Stack.
10. **FCV Transaxle with Motor Assembly:** Propels the vehicle (motive force).
11. **Compressor with motor Assy:** 3-phase, 340vAC HV electrically driven motor compressor.

12. **Hydrogen Tank:** 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).
13. **Hydrogen Tank Valve Assy:** Installed to each hydrogen tank, and opens and closes the hydrogen channels.
14. **Hydrogen Tank Temperature Sensor:** Detects the hydrogen fuel temperature inside the hydrogen tank and transmits it to the hydrogen fuel control ECU.
15. **Hydrogen Supply Regulator Assy:** 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).



Toyota **reduced the weight, size, and cost** of the high-pressure hydrogen storage system in the Mirai **while improving fueling performance**. The four 70 MPa tanks used on the 2008 Toyota FCHV-adv **were reduced** to two new larger diameter tanks; Toyota developed a new **optimized laminated structure** for tanks to reduce weight using a **high-strength low-cost carbon fiber material**. The shapes of the newly developed high-pressure hydrogen tanks were optimized to enable installation under the floor of the sedan. Further, Toyota reduced the size of the high-pressure valve and also modified a **high-pressure sensor** from a conventional vehicle for use in a high-pressure hydrogen atmosphere.

As a result, the whole storage system weighs approximately **15% less** than that in the Toyota FCHV-adv, while reducing the number of component parts by half **and substantially reducing cost**.

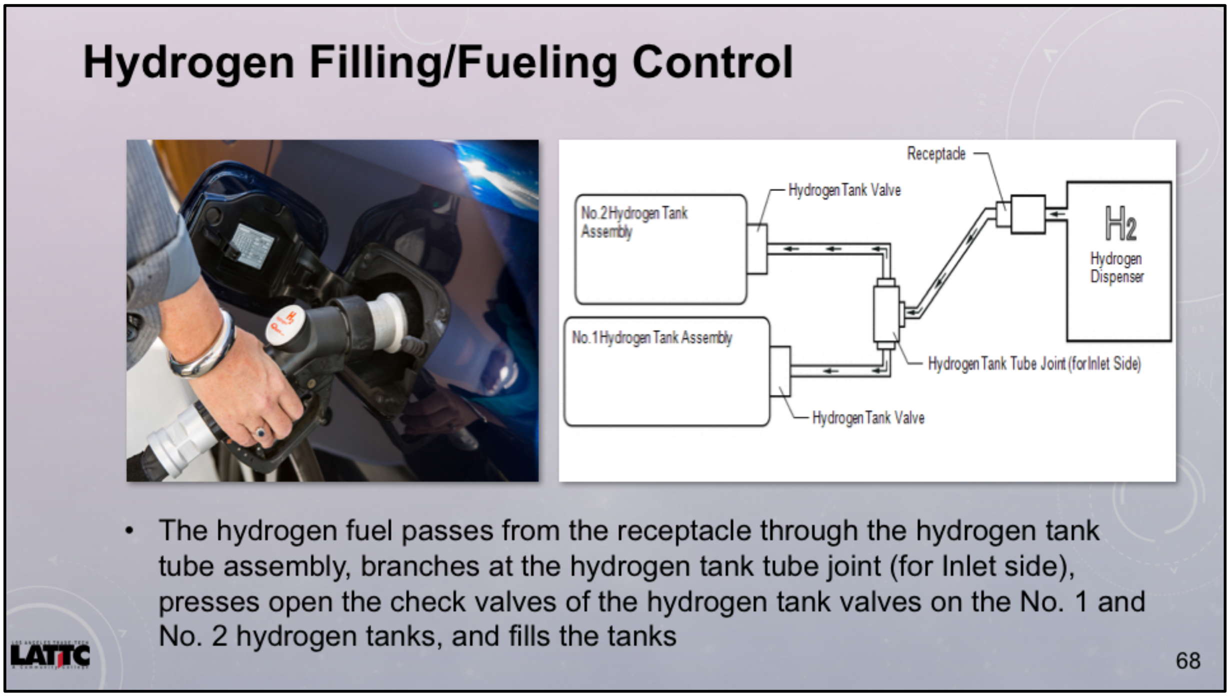


Hydrogen Tanks:

- The hydrogen tank is designed to handle a high filling pressure (87.5 MPa (892.3 kgf/cm2, 12688 psi)
- The hydrogen tanks have the date of removal from service that is written on the inside of the fuel door as the limit date of refueling. If continue to use vehicle, replace the hydrogen tanks with new ones

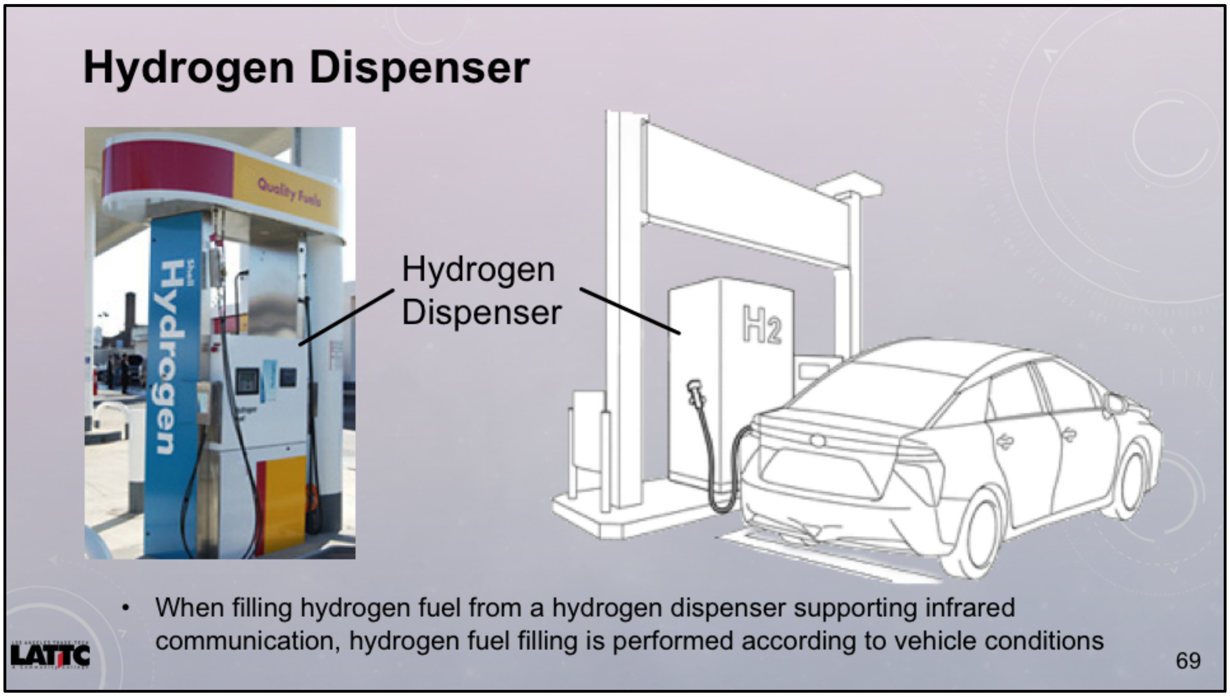
Hydrogen Tank Valves:

- Hydrogen tank valves are installed to each hydrogen tank, and perform fuel supply and shutoff
- In the event of a hydrogen gas leak, the hydrogen gas is detected and the electromagnetic valve closes, stopping the leakage of hydrogen gas
- **Defueling Valve:** Manually operated to release the gas in the hydrogen tank into the atmosphere
- **Manual Valve:** Manually operated to stop the flow of hydrogen gas
- **Pressure Relief Device (PRD):** When a vehicle fire has occurred, in order to reduce the occurrence of hydrogen tank rupture, the hydrogen gas inside the hydrogen tank is vented from the pressure relief device to the rear of the vehicle in a downwards diagonal direction



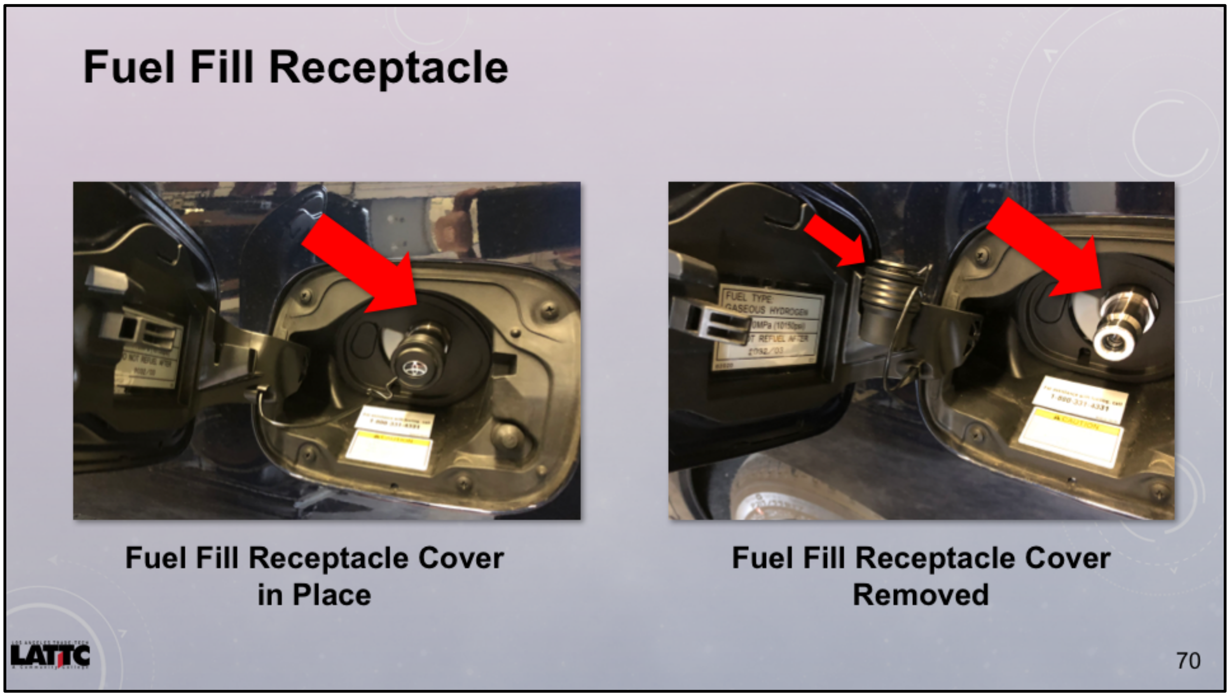
Fueling a FC vehicle:

- **Check Valve:** Pushed open by gas pressure during refueling. Hydrogen fuel that has been filled into the hydrogen tank is prevented from flowing in the reverse direction
- The hydrogen fuel from the hydrogen dispenser passes from the receptacle through the hydrogen tank tube assembly, branches at the hydrogen tank tube joint (for Inlet side), presses open the check valves of the hydrogen tank valves on the No. 1 hydrogen tank and No.2 hydrogen tank and is filled into the tanks

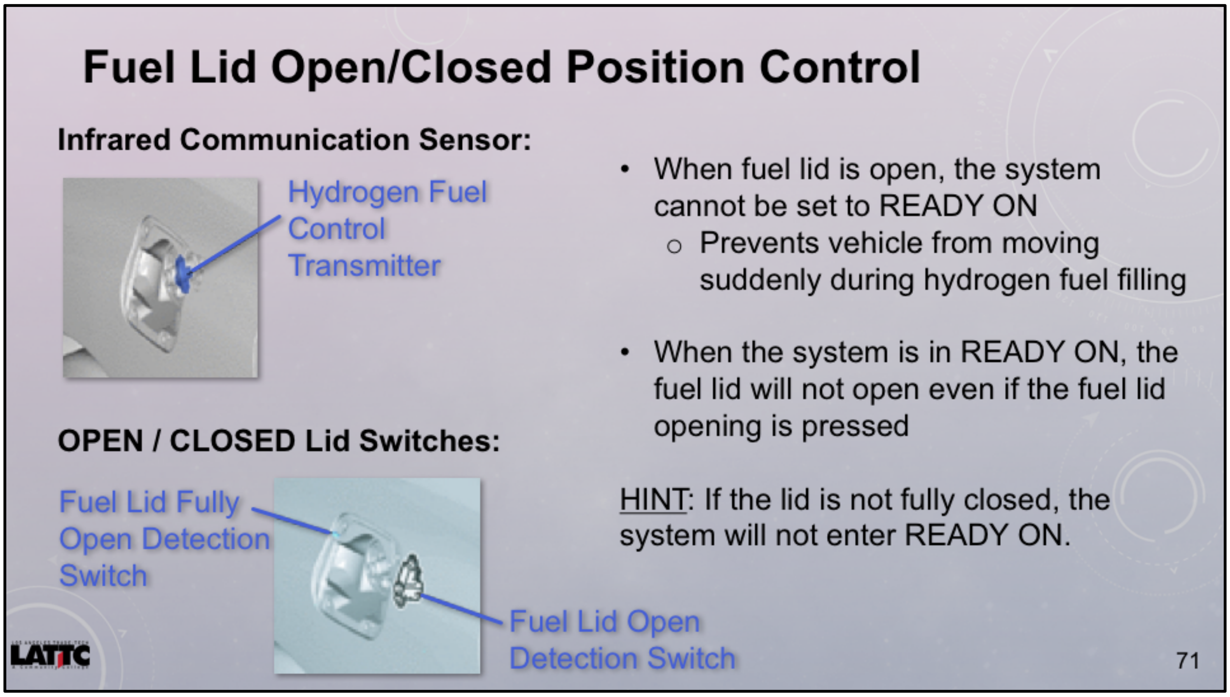


Fueling:

- During hydrogen fuel filling, the flow of fuel **may cause hissing**, whistling, or other sounds of gas flowing to be heard from behind the rear seat
- **The time** needed for filling and the amount of fuel filled into the tank **may differ** depending on the equipment at the hydrogen station. Some filling equipment **may not completely fill the tank**, **reducing the distance** that can be traveled until the next refueling



These photos show the Fuel Fill Receptacle with the cover in place and the with the cover removed.

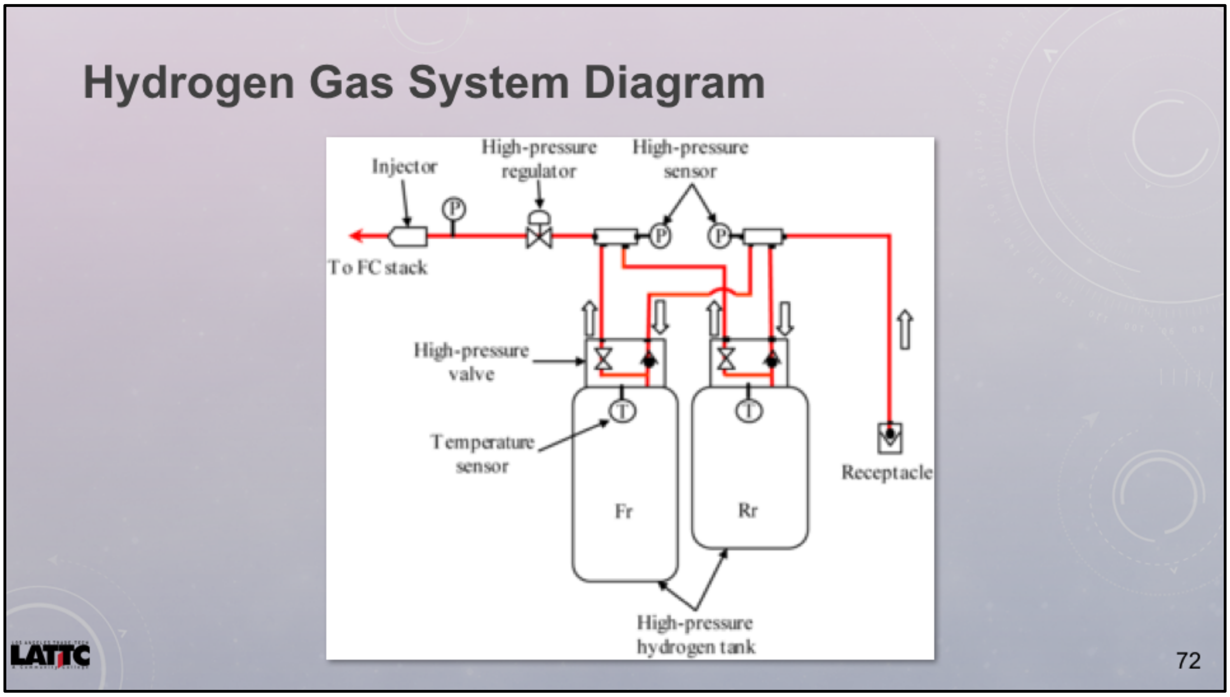


Infrared Communication:

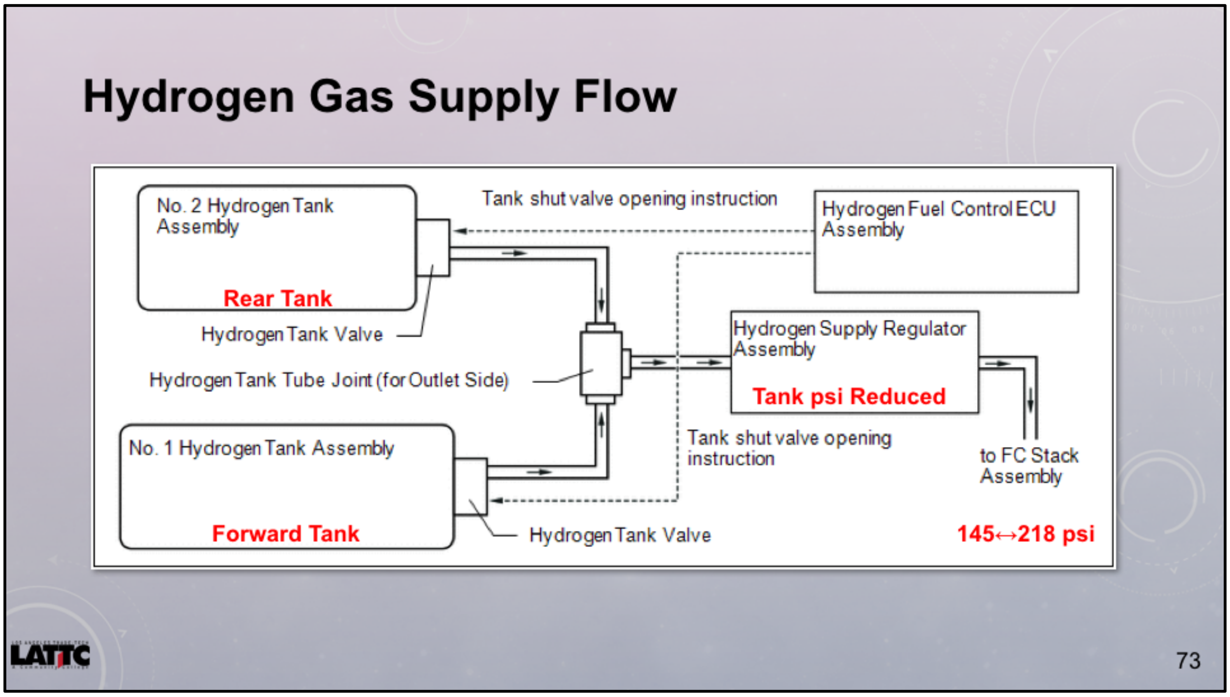
- The hydrogen fuel control ECU assembly uses **infrared communication** to transmit the hydrogen tank volume, the temperature inside the hydrogen tank and the pressure inside the hydrogen tank tube joint (for Inlet side) during hydrogen fuel filling, via hydrogen fuel control transmitter, to the hydrogen dispenser

Fuel Lid Switches:

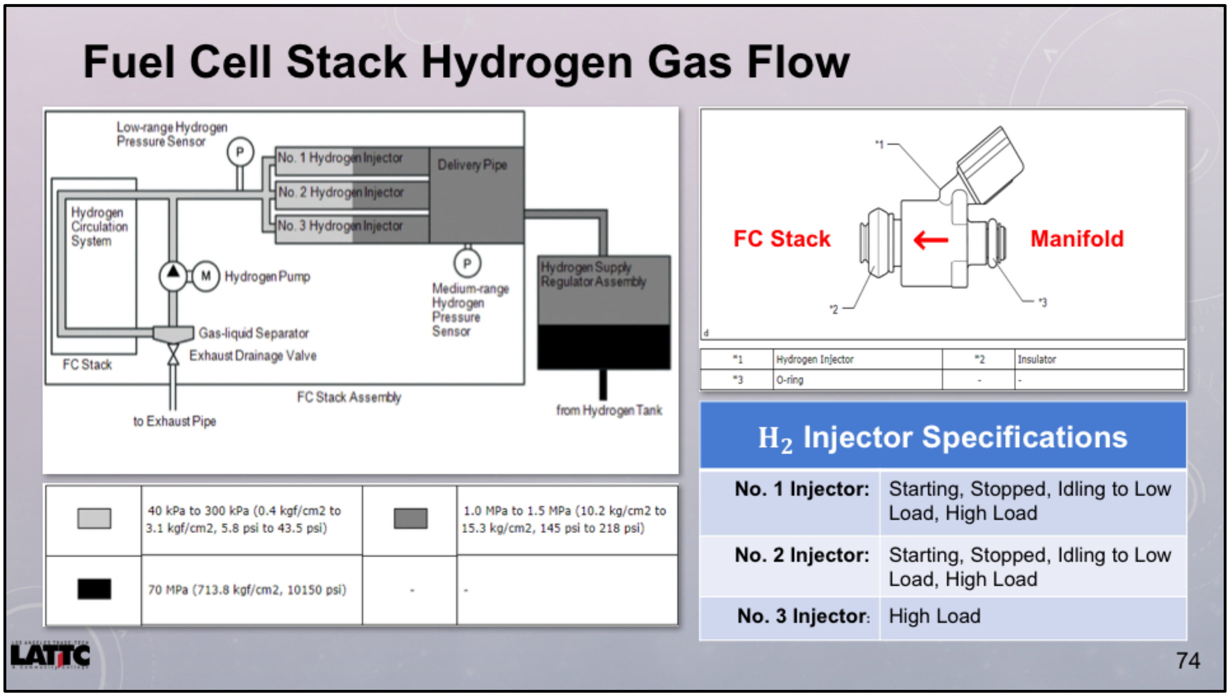
- The fuel lid has 2 switches to detect opening and closing, and the open/close status is transmitted to the hydrogen fuel control ECU assembly
- To prevent the vehicle from moving suddenly during hydrogen fuel filling, when the fuel lid is open, the system cannot be set to READY ON. In addition, when the system is in READY ON, the fuel lid will not open even if the fuel lid opening is pressed
- HINT: If the lid is not fully closed, the system will not enter READY ON



- Receptacle directs hydrogen gas from dispenser to both tanks simultaneously
- High pressure valves control the flow out of the tanks
- Tanks supply hydrogen gas to the high pressure regulator
- The high pressure regulator feeds the hydrogen injectors with fuel
- Fuel then is meter by the control module according to energy requests
- Most hydrogen **high pressure lines** are **painted Red color**

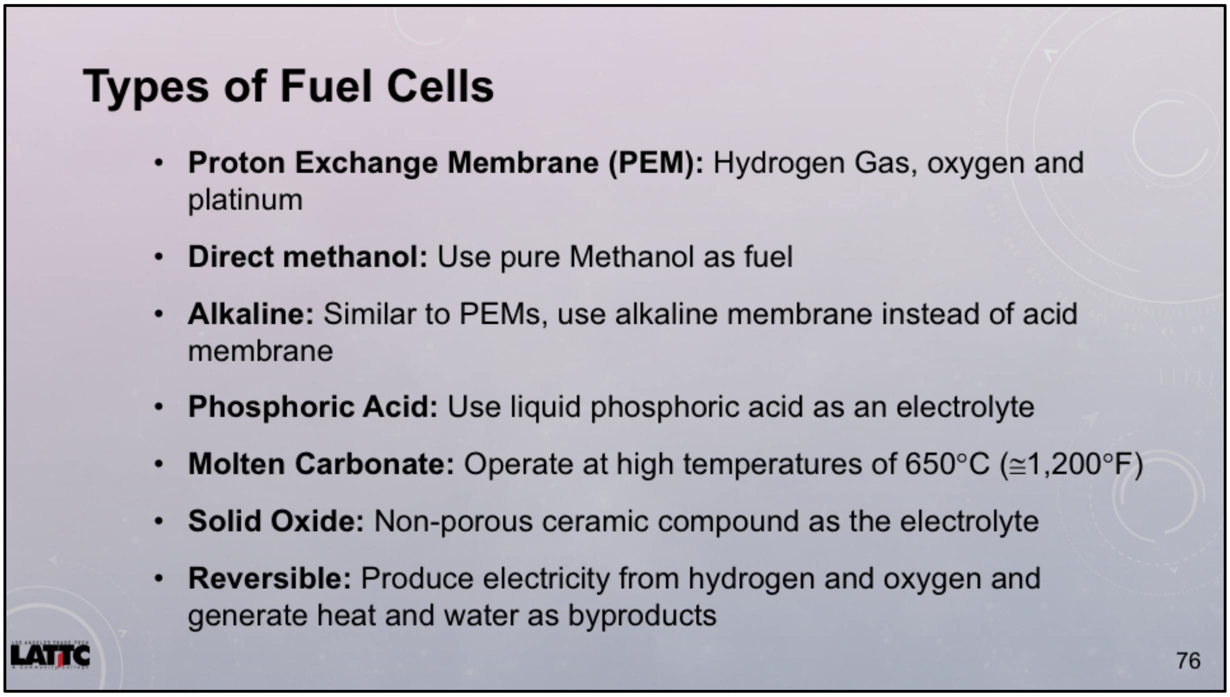


- The hydrogen fuel control ECU assembly supplies hydrogen fuel to the FC stack assembly
- The hydrogen fuel control ECU assembly opens the tank shut valves of the hydrogen tank valves on the No. 1 hydrogen tank assembly and No. 2 hydrogen tank assembly and combines the hydrogen fuel flows in the tube joint (outlet side), then the pressure is reduced in the hydrogen supply regulator and the fuel is supplied to the FC stack
- Hydrogen supply regulator reduces tank pressure down to 145↔218 psi

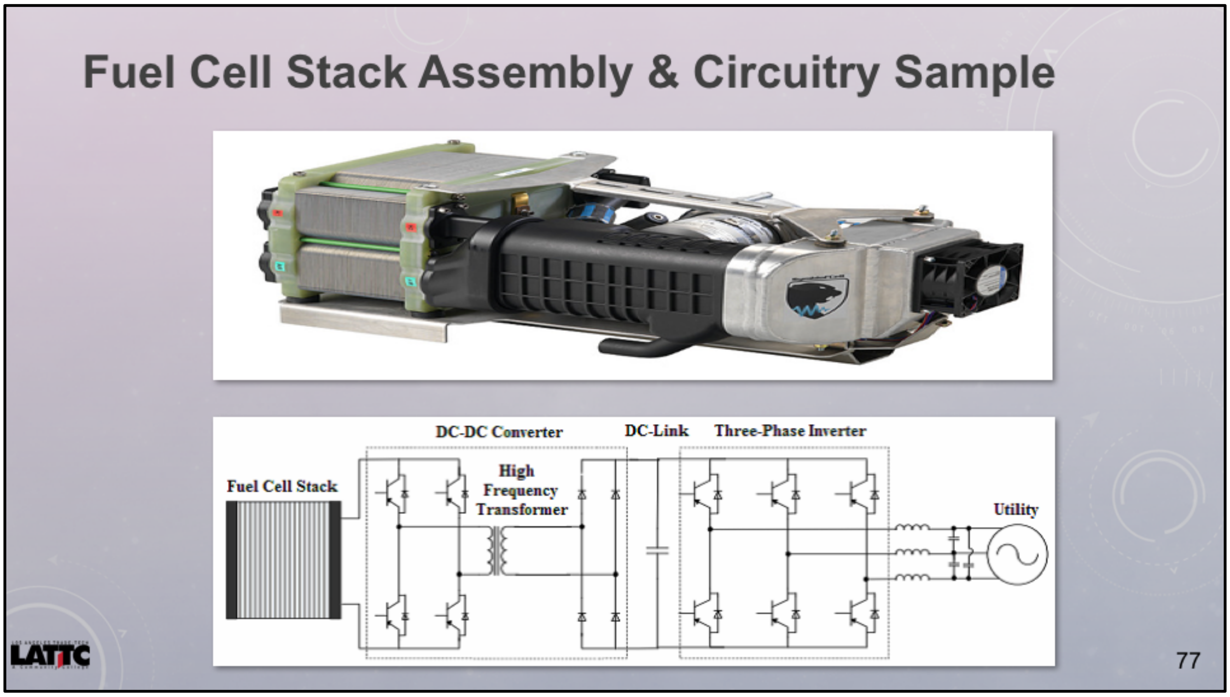


- The hydrogen circulation system of the FC stack assembly circulates the hydrogen fuel supplied from the injector to the hydrogen pump, and so the optimum hydrogen supply for FC stack electricity generation can be provided under all operating conditions
- The hydrogen circulation system of the FC stack assembly includes a gas-liquid separator and an exhaust drainage valve so that the generated water and nitrogen that could interfere with electricity generation are exhausted / drained from the hydrogen circulation system
- The FC control ECU takes information about FC stack electrical generation amount, electrical current value, etc. from the FC boost ECU (FC stack assembly) and controls the hydrogen pump so that the circulating hydrogen amount is appropriate to operating conditions
- Fuel Cell Stack operates under hydrogen pressures anywhere from 5.8↔43.5 psi
- **Hydrogen Injector:** Rubber seal construction to support high pressures. At the delivery port, a **O-ring cylindrical seal** and the fuel cell stack port (or manifold), is provided with an **insulator**

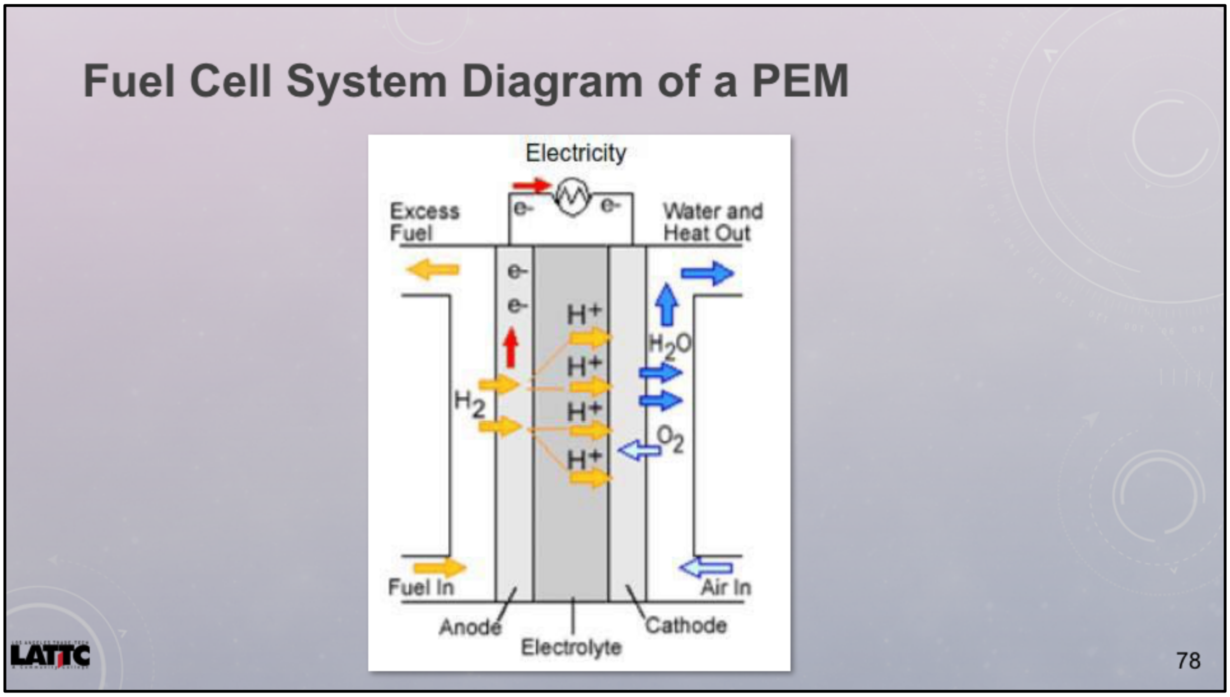

FUEL CELL STACK
OPEN DOCUMENT
75



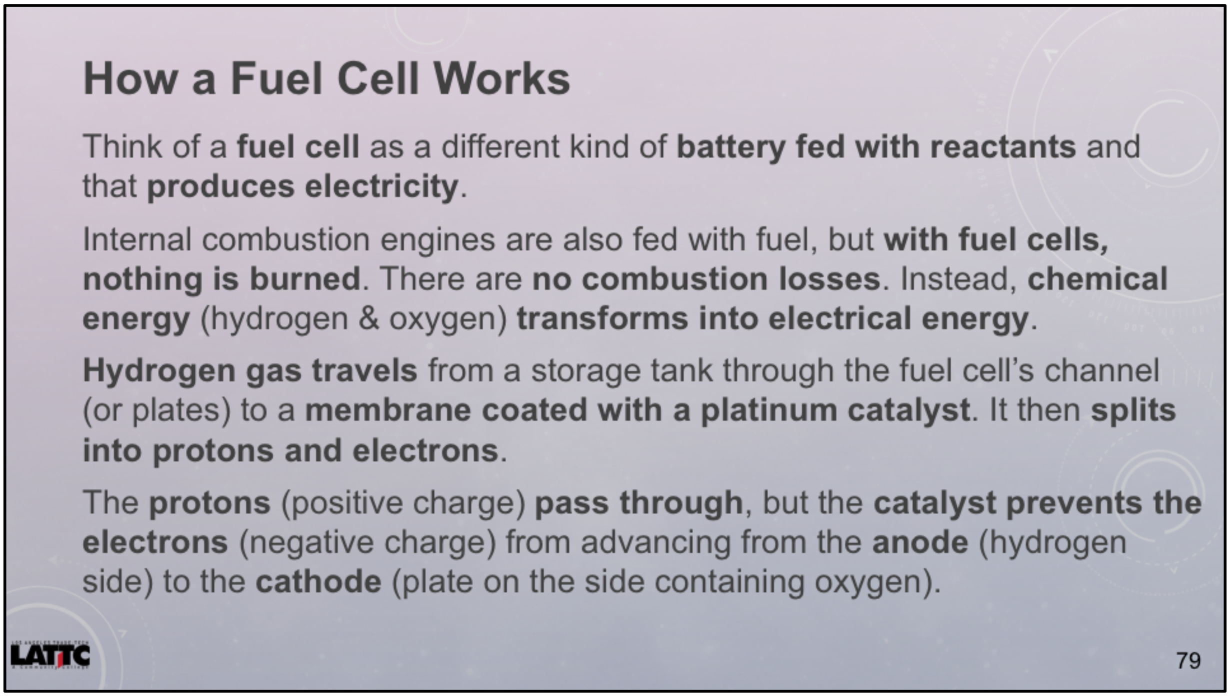
Fuel cells come in many designs which are determined by their many applications and variants based on needs. It is important to note here that this electro-chemistry advanced science and technologies hold a bright and promising future ahead as it is capable of performing in many environments, under various conditions and in many energy sectors. From residential to transportation and from rockets to space travel; it is definitely a feasible energy platform from which to continue supporting and developing of human life energy needs beyond current sources (i.e. fossil fuels).



- A fuel cell requires several hundred single cells connected in series to form a "Stack"
- Number of cells is determined by the output capacity design of the fuel cell
- Because they are connected in series to increase the voltage, the more cells the higher the output
- Fuel Cell output voltage is then stepped up and may get as high as 650 volts
- Fuel cells produce direct current which needs to be inverted to alternating current to maximize the energy efficiency in conjunction with the motor (utility)



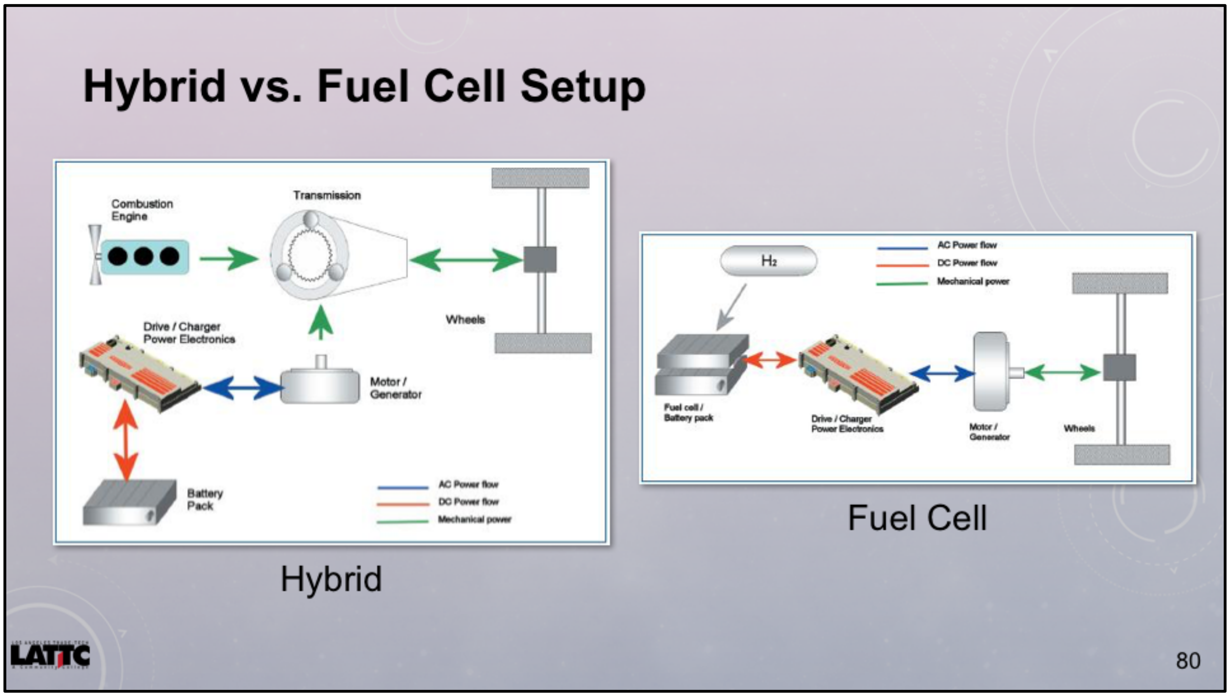
The PEM is sandwiched between two electrodes which have the catalyst embedded in them. The electrodes are electrically insulated from each other by the PEM. These two electrodes make up the anode and cathode respectively.
The PEM is proton permeable but electrical insulator barrier. This barrier allows the transport of the protons from the anode to the cathode through the membrane but forces the electrons to travel around a conductive path to the cathode thus generating electricity.



Fuel cells have been called "Range Extenders". Indeed, they arrive at an existing Electric Vehicle platform as "on-the-go" electric generators, to charge the EV's high voltage battery which is the main traction motor feed/supplier. The fuel cell by itself is incapable of the high amperage required by it. The fuel cell primarily function is to constantly replenish the EV HV battery back up after acceleration/climbing and therefore, they complement each other to extend the mileage range desired [and dreamed of] by any EV owners.

Think of a fuel cell as a different kind of battery; one that is fed with reactants and produces electricity. An internal combustion engine is similarly fed with fuel, but with a fuel cell, nothing is burned. There are no combustion losses. Instead, it transforms a chemical form of energy (hydrogen & oxygen) into electrical energy.

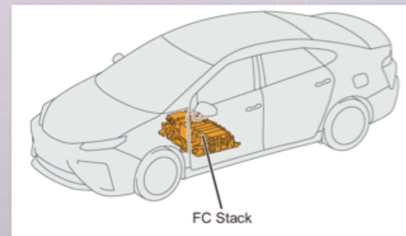
Hydrogen gas stored in a tank travels through the fuel cell's channel (or plates) until it encounters a membrane coated with a platinum catalyst. It then splits apart into protons and electrons. The protons, with a positive charge, pass through, but due to the properties of the catalyst, the electrons, which have a negative charge, can't advance from the hydrogen side (the anode) to another plate on the side containing oxygen (the cathode).

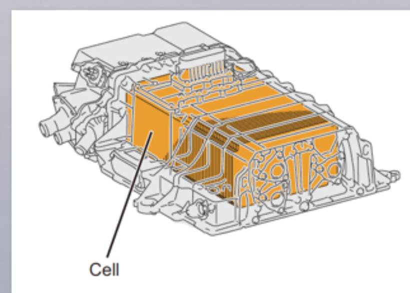


Basically by eliminating wasteful and un-needed mechanisms and components from conventional hybrid platforms and using a fuel cell in their place, the waste is reduced and the efficiency of the setup increases.

Fuel Cell Stack

- Heart of a fuel cell power system
- Generates direct current (DC) from electro-chemical reactions in fuel cell
- Single fuel cell produces less than 1V
  - Insufficient for most applications
- Cells combined in series into a fuel cell stack
  - May consist of hundreds of fuel cells
- Power depends on cell type, size, temperature, and pressure of gases





LATTC

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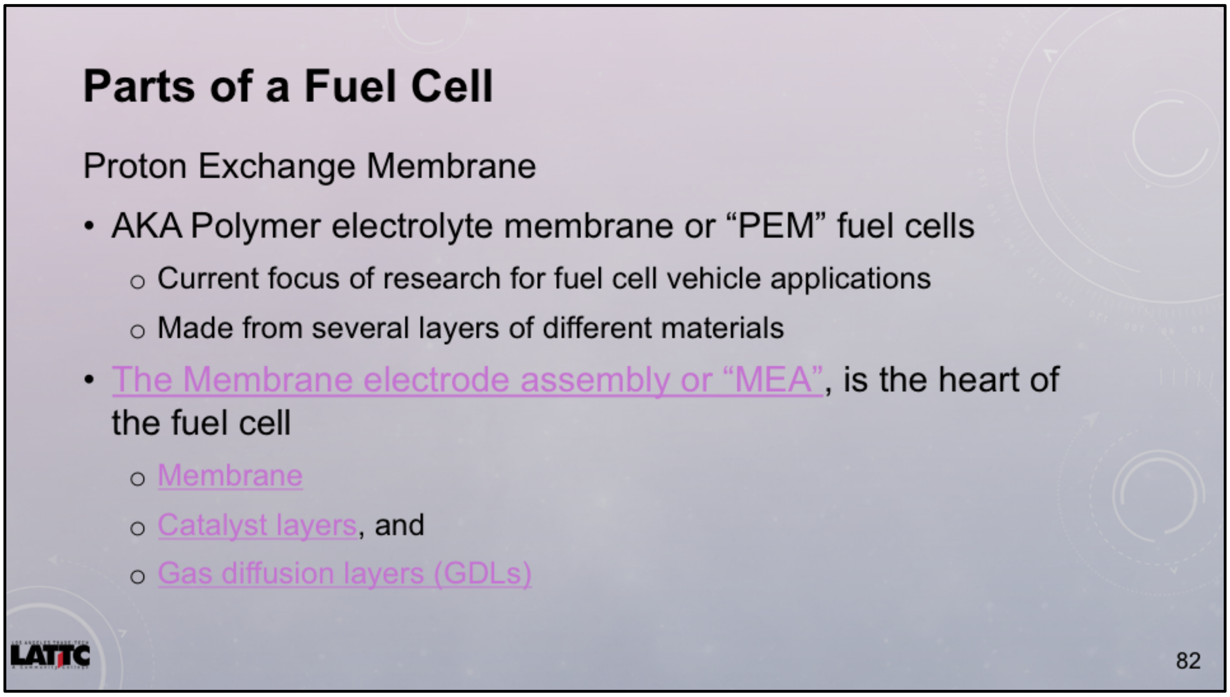
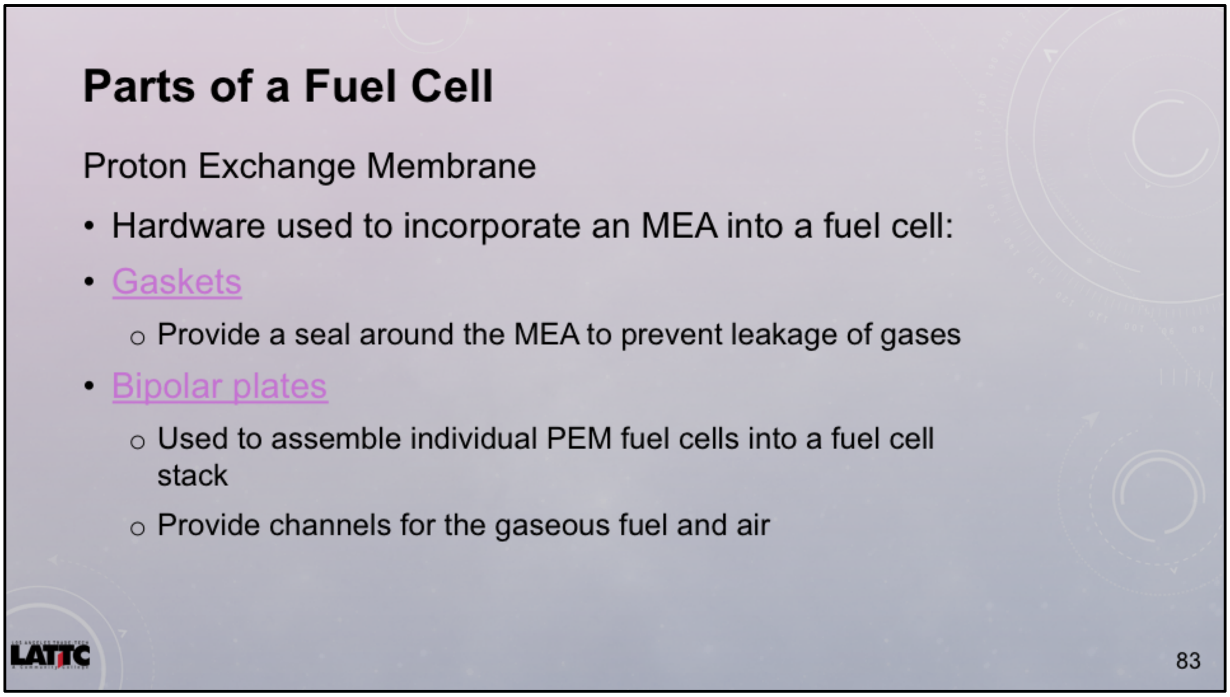
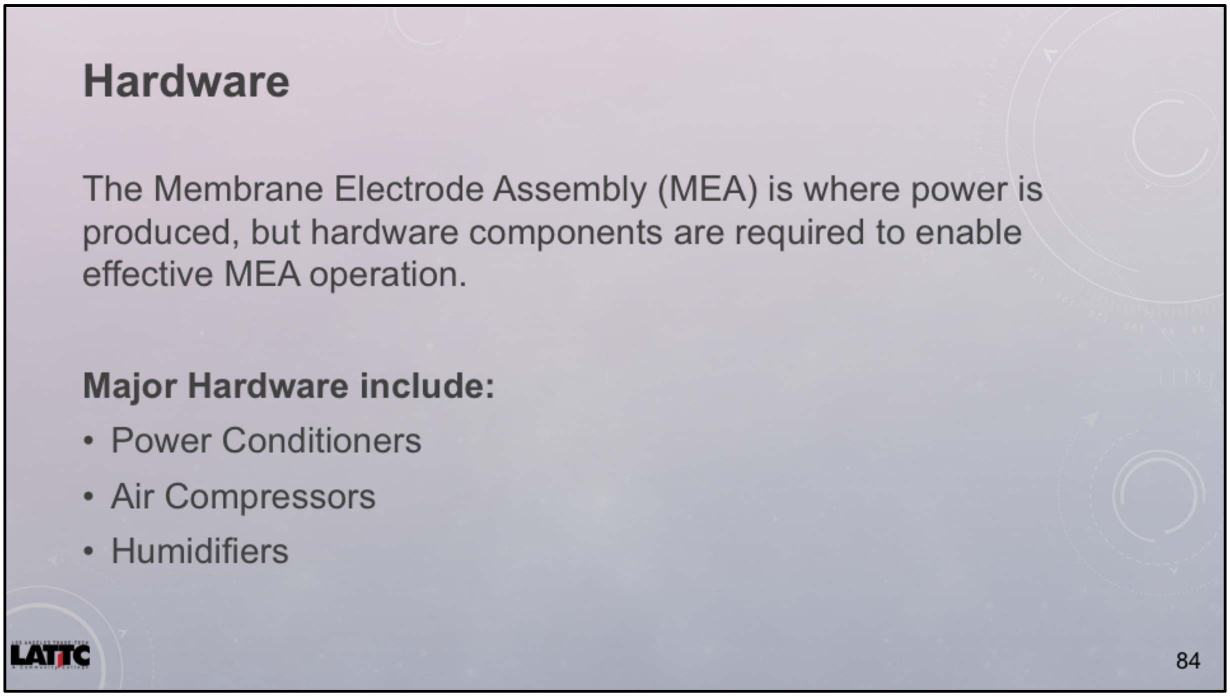
The fuel cell stack is the heart of a fuel cell power system. It generates electricity in the form of direct current (DC) from electro-chemical reactions that take place in a fuel cell. A single fuel cell produces less than 1 V, which is insufficient for most applications. Therefore, individual fuel cells are typically combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells. The amount of power produced by a fuel cell depends upon several factors, such as fuel cell type, cell size, the temperature at which it operates, and the pressure of the gases supplied to the cell.



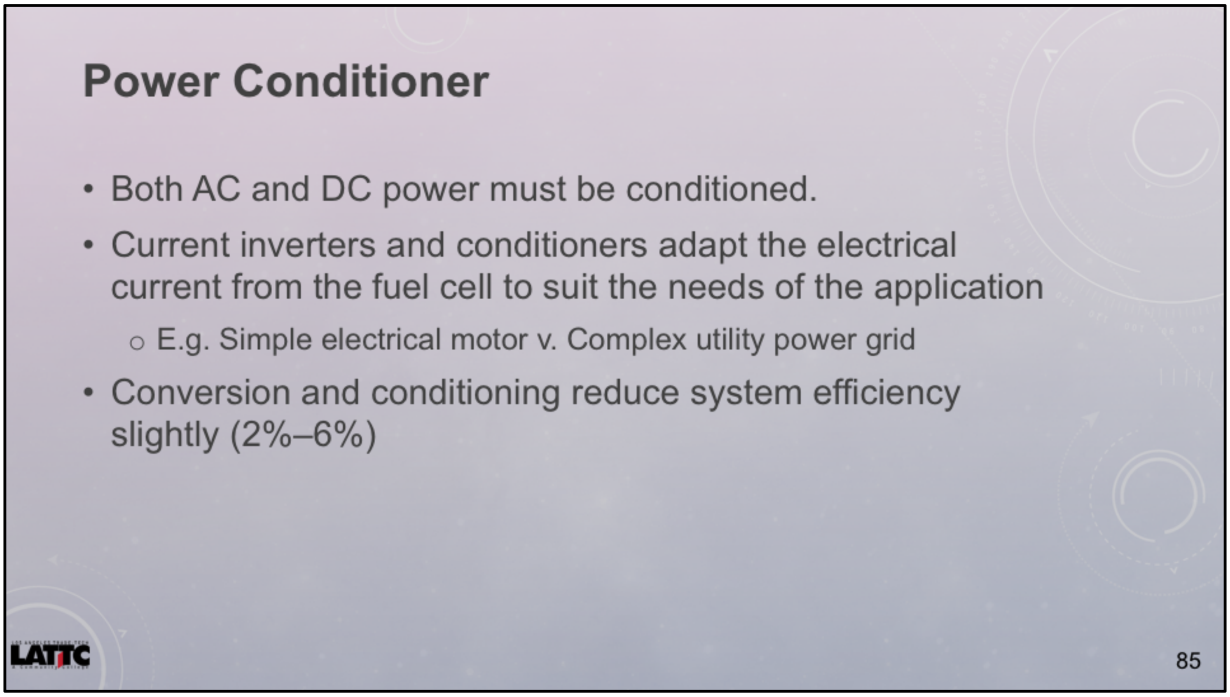
Also known as Polymer electrolyte membrane or "PEM" fuel cells, are the current focus of research for fuel cell vehicle applications. PEM fuel cells are made from several layers of different materials. The main parts of a PEM fuel cell are described below. The heart of a PEM fuel cell is the membrane electrode assembly (MEA), which includes the membrane, the catalyst layers, and gas diffusion layers (GDLs).



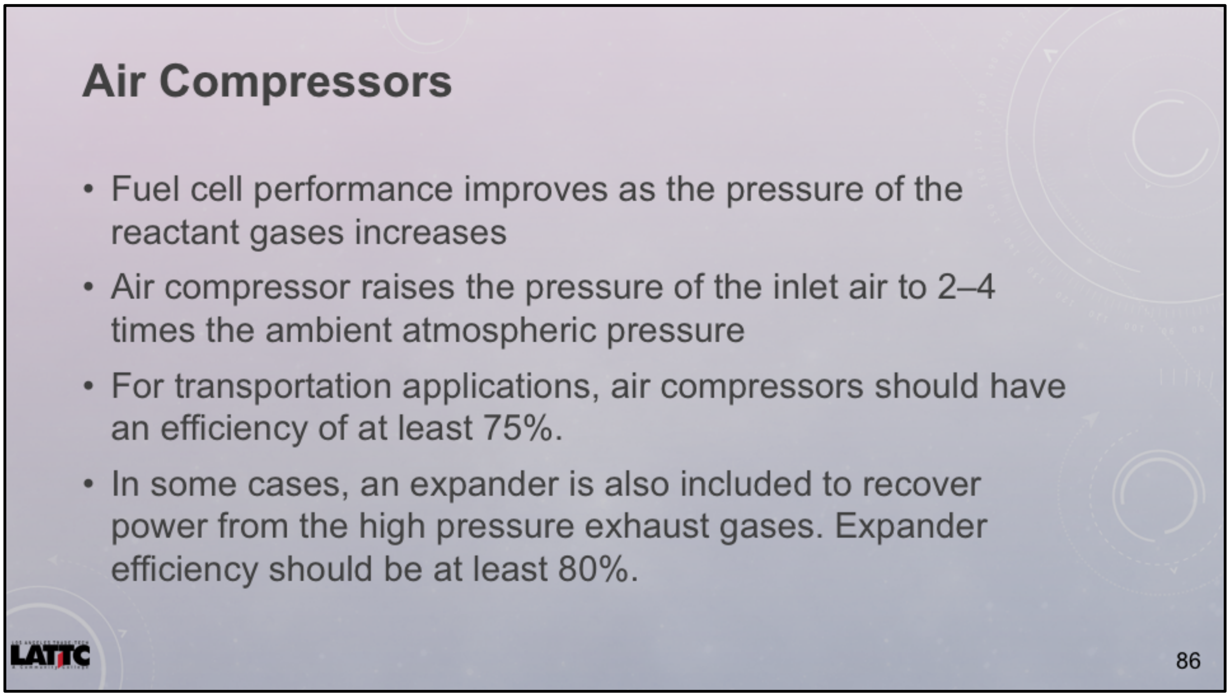
Hardware components used to incorporate an MEA into a fuel cell include gaskets, which provide a seal around the MEA to prevent leakage of gases, and bipolar plates, which are used to assemble individual PEM fuel cells into a fuel cell stack and provide channels for the gaseous fuel and air.



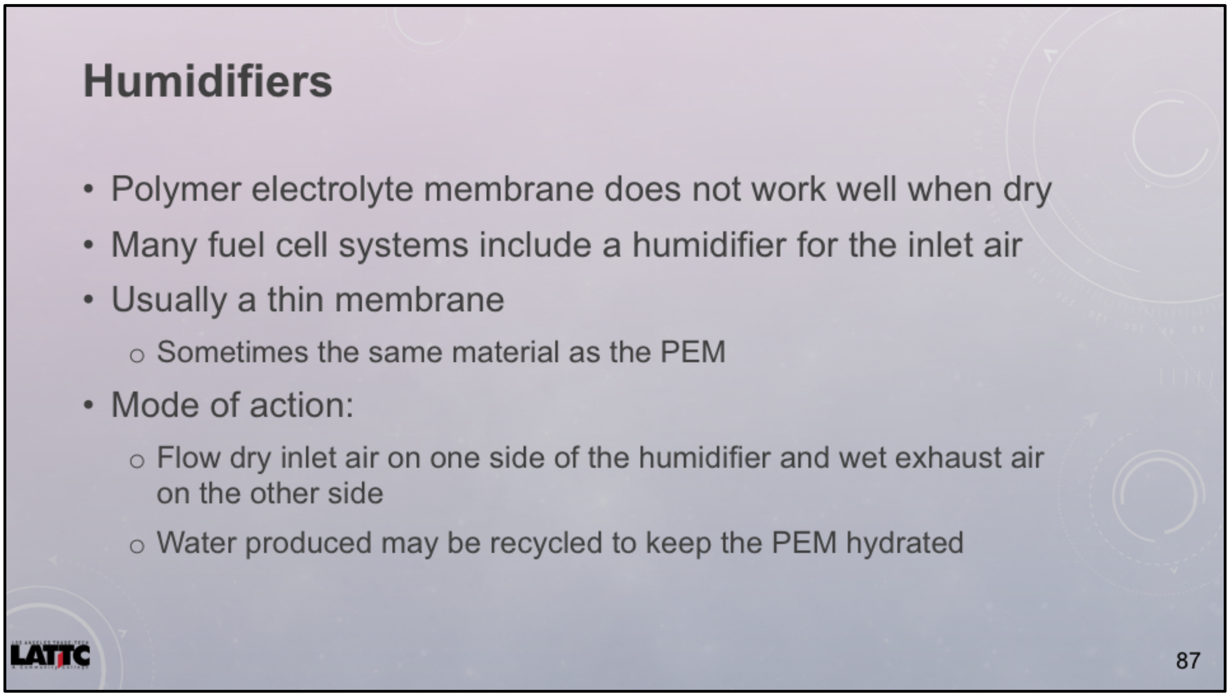
The MEA is the part of the fuel cell where power is produced, but hardware components are required to enable effective MEA operation



Both AC and DC power must be conditioned. Current inverters and conditioners adapt the electrical current from the fuel cell to suit the electrical needs of the application, whether it is a simple electrical motor or a complex utility power grid. Conversion and conditioning reduce system efficiency only slightly, around 2%–6%.



Fuel cell performance improves as the pressure of the reactant gases increases; therefore many fuel cell systems include an air compressor, which raises the pressure of the inlet air to 2–4 times the ambient atmospheric pressure. For transportation applications, air compressors should have an efficiency of at least 75%. In some cases, an expander is also included to recover power from the high pressure exhaust gases. Expander efficiency should be at least 80%.



The polymer electrolyte membrane at the heart of a PEM fuel cell does not work well when dry, so many fuel cell systems include a humidifier for the inlet air. Humidifiers usually consist of a thin membrane, which may be made of the same material as the PEM. By flowing dry inlet air on one side of the humidifier and wet exhaust air on the other side, the water produced by the fuel cell may be recycled to keep the PEM well hydrated.

Just as with smart phone technology trends, technology on vehicles are following and parallel their behavior. Here are some of the advances in technology which increase the over-all FC vehicle performance and efficiency.


FUEL CELL TECHNOLOGICAL
INNOVATIONS
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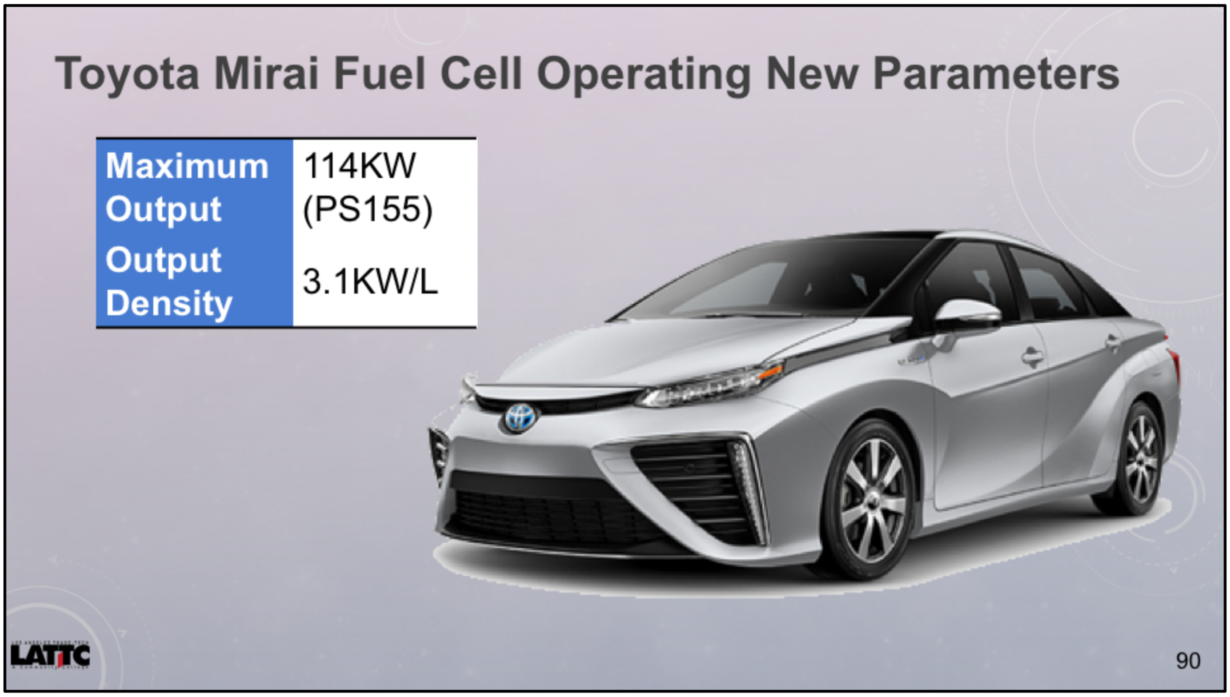
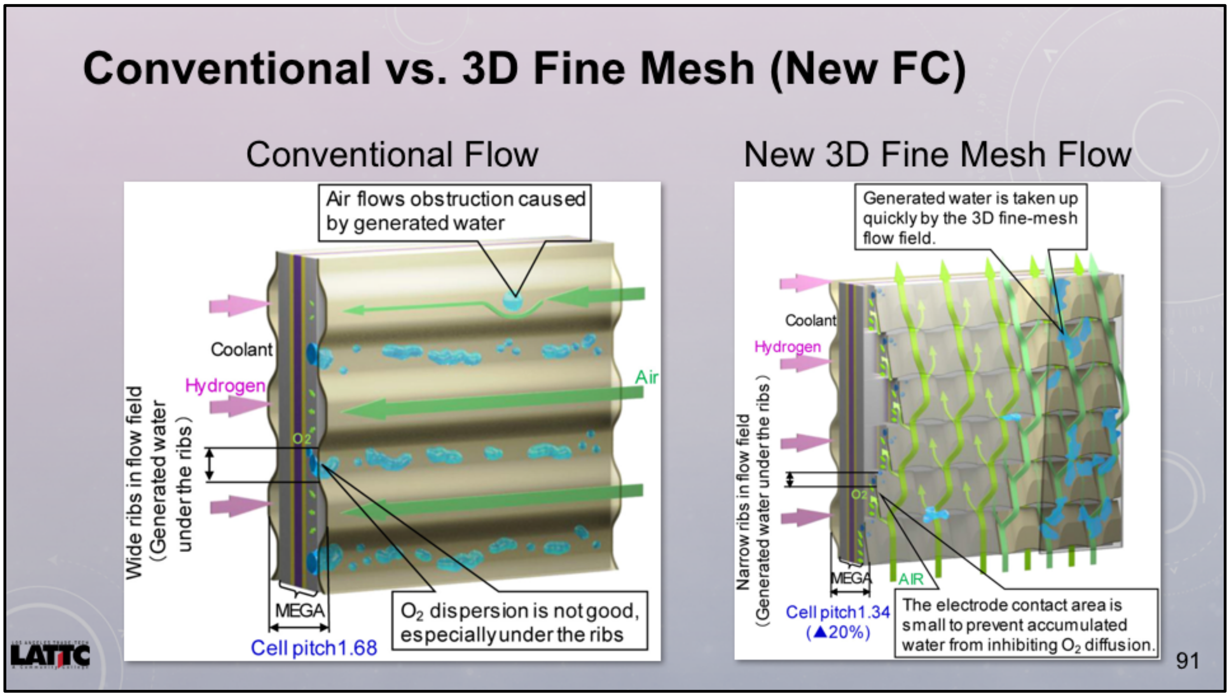


Increasing the output and decreasing the weight…

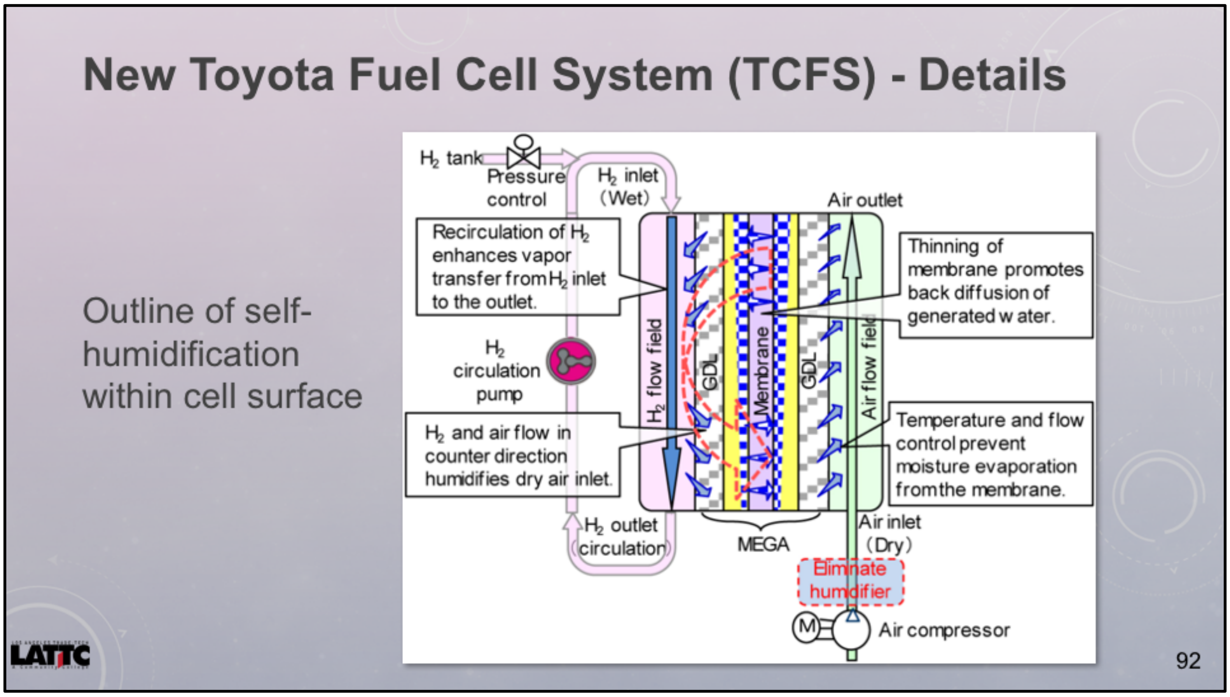


Conventional flow field structure:

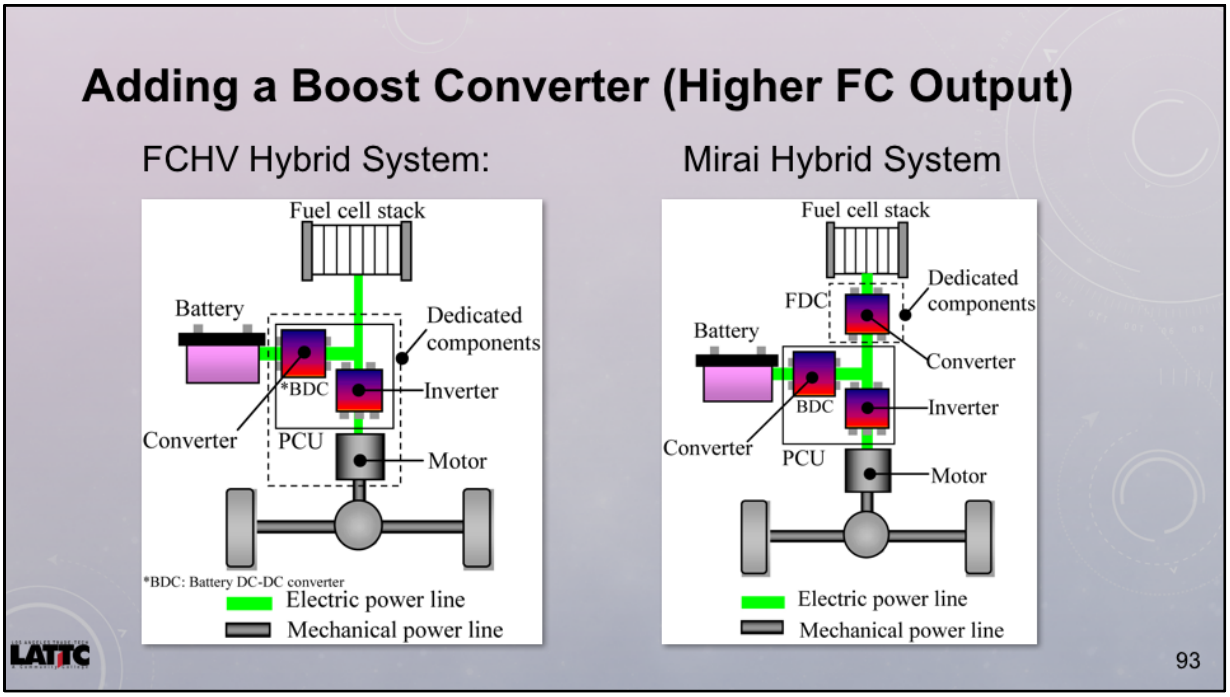
- Unlike conventional strait channel and porous metal flow fields, the new Toyota fuel cell uses a 3D fine-mesh flow field in the cathode. The 3D micro-lattice directs air toward the MEGA and promotes O2 diffusion to the catalyst layer. The designers optimized the geometry and surface wettability of the flow field to draw water generated by the MEGA to the back surface of the 3D flow field

New 3D fine mesh flow field structure:

- For the anode, Toyota engineers used an integrated channel-based fine-pitch flow field structure with H2 flow on the front and coolant flow on the back. This creates a 2-turn, 3-step cascade microstructure in which the H2 and air flow in counter directions on either side of the membrane electrode assembly (MEA)



- To enhance performance without a humidifier, Toyota reduced the electrolyte membrane thickness by two-thirds, promoting the generation of water by back diffusion and increasing the proton conductivity by a factor of at least 3. Other measures restrict chemical deterioration of the electrolyte membrane
- **MEGA:** **M**embrane **E**lectrode and **G**as diffusion layer **A**ssembly (the fuel cell itself)



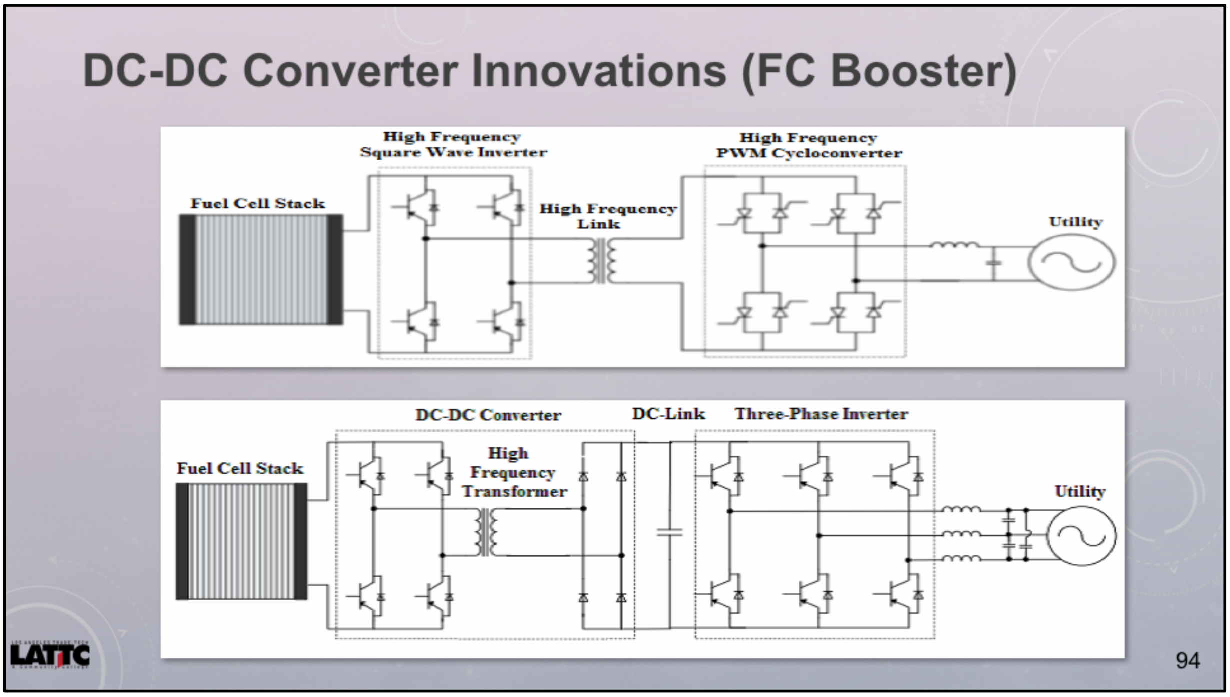
2008 FCHV-adv

- The fuel cell and inverter are directly connected;
- FC voltage is virtually the same as the motor voltage, and the inverter and motor have dedicated designs

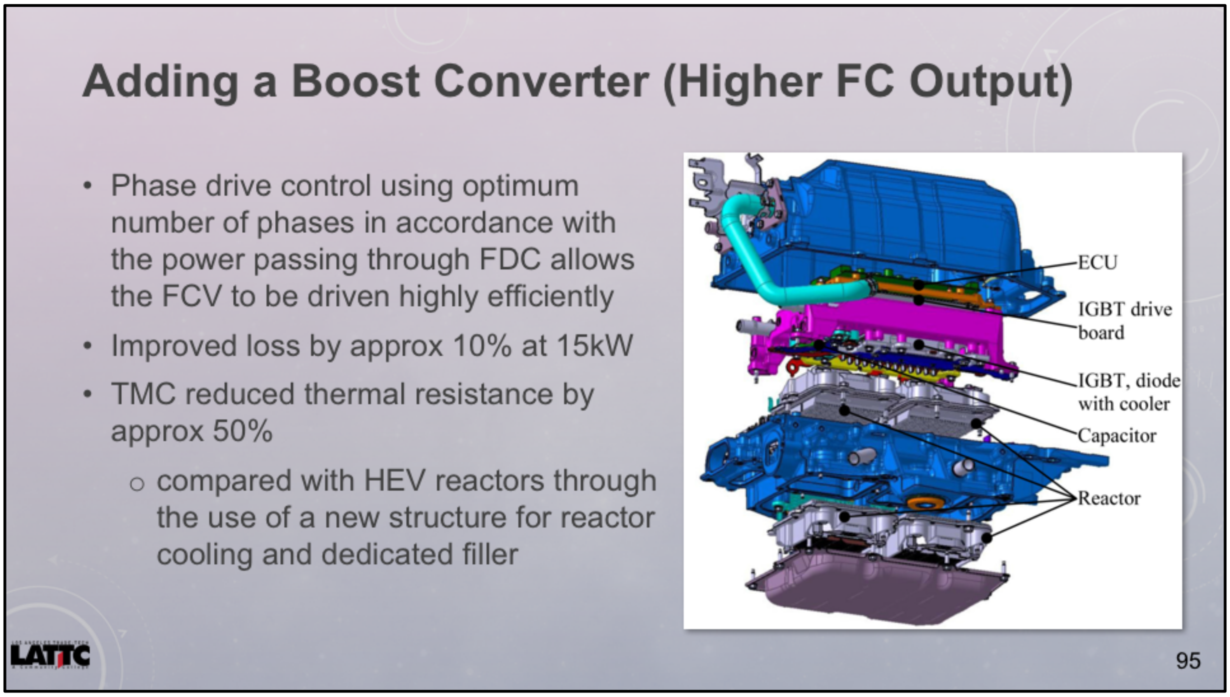
Mirai

- Uses the same inverter and motor as already adopted in mass-production hybrid electric vehicles
- Because the maximum fuel cell voltage is lower than the maximum motor voltage (650V), the two components cannot be connected directly

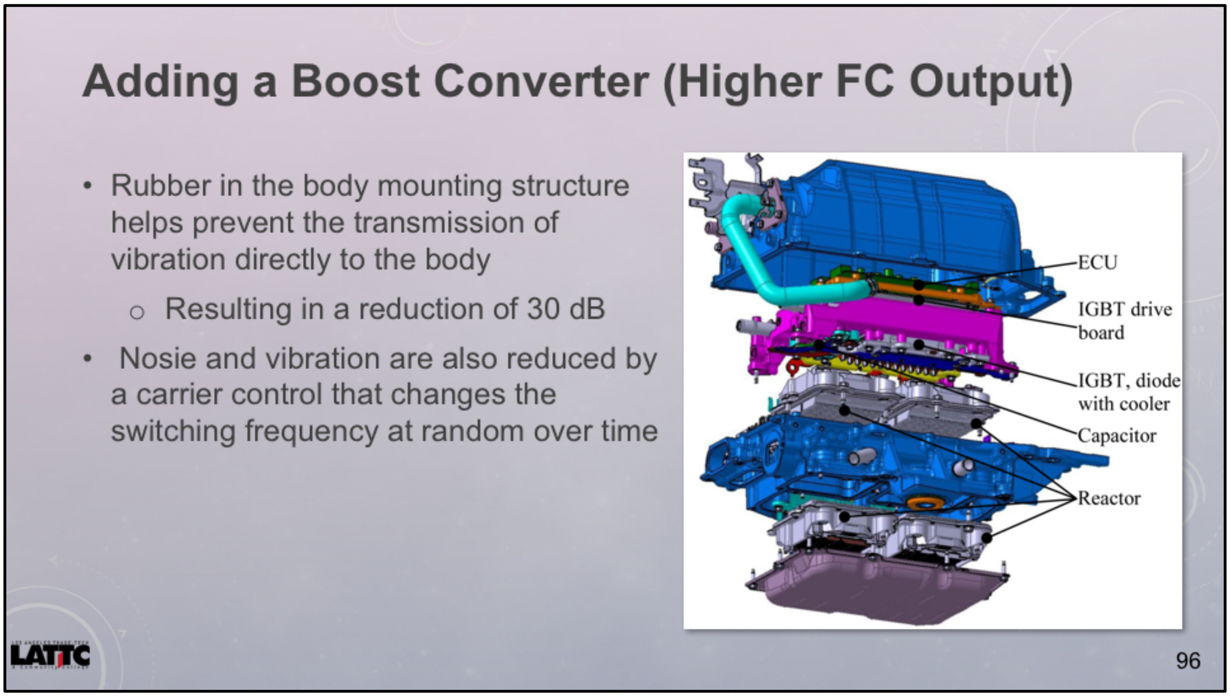
The new system implements the boost converter between the fuel cell and the inverter to step up the voltage from the fuel cell. By developing the FDC, it was possible to increase the voltage of the motor, reduce the number of fuel cell stack cells, and reduce the size and weight of the system. In addition, design innovations to the voltage-boost control and case structure provide quiet operation. The new system can be used with existing HV units, enhancing reliability and greatly reducing costs.



By adding a power booster to the existing fuel cell stack directly at its output, Toyota was able to increase the generated power output while decreasing the size of the fuel cell for increase efficiency.



- The phase drive control using the optimum number of phases in accordance with the power passing through **F**uel cell **D**C-DC **C**onvertor (FDC) allows the FCV to be driven highly efficiently. Use of this control improved the loss by approximately 10% at 15kW
- TMC also reduced thermal resistance by approximately 50% compared with HEV reactors through the use of a new structure for reactor cooling and a dedicated filler



- Rubber in the body mounting structure helps prevent the transmission of vibration directly to the body, resulting in a reduction of 30 dB
- Nosie and vibration are also reduced by a carrier control that changes the switching frequency at random over time

- Toyota is continuing to develop and adopt new materials and further reduce the size of the FDC.

Power available for emergencies:

- A power-out jack and associated energy station, not currently offered on any passenger cars, would likely offer a unique selling proposition that underscores the Mirai's ability to generate emission-free electricity--and quite a lot of it too
- The energy capacity of the fuel-cell vehicle's 5 kilograms of hydrogen, compressed at 10,000 psi, is more than 150 kilowatt-hours


TOYOTA'S NEW FC STACK STRUCTURE
TOYOTA INFORMATION SYSTEM - TIS
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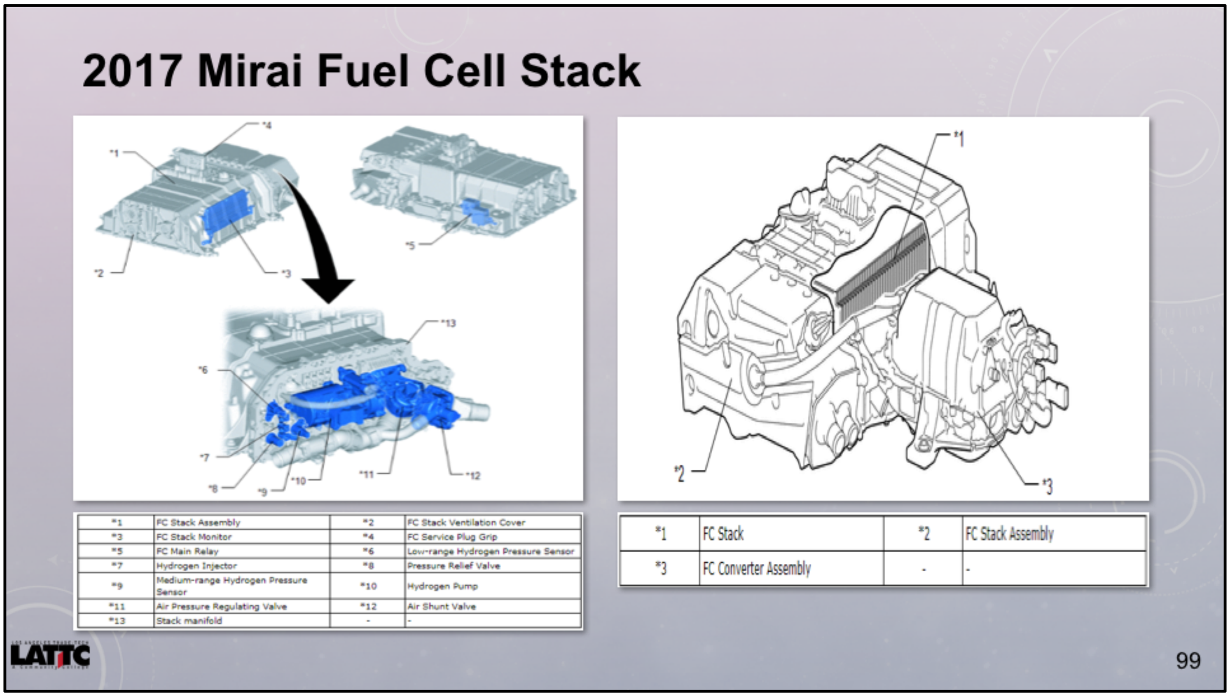
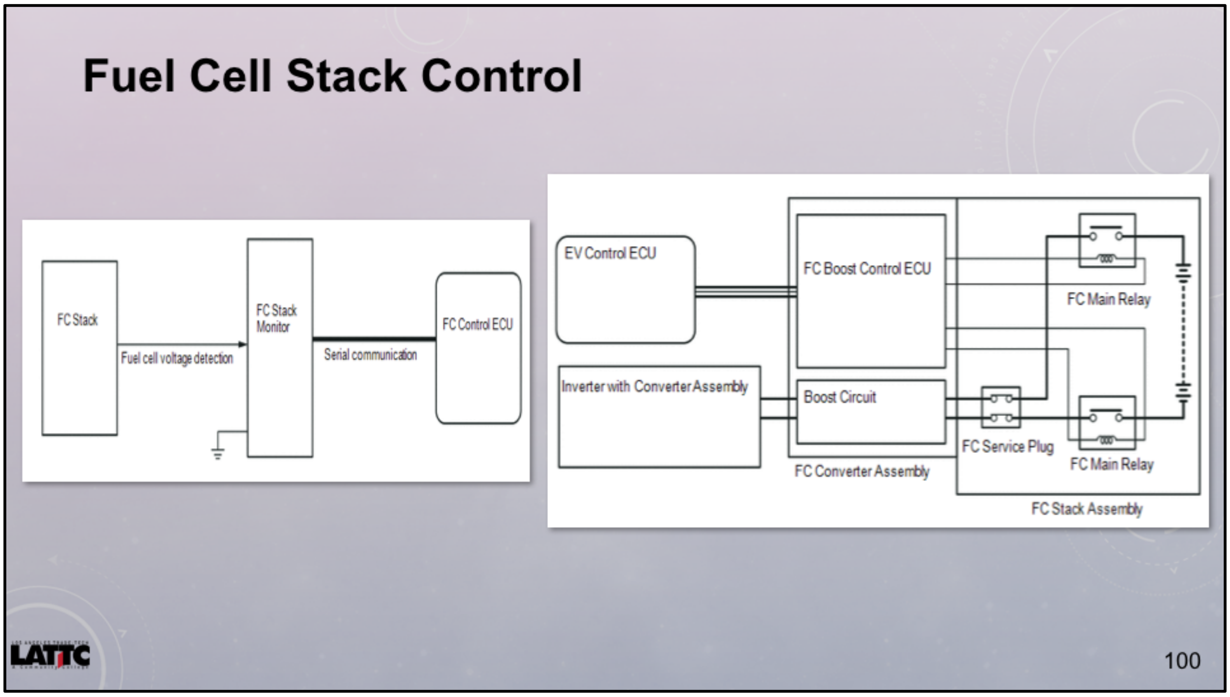
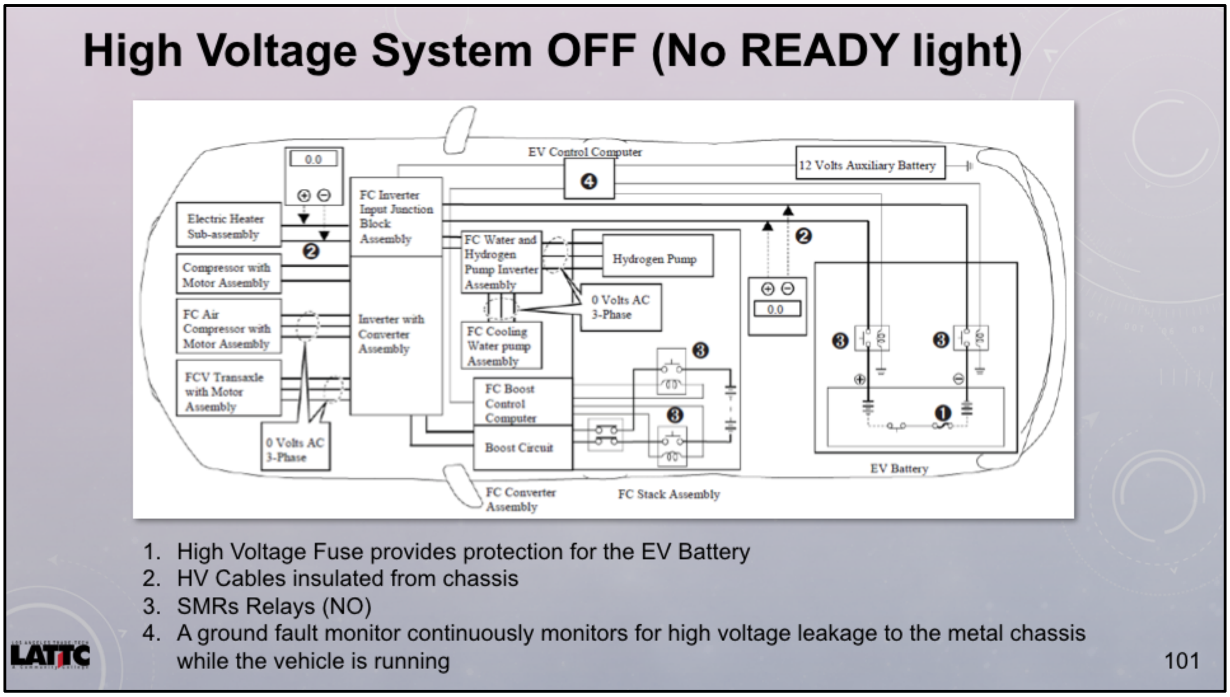


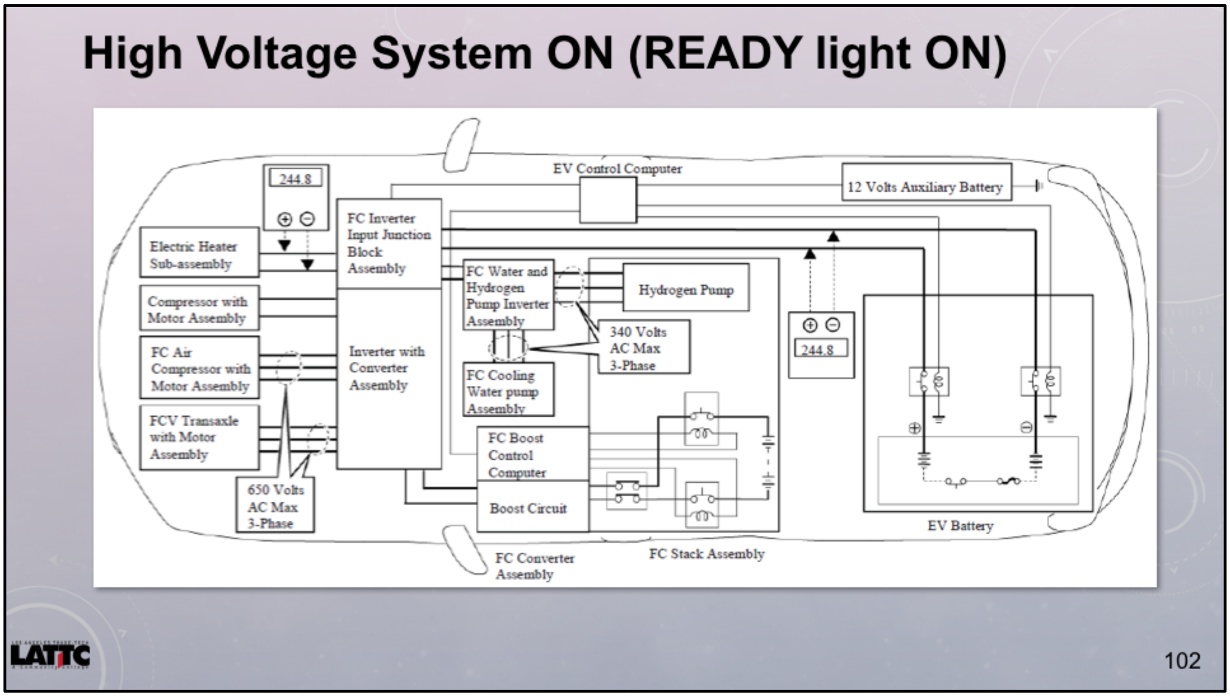
- The FC stack assembly is composed of the 370 layers of fuel cells, FC stack monitor, hydrogen system components (hydrogen pump, injector, etc.), air system components (air diverter valve, air pressure regulator valve, etc.), cooling system components, high voltage components, etc.
- The FC service plug grip has been provided to shut off the high voltage circuits, ensuring technician safety during service operations
- Hydrogen system components and air system components have been grouped in the area around the FC stack assembly and given improved controllability, enabling reductions in mass and bulk
- The stack case contains many high voltage components, and for these components the case performs the functions of containing, waterproofing, dustproofing, and providing protection against contact with high voltage
- Because the stack case is located in the vehicle underfloor environment, it has been anodized for superior corrosion resistance



- The FC stack monitor detects the FC stack condition (voltage) and sends it to the FC control ECU
- The FC main relay is controlled by the FC boost control ECU (built into FC converter assembly), and is the relay that connects and disconnects the high voltage circuits coming out of the FC stack. Relays are installed on both the positive and negative lines of the FC stack output
- When a relay actuation command is received from the EV control ECU, the FC boost control ECU (built into FC converter assembly) operates the actuation circuit to drive the FC main relay and connect or disconnect the high voltage circuits



It is good practice to identify the points at which different systems coincide. The High Voltage system of the Mirai, works together with the Fuel Cell System to provide smooth system performance and control. Its is also important to know where are these points and what is occurring there as far as safety concerns and procedures when performing work. The diagram above shows the FC vehicle in the **OFF state**. Note the SMR relays are **OPEN** and the test voltmeters show **0 (zero) volts**.



This diagram clearly shows the high voltages alive after the vehicle has been turned ON (READY light solid ON). Notice the important of the many differences on voltages throughout the **HV system (244.8v↔650v).** It is imperative to understand these differences from a diagnostic and technician safety point of view.


FUEL STORAGE AND SAFETY
TOYOTA MOTOR CORPORATION
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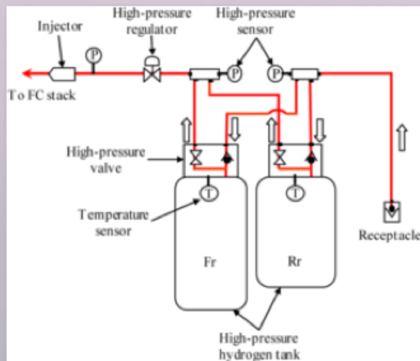
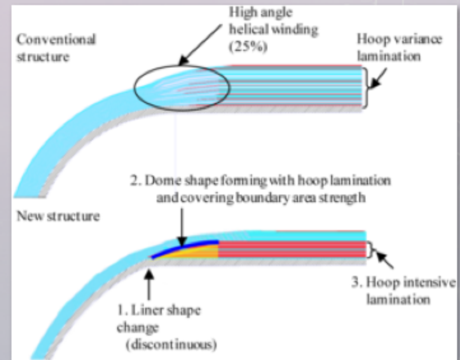
Storage



Basic configuration of high-pressure storage system. The high pressure from the two hydrogen tanks is reduced in two stages by the high-pressure regulator and injector before reaching the fuel cell (FC) stack.



Comparison of conventional and new lamination methods. Toyota made three critical changes to the lamination method, resulting in a thinner tank wall and reduced weight.

LATTC

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Storage:

- Toyota reduced the weight, size, and cost of the high-pressure hydrogen storage system in the Mirai while improving fueling performance. The four 70 MPa tanks used on the 2008 Toyota FCHV-adv were reduced to two new larger diameter tanks; Toyota developed a new optimized laminated structure for tanks to reduce weight using a high-strength low-cost carbon fiber material. The shapes of the newly developed high-pressure hydrogen tanks were optimized to enable installation under the floor of the sedan. Further, Toyota reduced the size of the high-pressure valve and also modified a high-pressure sensor from a conventional vehicle for use in a high-pressure hydrogen atmosphere
- As a result, the whole storage system weighs approximately 15% less than that in the Toyota FCHV-adv, while reducing the number of component parts by half and

substantially reducing cost

- Toyota engineers also reduced the time required to fuel the FCV by chilling the filling gas temperature at the hydrogen filling station to −40°C (as per SAE J2601). Furthermore, the layout of the tank temperature sensor and other aspects of the design were adjusted to increase the State of Charge (SOC) determined by SAE J2799 IrDA communications between the vehicle and hydrogen station
- The tanks use a plastic liner at the innermost layer to seal in the hydrogen gas. The liner is surrounded by a strong CFRP layer capable of withstanding high pressures, which itself is surrounded by a glass fiber reinforced plastic (GFRP) layer with high impact resistance, and a protector. Aluminum bosses are provided at both ends of the plastic liner, with one side for the valve fitting. The weight of the newly developed tanks was reduced by improving the CFRP layer and reducing the amount of material used
- Conventional tanks combine three types of winding methods: hoop winding to strengthen the central region of the tank; low-angle helical winding to strengthen the dome regions (in the axial direction); and high-angle helical winding to reinforce the boundaries of these regions. By necessity, the high-angle helical winding required to strengthen the boundary regions is also wound over the central region
- Because the high-angle helical winding is wound around the central region of the tank at an angle of 70°, the reinforcement efficiency is reduced. Toyota, however, made three critical changes to the lamination method:
    - The sectional shape of the liner was flattened to enable lamination by hoop winding at the boundary regions
    - The boundary regions were strengthened while forming the conventional liner shape by gradually retracting the end positions of the hoop winding

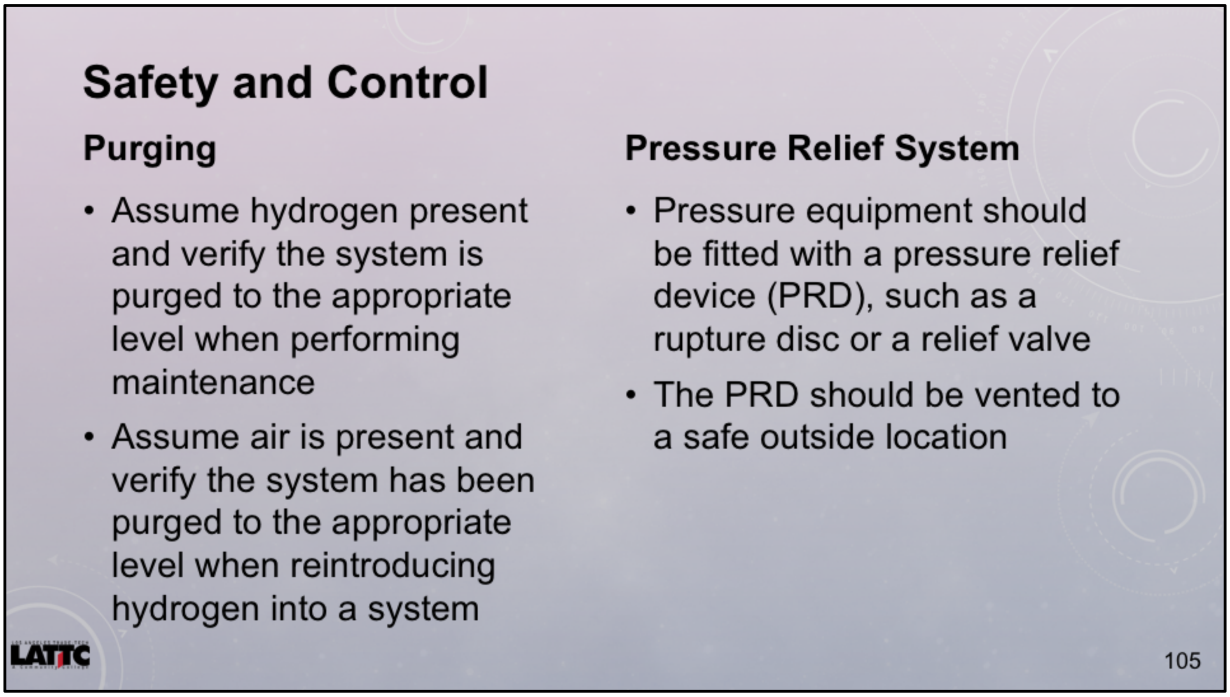
  - Hoop winding lamination was concentrated in the inner layers

- These changes had the following two effects. First, the high-angle helical winding, which accounted for approximately 25% of the total laminated structure, was eliminated. Second, hoop winding, which is a highly effective way of strengthening the central region of the tank, was concentrated in the inner layers where the generated stress is highest. This allowed the strength of the fibers to be used more effectively. This dual effect enabled a 20 wt% reduction in CFRP compared to the conventional lamination method

—Yamashita et al.

For the FCHV-adv, Toyota had used aerospace grade carbon fiber. For Mirai, Toyota worked with carbon fiber providers to improve the properties of less costly general purpose carbon fiber.

On the road toward its anticipated future full-scale commercialization of fuel cell vehicles, Toyota will work to continue further to reduce the size of the hydrogen storage system and advance the performance of the next-generation FCV.

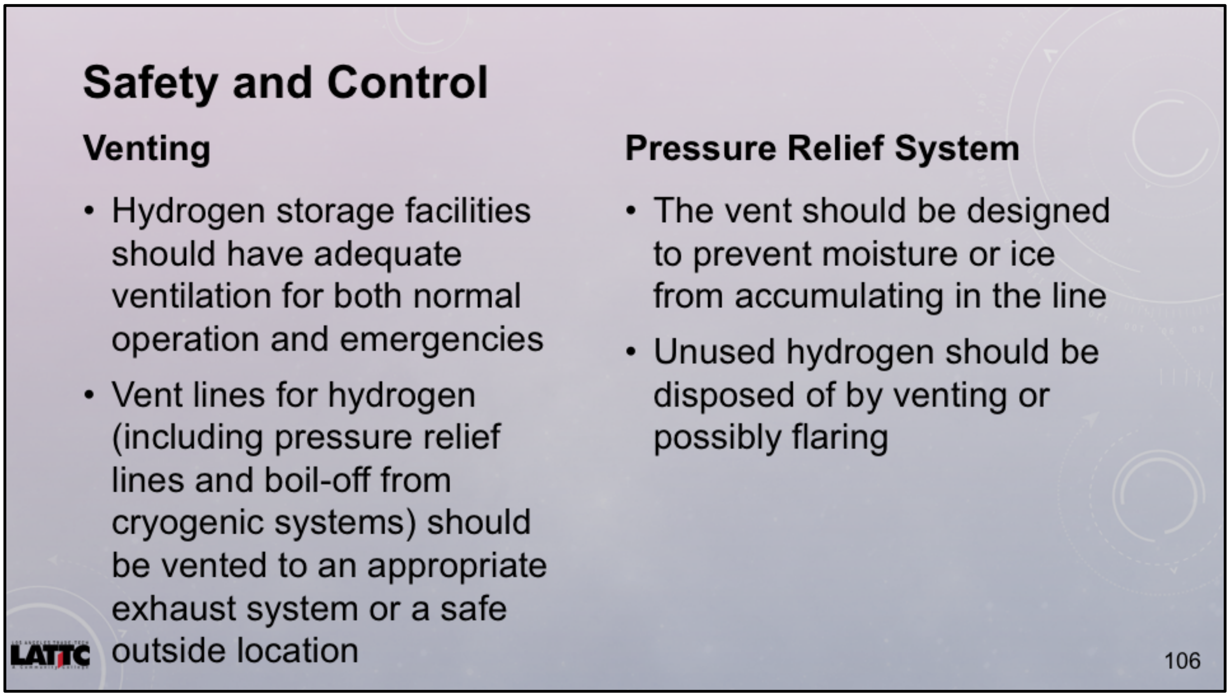


Purging:

- One should always **assume that hydrogen is present** and verify that the system has been purged to the appropriate level when performing maintenance on a hydrogen system
- Likewise, one should always assume that **pressurized air is present** and verify that the system has been purged to the appropriate level when reintroducing hydrogen into a system

Pressure Relief System:

- Pressure equipment should be fitted with a **pressure relief device** (PRD), such as a rupture disc or a relief valve
- The PRD should be **vented to a safe** outside location

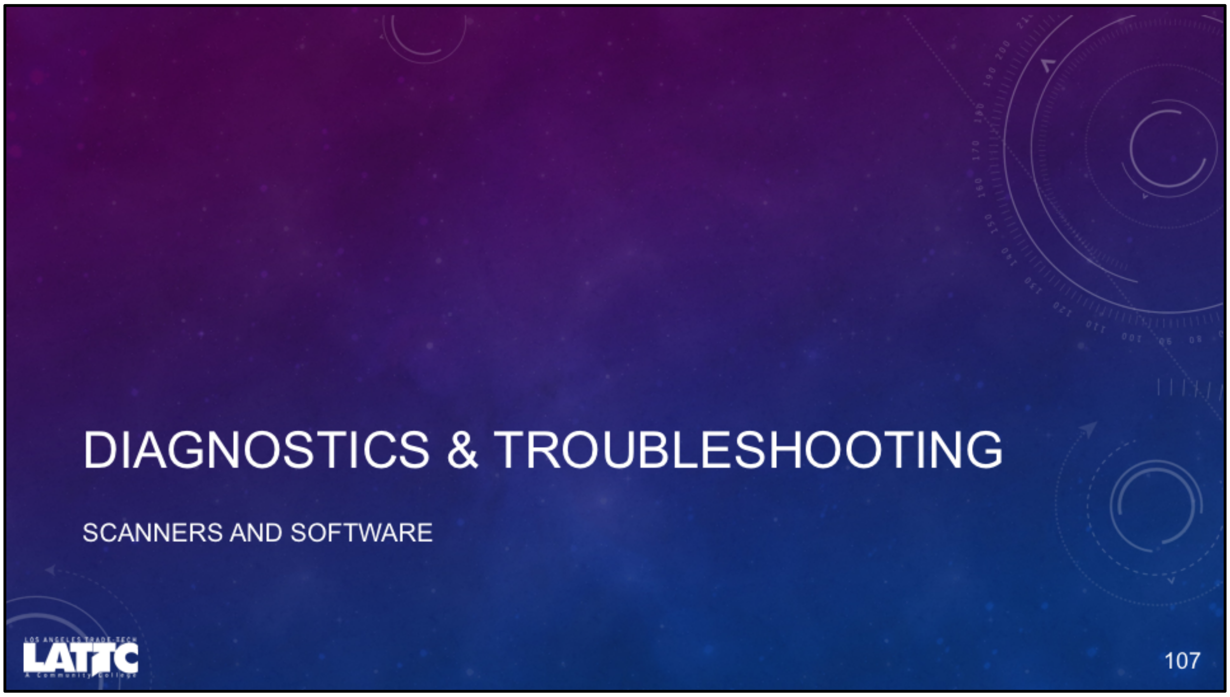


Venting:

- Hydrogen storage facilities should be provided with **adequate ventilation** for both normal operating conditions and emergency situations
- Vent lines for hydrogen (including pressure relief lines and boil-off from cryogenic systems) should be vented to an **appropriate exhaust system** or a safe outside location
- The vent should be designed to prevent moisture or ice from accumulating in the line
- Unused hydrogen should be disposed of **by venting** or possibly flaring

Pressure Relief System:

- The vent should be designed to **prevent moisture** or ice from accumulating in the line or causing restriction to the flow
- Unused hydrogen should be disposed of **by venting** or possibly flaring


DIAGNOSTICS & TROUBLESHOOTING
SCANNERS AND SOFTWARE
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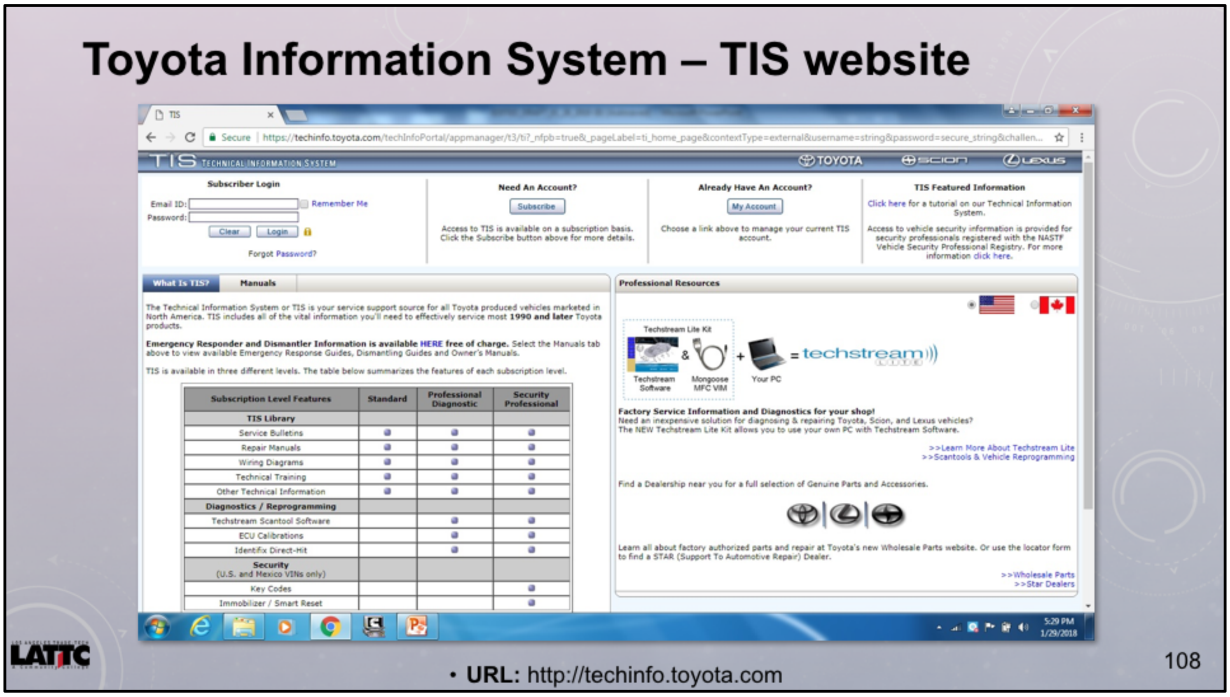
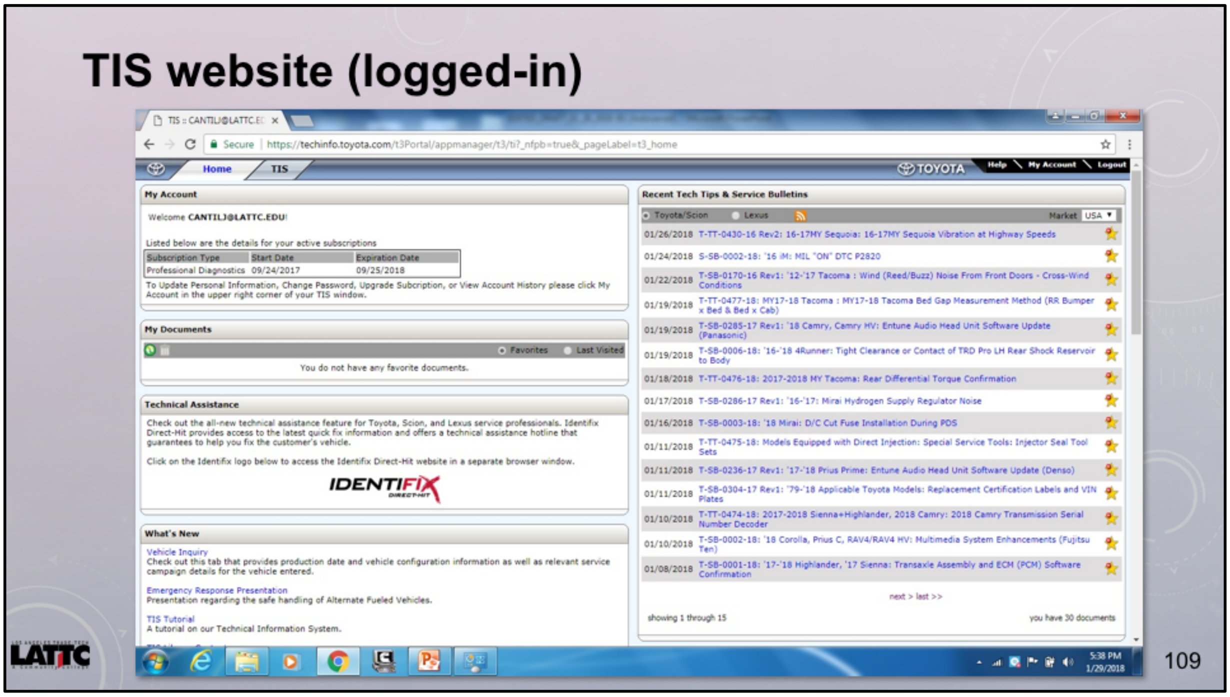


TIS is a an online-based website where anyone anywhere can access Toyota's product information and specifications directly from the OEM. A online account and a login are required.

- Excellent and detailed information on all areas of product interest
- All material is available to download, print and/or saved
- **URL:** http://techinfo.toyota.com

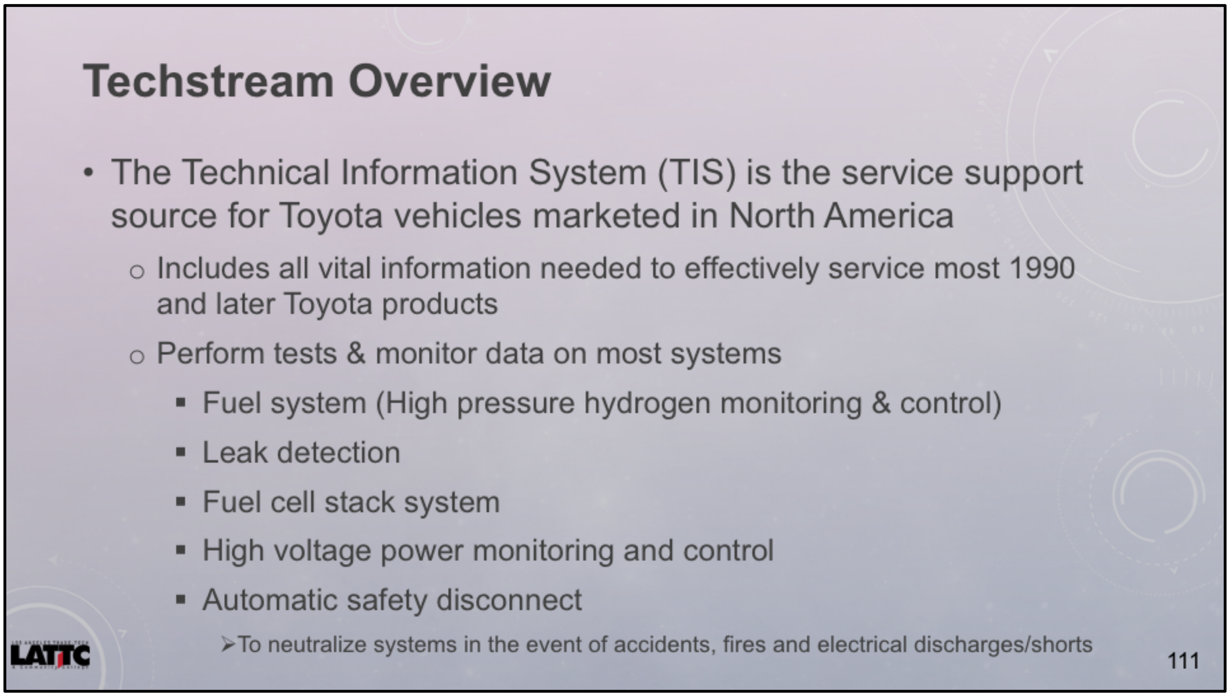


After accessing the TIS website with your login, this is the "Home" screen which appears. From here you can select the other tab "TIS" [at the upper-left], to specify more to detail your search for a specific resource.

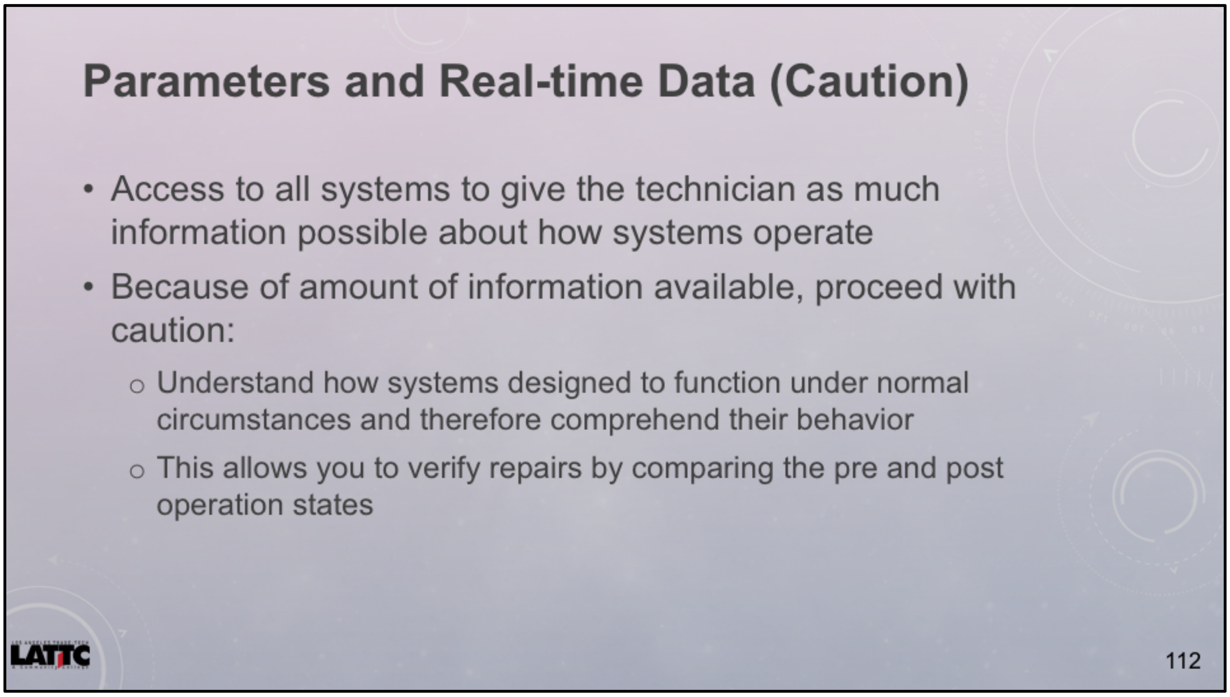
1. **HOME** tab:
   - You can access such things as "Technical Assistance" and/or "Recent Tech Tips & Service Bulletins" for examples. There are many more!
2. **TIS** tab:
   - This tab allows you to zero-in into a specific information about a specific vehicle or system. Again, many more are available. Priceless!

Toyota Onboard Diagnostics offer a comprehensive and wide range of technical resources through their official OEM scanner. Their diagnostic system is call **Teachstream** and a portable PC platform (i.e. Laptop), **loaded** with the Teachstream software (**Purchase** with **yearly** subscription renewal) is required.

This donates the technician with ample abilities to access DTCs, monitor real-time data, perform calibrations and execute tests of all their control systems.

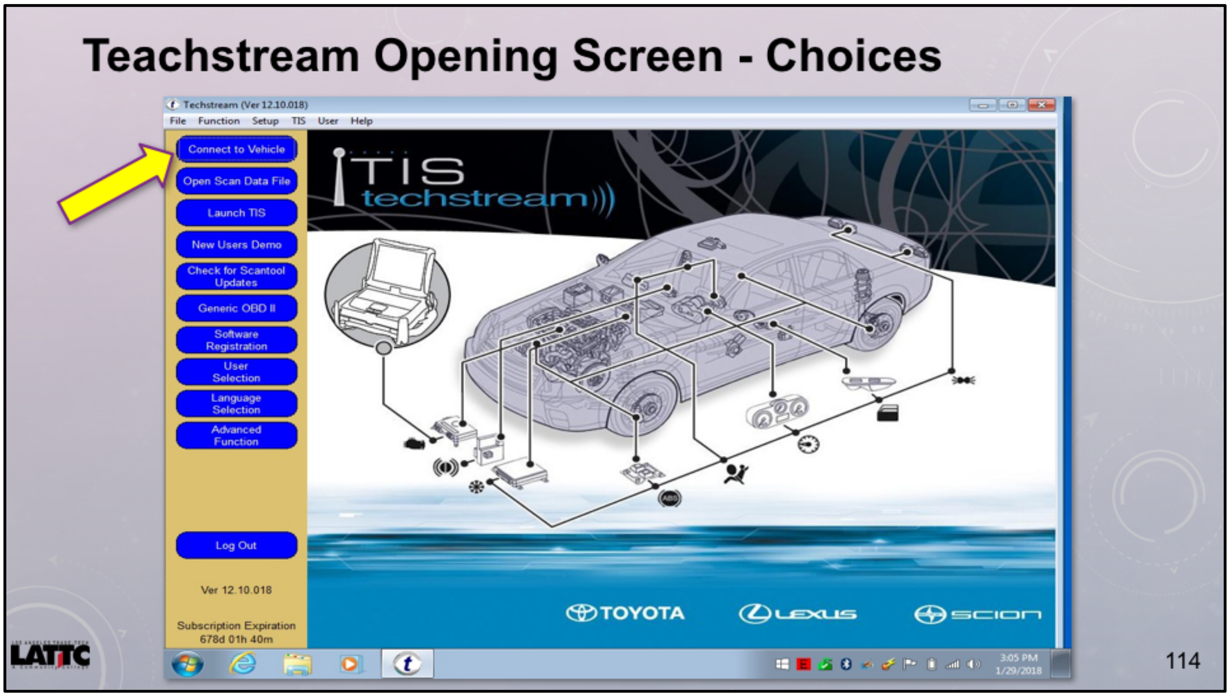


The Technical Information System or TIS is your service support source for all Toyota produced vehicles marketed in North America. TIS includes all of the vital information you'll need to effectively service most 1990 and later Toyota products. The system offers a wide range of access to perform tests, monitor data and execute tests on most of its systems. It includes the fuel system (High pressure hydrogen sensing monitoring & control), leak detection, Fuel cell stack system and high voltage power monitoring and control along with the automatic safety disconnect to neutralize systems in the event of accidents, fires and electrical discharges/shorts.



Access to all systems are built into and designed to give the technician as much system information as the systems themselves use to operate. This ample approach efficiently increases any diagnostic procedure needed to successfully diagnose, repair and solve any bad operational states o the vehicle. Because of the size of the information available, it is wise to approach and proceed with caution, have a good understanding of what systems are design to operate under normal circumstances and therefore comprehend their behavior. It will also serve as verification after repairs have been completed by comparing the pre and post operation states.

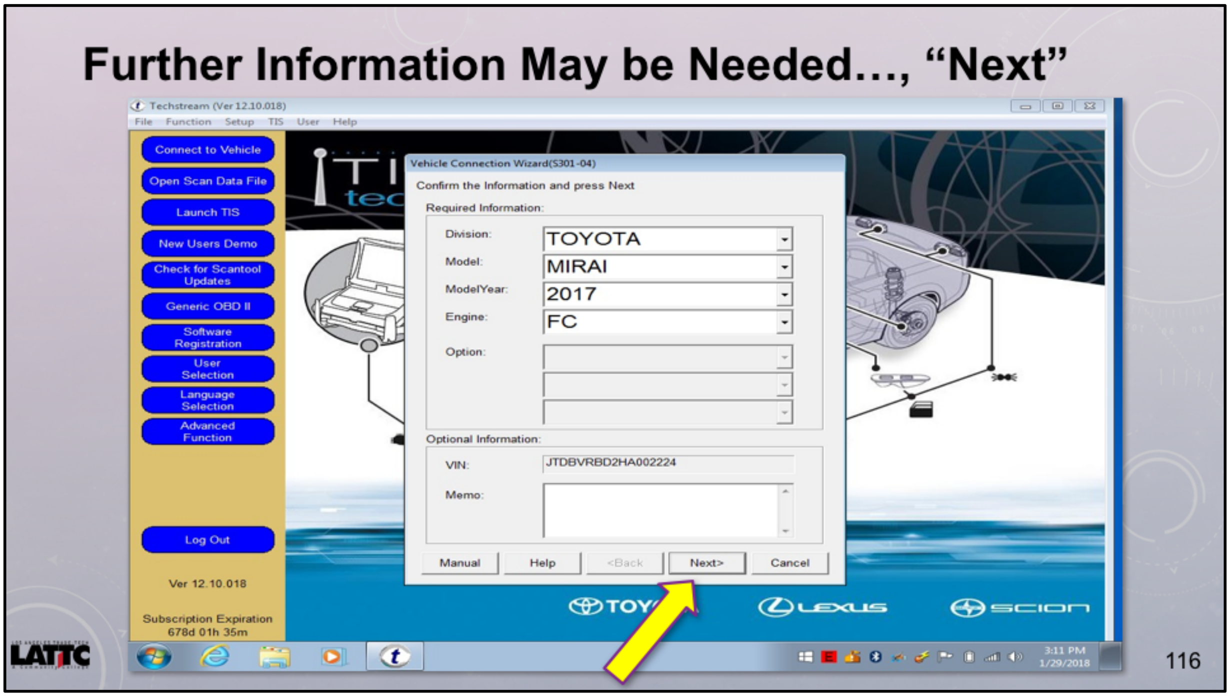
When accessing the Toyota diagnostic software “Techstream”, note the **Icon symbol design** so you can easily identify it and click it to lunch it.



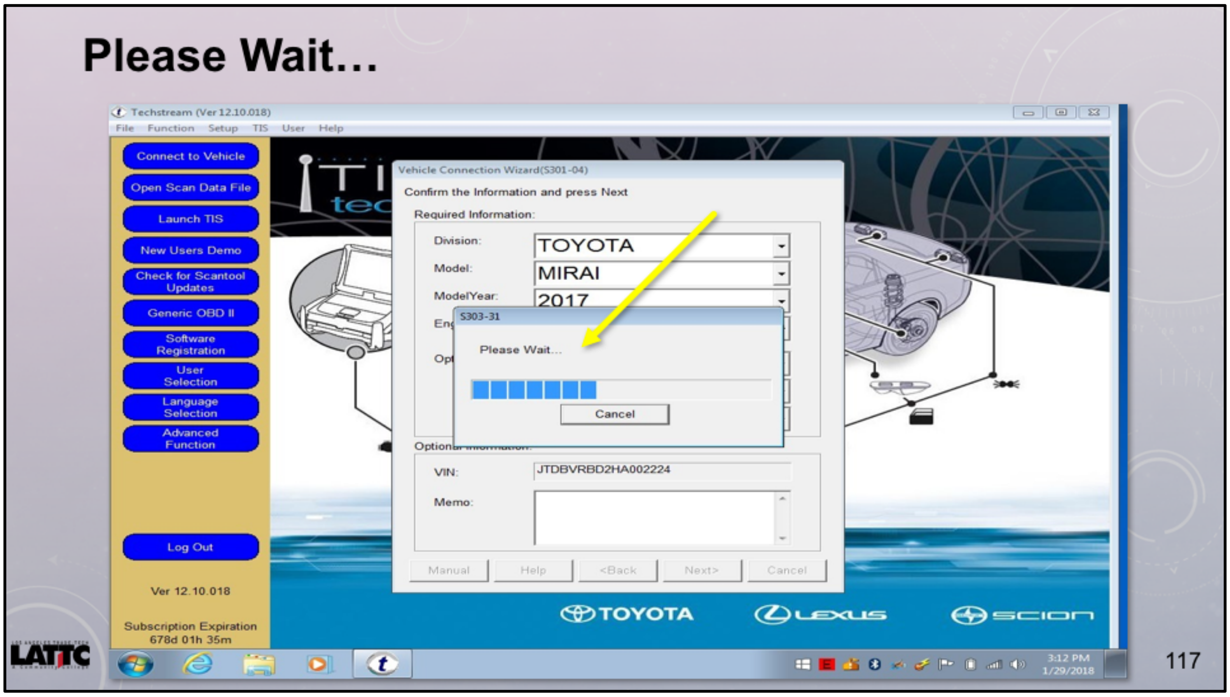
This is where the software take you after you click on its icon. From here, you need to physically (wired) connect to a vehicle. There may be a wireless connectivity in some form (we won't assume you have it and proceed with hard wire connection).

For the software to read your vehicle's control data and "talk" to it, need to turn the vehicle's ignition key ON, connect PC cable to OBD port on vehicle and click "Connect to Vehicle".

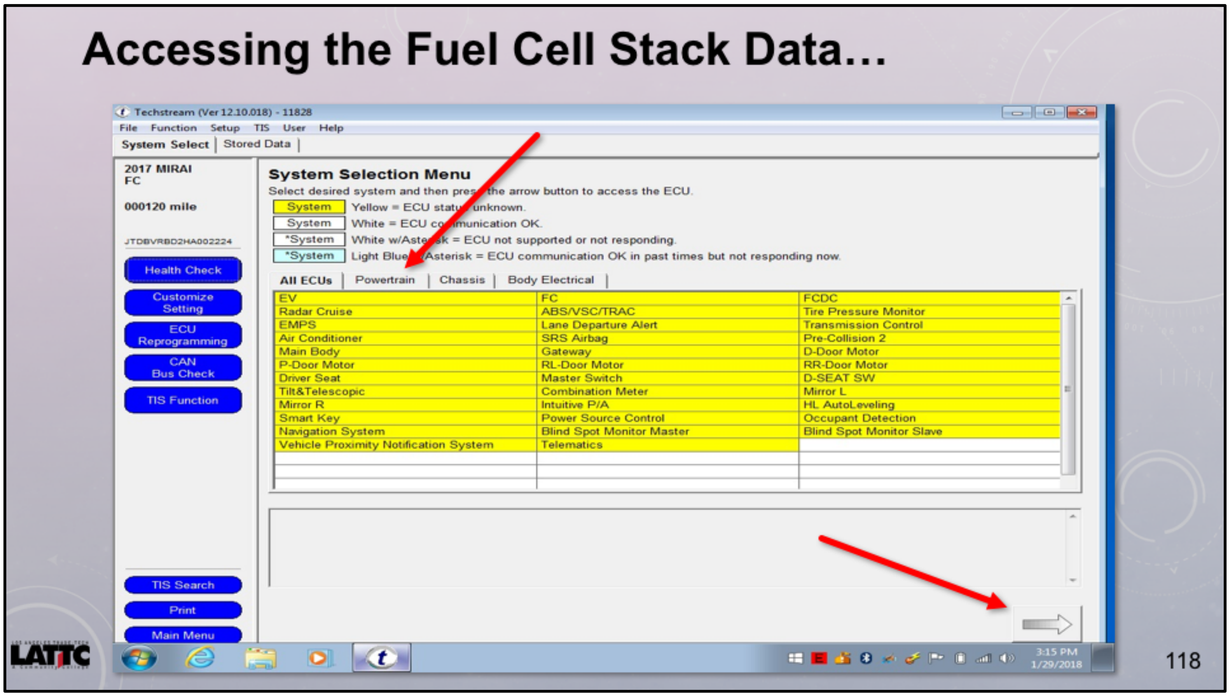
After clicking connect (previous slide), the software automatically tries and access the vehicle systems and shows you it is connecting.



You may be prompted to enter further information about your specific vehicle. Do this till the "Next" button becomes clickable (lower area of the window).



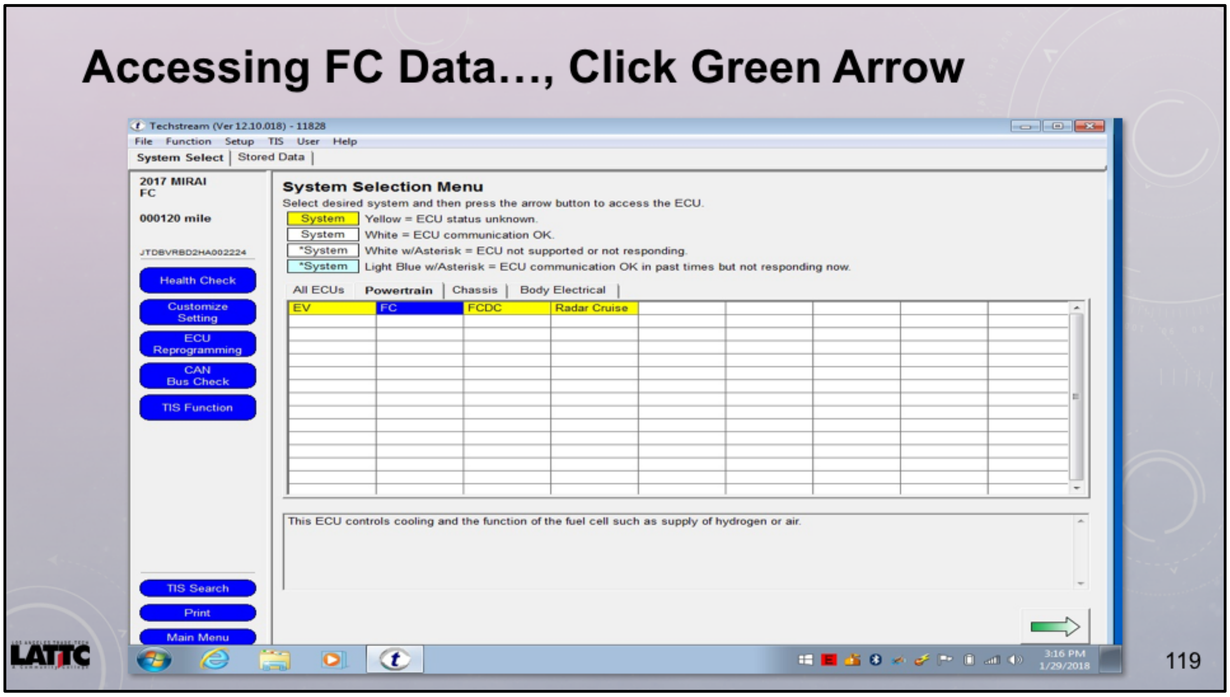
Once you click the “Next” button, it asks you to “Please wait…”



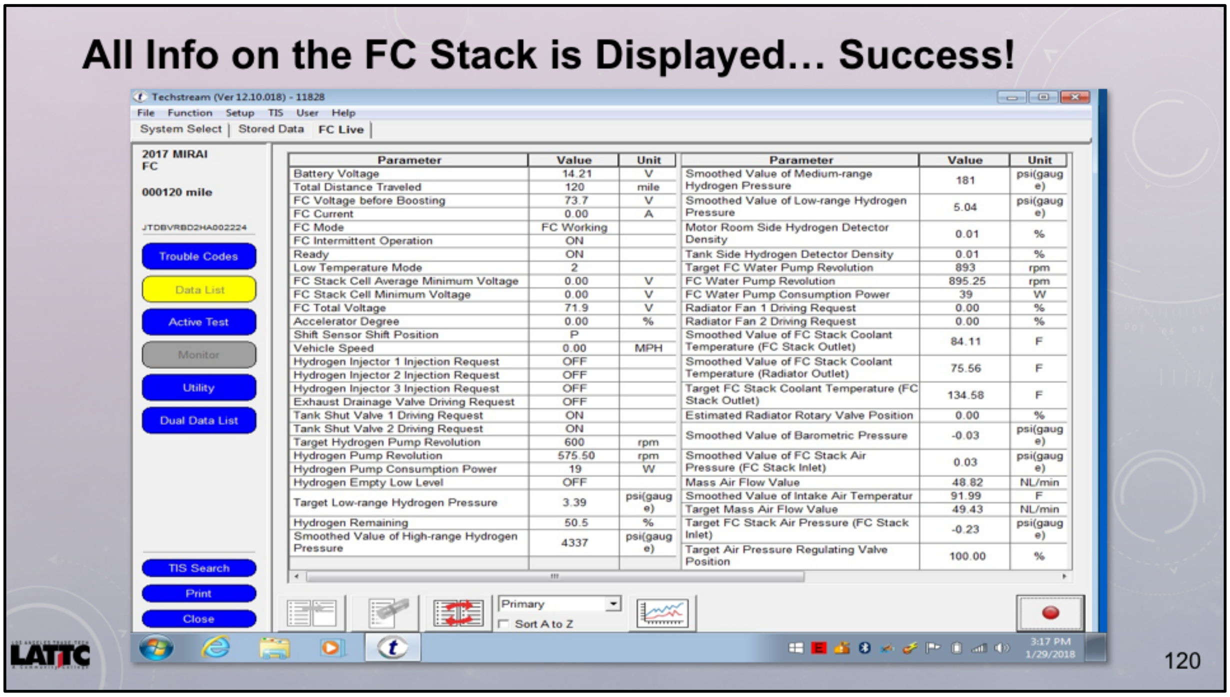
As you can see towards the upper right corner of the screen, it reads and displays the vehicle year, model and odometer millage along with the vehicle's VIN number (lower). This verifies successful connection. After successful connection, the software defaults to a teachstream, positive vehicle connection homescreen. The screen shows all the control modules which are installed on this vehicle and accessible for testing and monitoring. Note the navigation choices to the right in blue-colored buttons. These are the various areas of each system which can be selected for data read. There is also a "Heath Check" button which scans all the modules for any fault(s).

As you can see, this is a 2017 Mirai FC unit, with only 120 miles on the odometer!

For this vehicle, we want to access Fuel Cell Stack (FC) data. So the FC is part of the Powertrain, so I clicked on its Tab "Powertrain" and click on the arrow towards the lower-right corner of the screen.

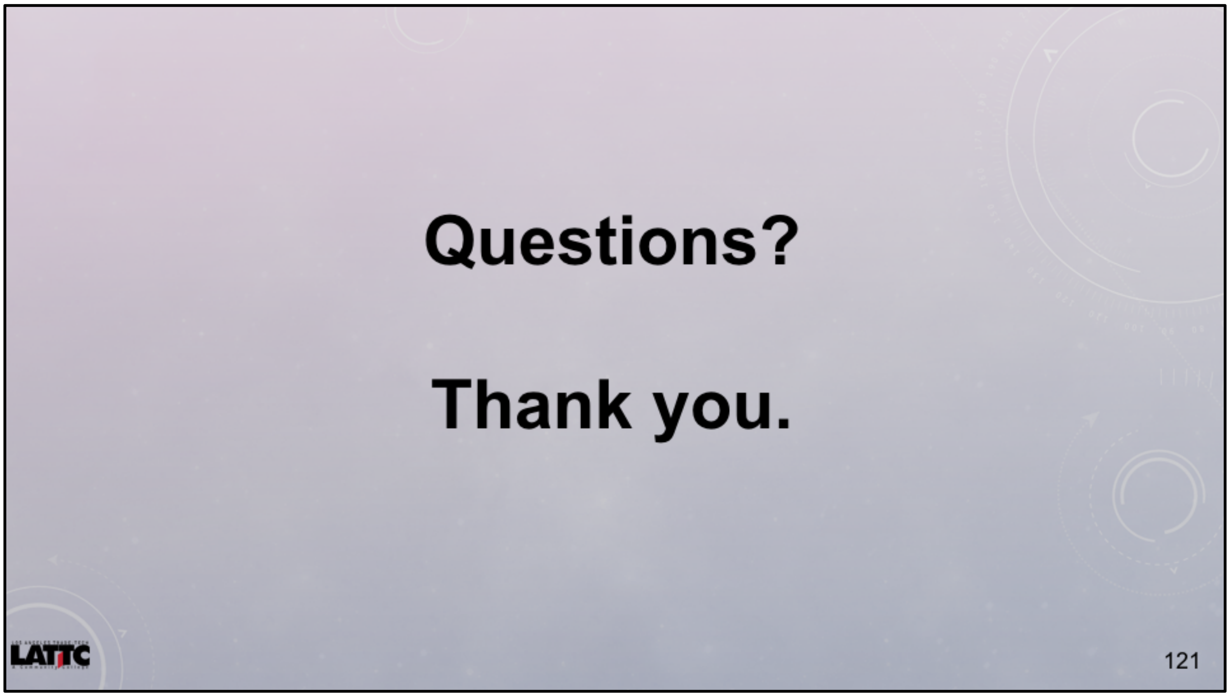


The FC box turns blue and the green arrow towards the lower-right corner becomes clickable…, click on it to go there.



Here we can read what the FC Control module is "seeing". Here is where this tool becomes really valuable and time-saver. Some of the things which are displayed here are fopr you to see and confirm are:

- Battery voltage: 14.21V = Vehicle's 12v auxiliary power system is being supplied/charged
- FC Mode: FC Working = **FC is ON**
- Ready: **ON** = The vehicle's **READY light** on the dashboard should be **ON**
- All 3 hydrogen injectors are **OFF** = No loads are being applied to the vehicle (Vehicle was just sitting there=TRUE!)
- Hydrogen Remaining: **50%** = There is still some hydrogen gas present inside the fuel cell stack (**No wonder all 3 injectors are OFF**)
- And so on…………∞


Questions?
Thank you.
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RESOURCES AND LINKS
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Links for Resources

Online Documents	Web Address
Toyota Mirai:	
Cruises 300 miles	http://bit.ly/2roGEvk
A Preview of future propulsion	http://bit.ly/2ru0CVE
Run your home in an emergency	http://bit.ly/2nqYXuO

Websites	Web Address
U.S. Department of Energy Quiz: How much do you know about hydrogen?	http://bit.ly/2EfKqdb

Videos	Web Address
Visual hydrogen atom (1:21)	http://rsc.li/2DSUoRC
Hydrogen properties (7:15)	http://rsc.li/2Dufkkp
Toyota Fuel Cell System (3:23)	http://bit.ly/2DnALAg
Toyota Motor Corporation (Requires Account Login)	
Toyota Information System TIS	http://toyota.us/2npclKy
Mirai FCV Mayor Tech Specs	http://toyota.us/2EkBK5C

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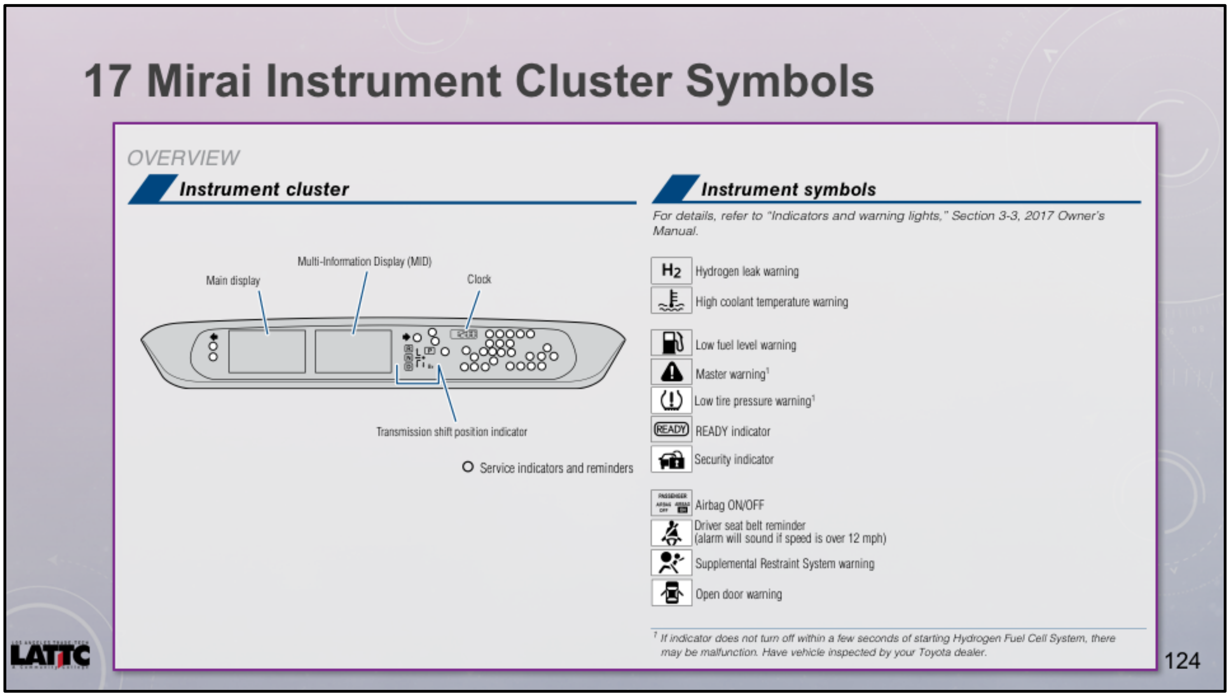
17 Mirai Instrument Cluster Symbols
OVERVIEW
Instrument cluster
Main display
Multi-Information Display (MID)
Clock
Transmission shift position indicator
Service indicators and reminders
Instrument symbols
For details, refer to "Indicators and warning lights," Section 3-3, 2017 Owner's Manual.
Hydrogen leak warning
High coolant temperature warning
Low fuel level warning
Master warning
Low tire pressure warning
READY indicator
Security indicator
Airbag ON/OFF
Driver seat belt reminder (alarm will sound if speed is over 12 mph)
Supplemental Restraint System warning
Open door warning
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.
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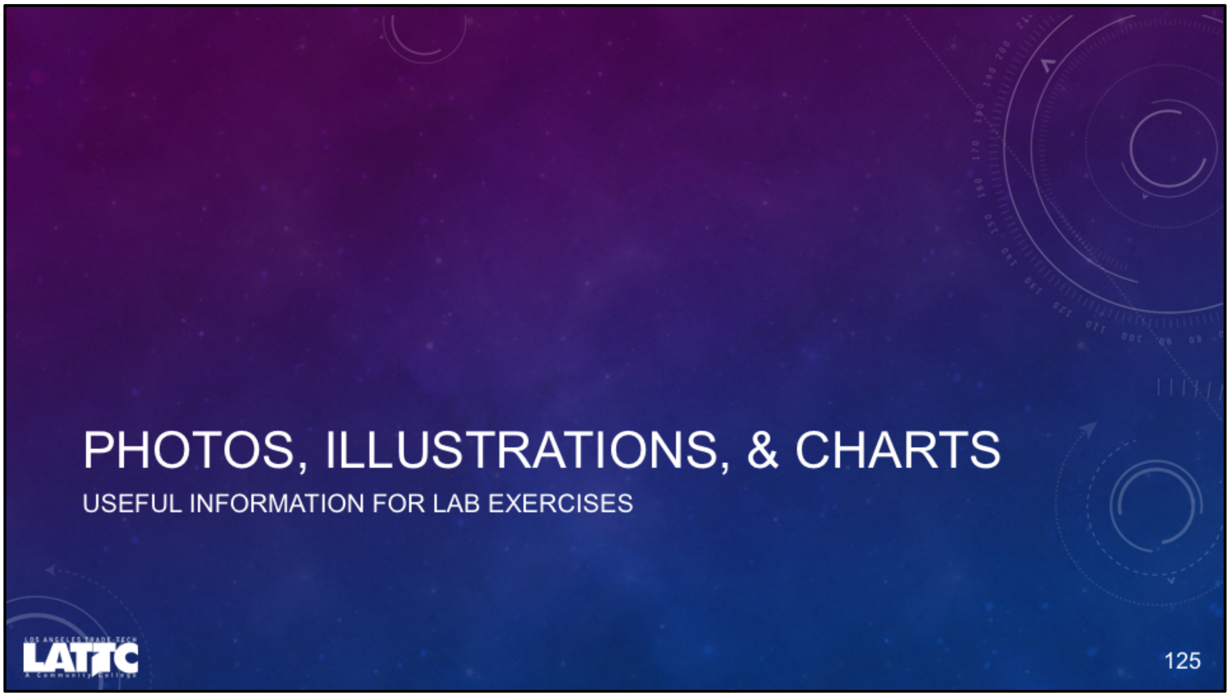
PHOTOS, ILLUSTRATIONS, & CHARTS
USEFUL INFORMATION FOR LAB EXERCISES
LATTC
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Fueling a Hydrogen Vehicle

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Dashboard Instruments

Dashboard Buttons

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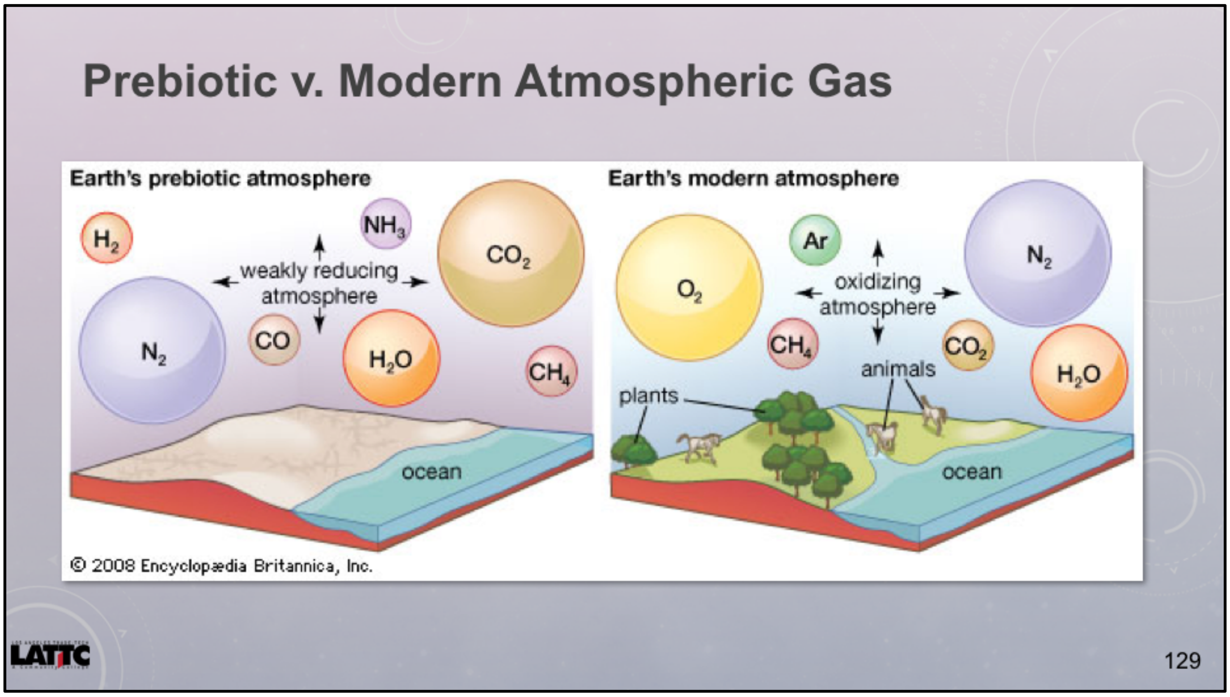
Prebiotic v. Modern Atmospheric Gas
Earth's prebiotic atmosphere
H2
NH3
CO2
weakly reducing atmosphere
N2
CO
H2O
CH4
ocean
© 2008 Encyclopædia Britannica, Inc.
Earth's modern atmosphere
O2
Ar
N2
oxidizing atmosphere
CH4
CO2
animals
H2O
plants
ocean
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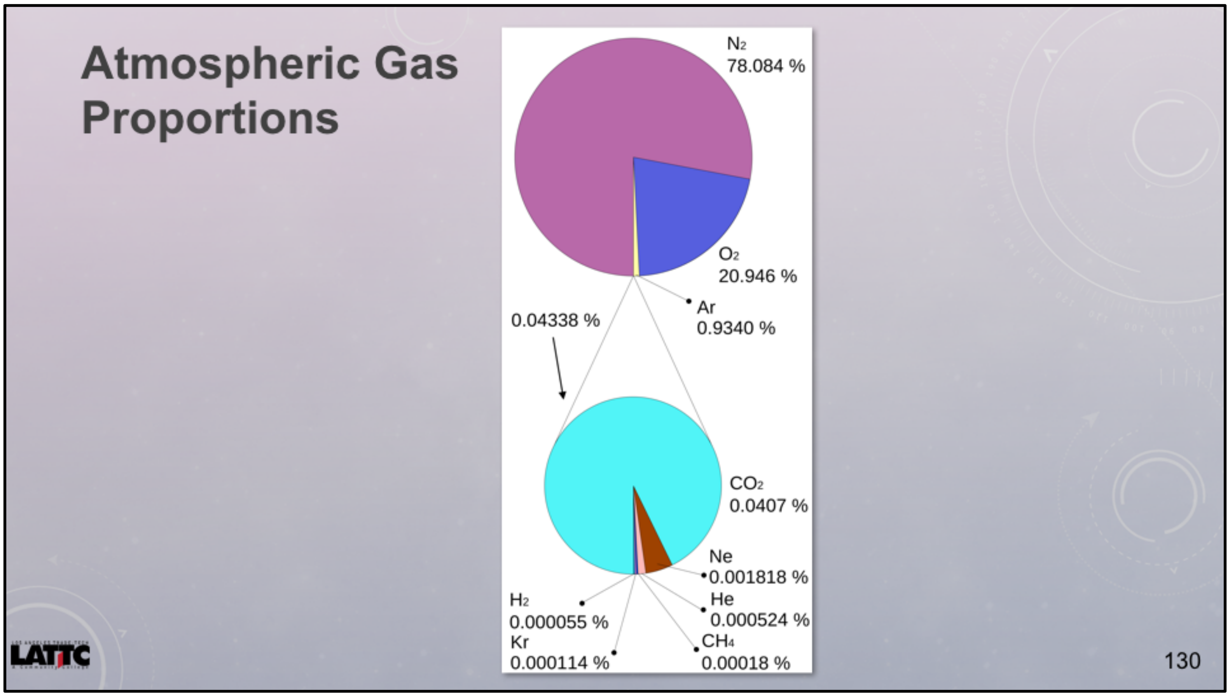
Atmospheric Gas Proportions
N2
78.084 %
O2
20.946 %
Ar
0.9340 %
0.04338 %
CO2
0.0407 %
Ne
0.001818 %
He
0.000524 %
CH4
0.00018 %
H2
0.000055 %
Kr
0.000114 %
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Propane Flame v. Hydrogen Flame - Night
Propane Flame
Hydrogen Flame
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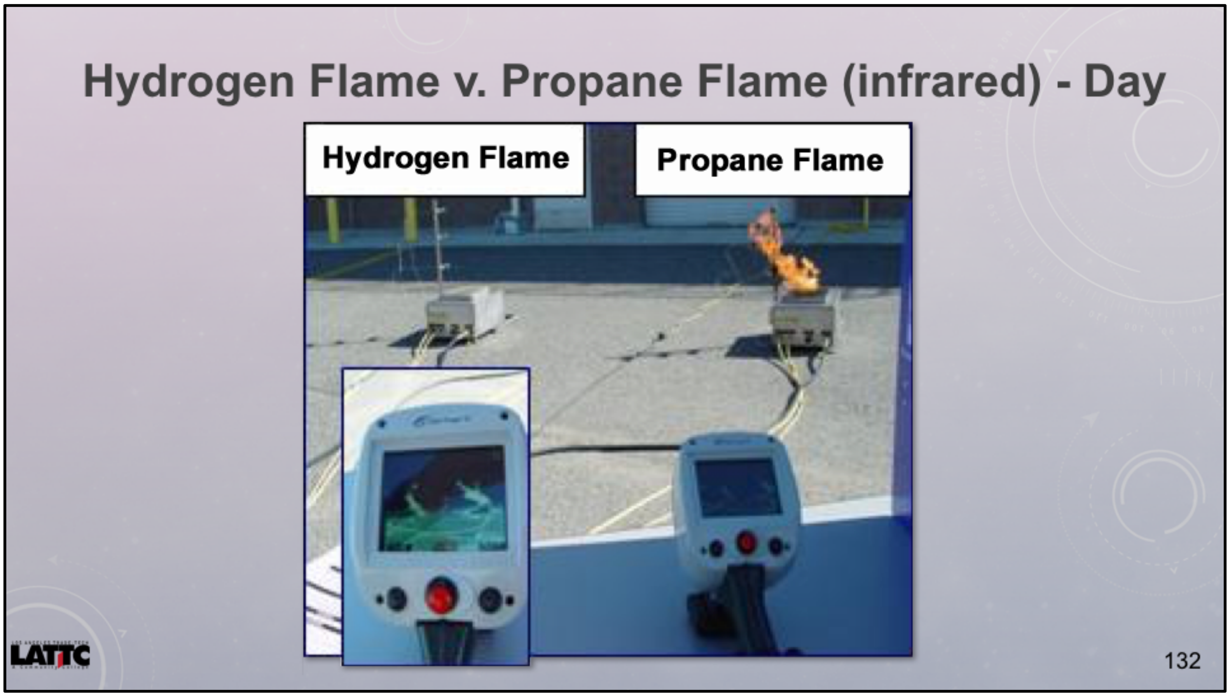
Hydrogen Flame v. Propane Flame (infrared) - Day
Hydrogen Flame
Propane Flame
132


Hydrogen Atom
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TIS-techstream (closed)

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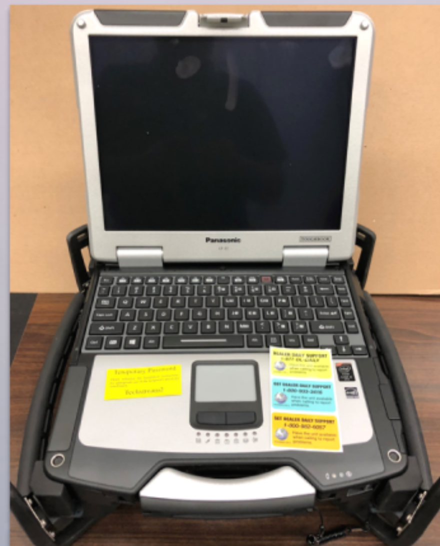
TIS-techstream (open & off)



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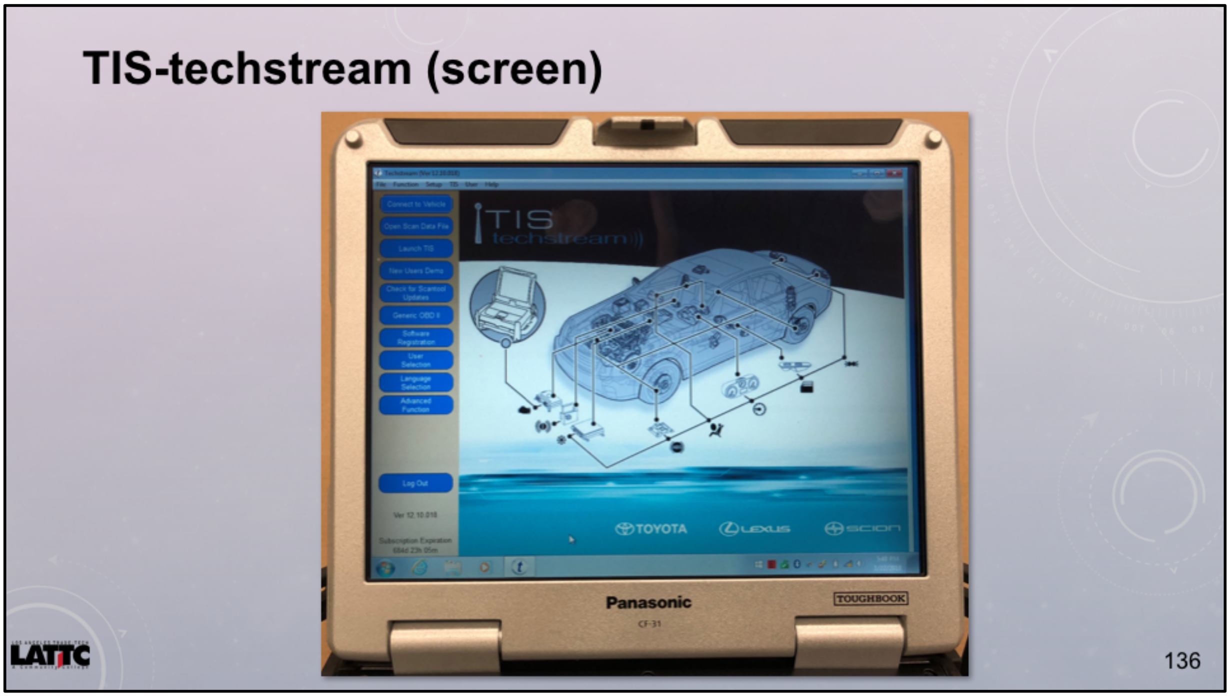
TIS-techstream (screen)
TIS
techstream
TOYOTA
LEXUS
SCION
Panasonic
TOUGHBOOK
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TIS-techstream (open & on)

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