FRONTIER energy

Webinar for Code Officials

July 19, 2017

Conducted in partnership:

Gia Brazil Vacin

ZEV Infrastructure Project Manager

CA Governor's Office of Business and Economic Development

Jennifer Hamilton

Safety, Education, Codes & Standards Project Manager

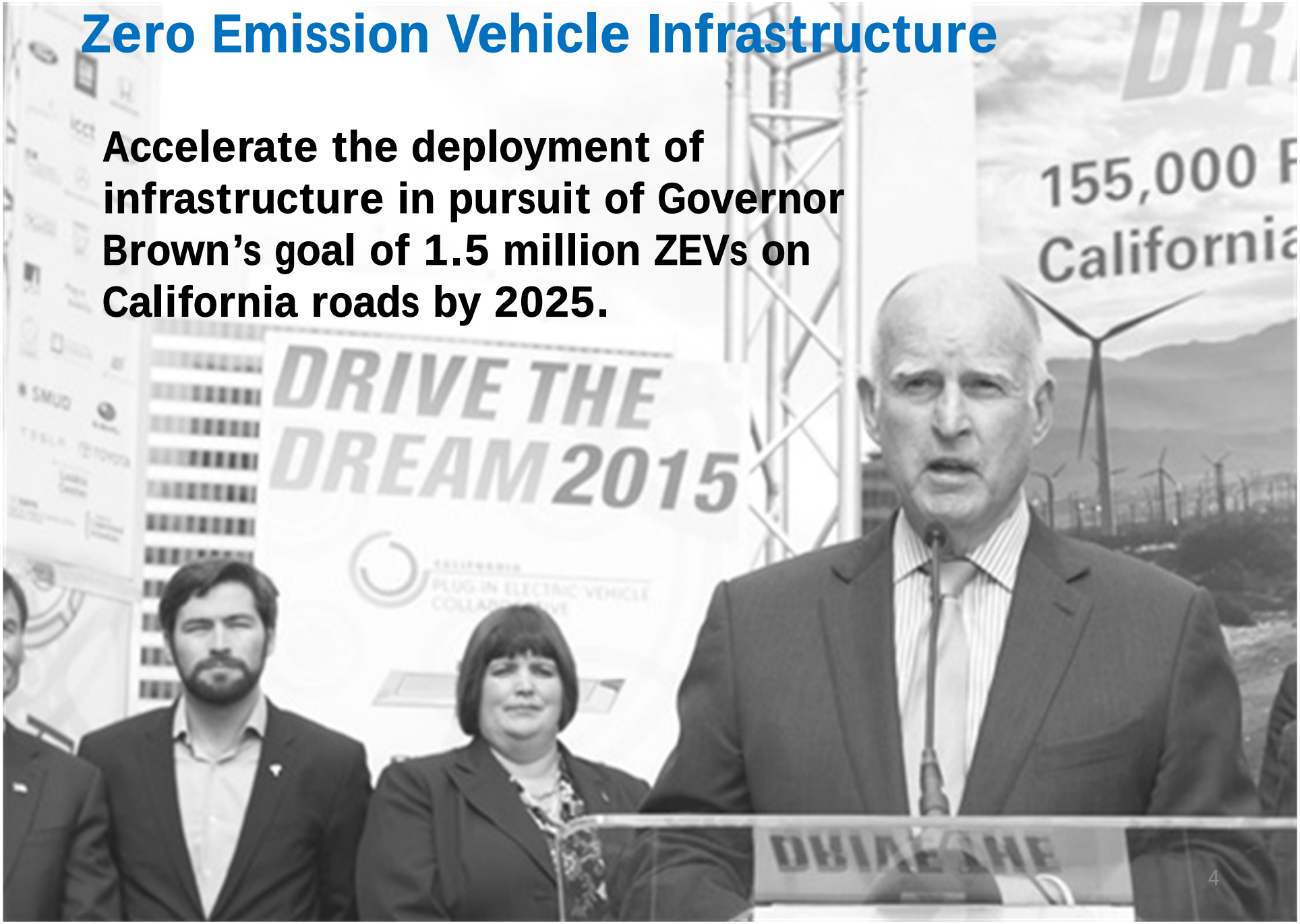
California Fuel Cell Partnership

Gia Brazil Vacin

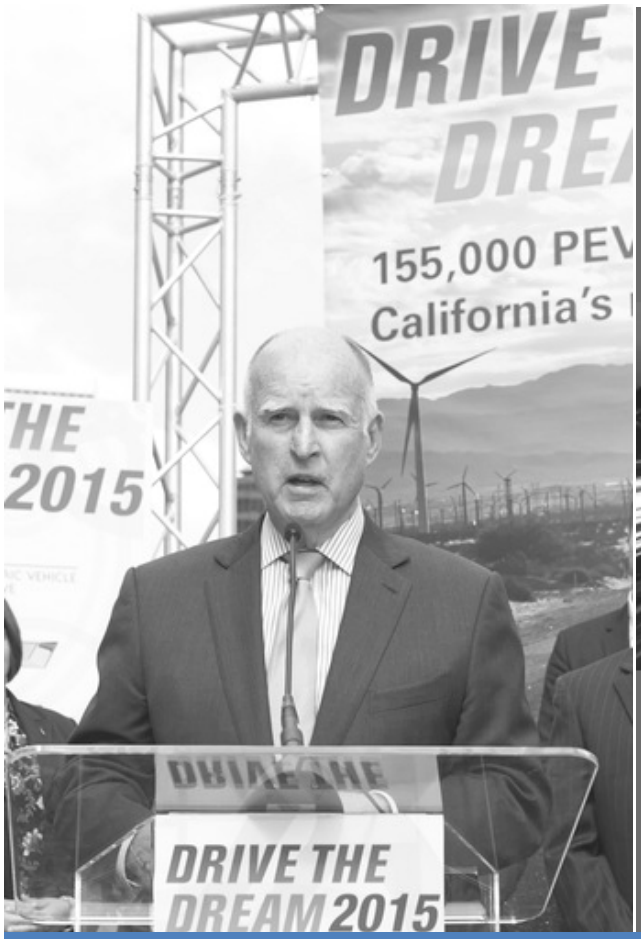
WELCOME AND OVERVIEW

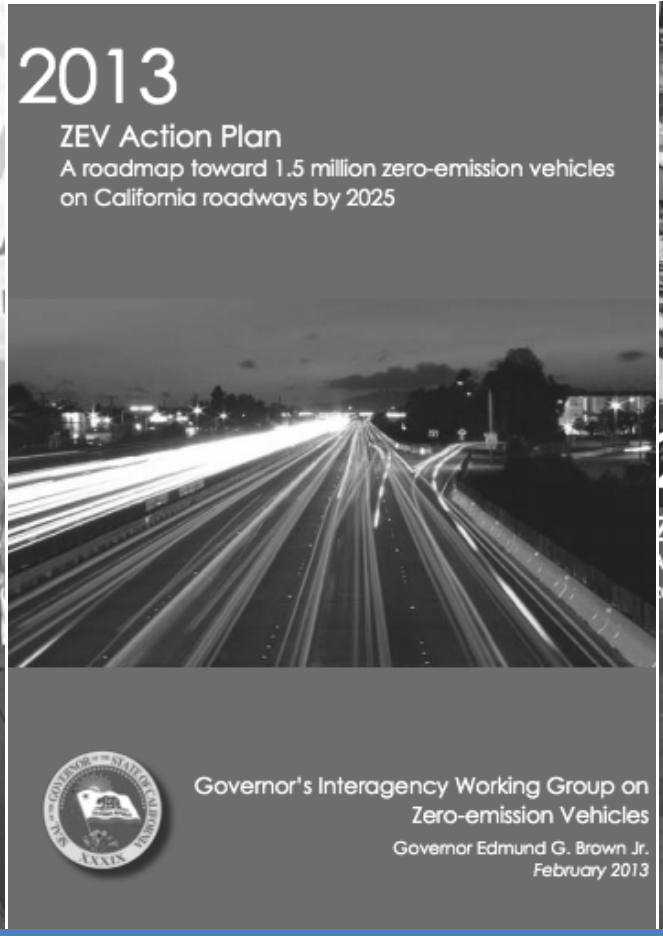
Zero Emission Vehicle Infrastructure

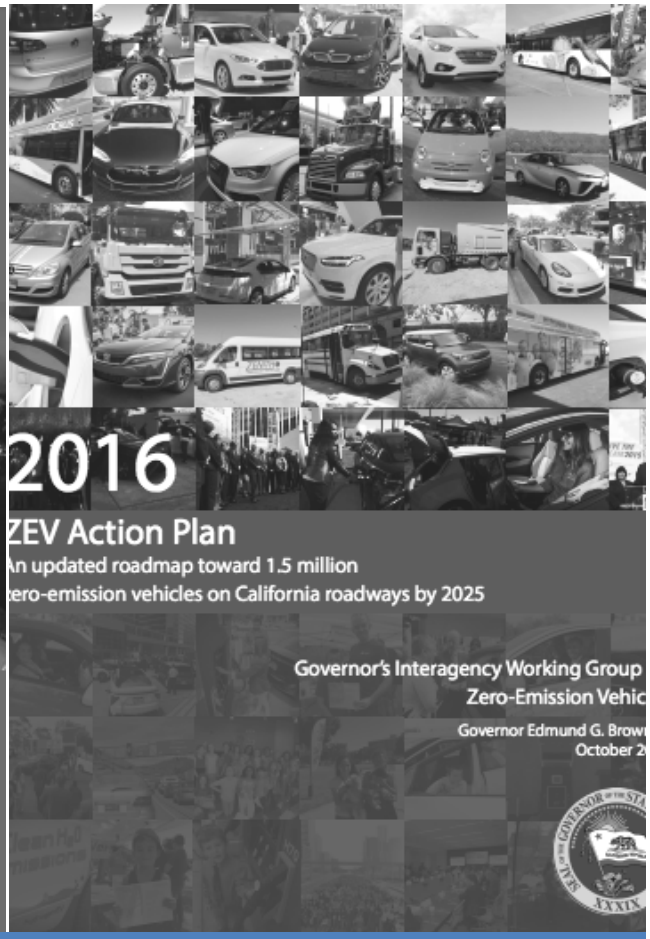
Accelerate the deployment of infrastructure in pursuit of Governor Brown's goal of 1.5 million ZEVs on California roads by 2025.



Governor's Office Action

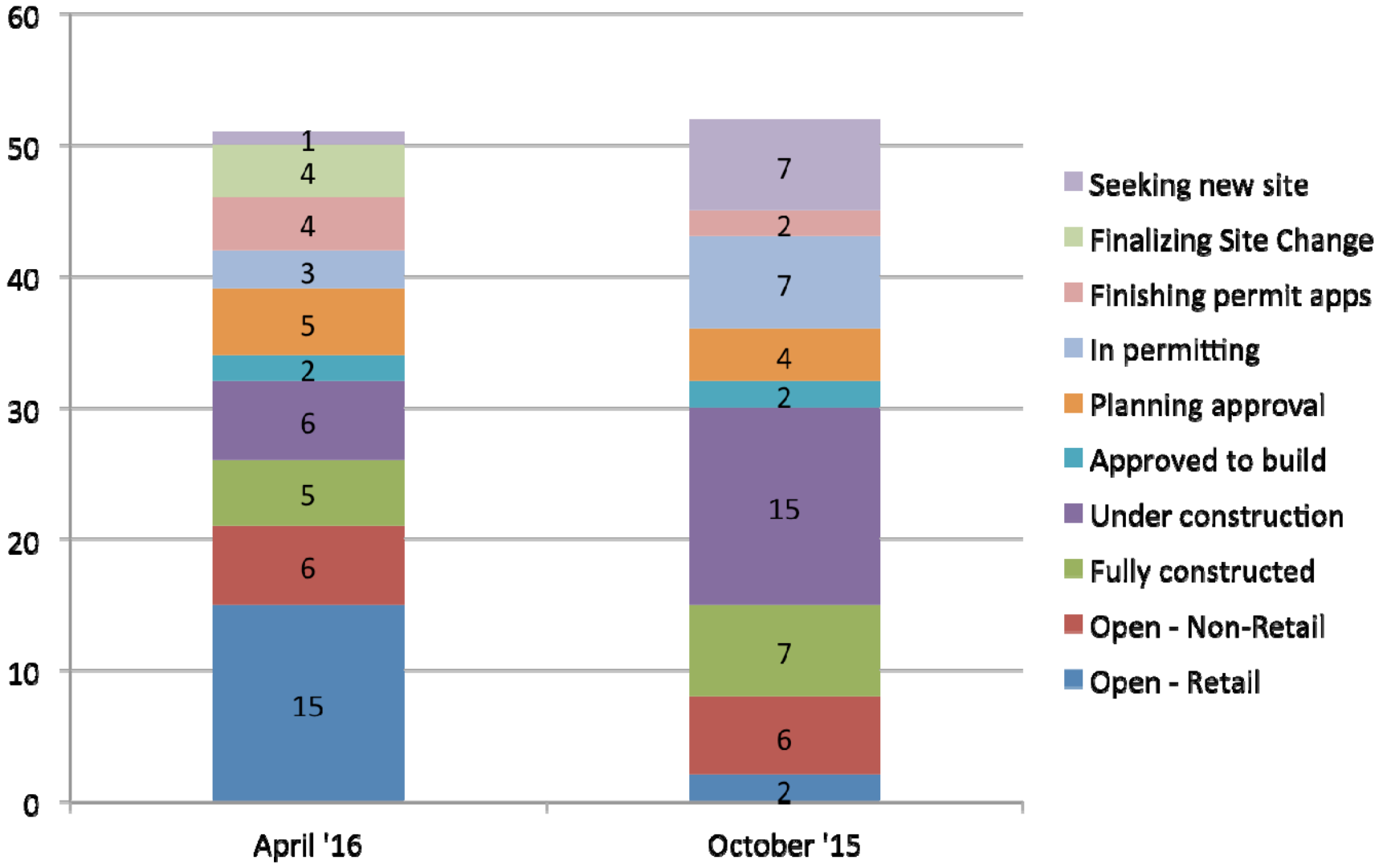




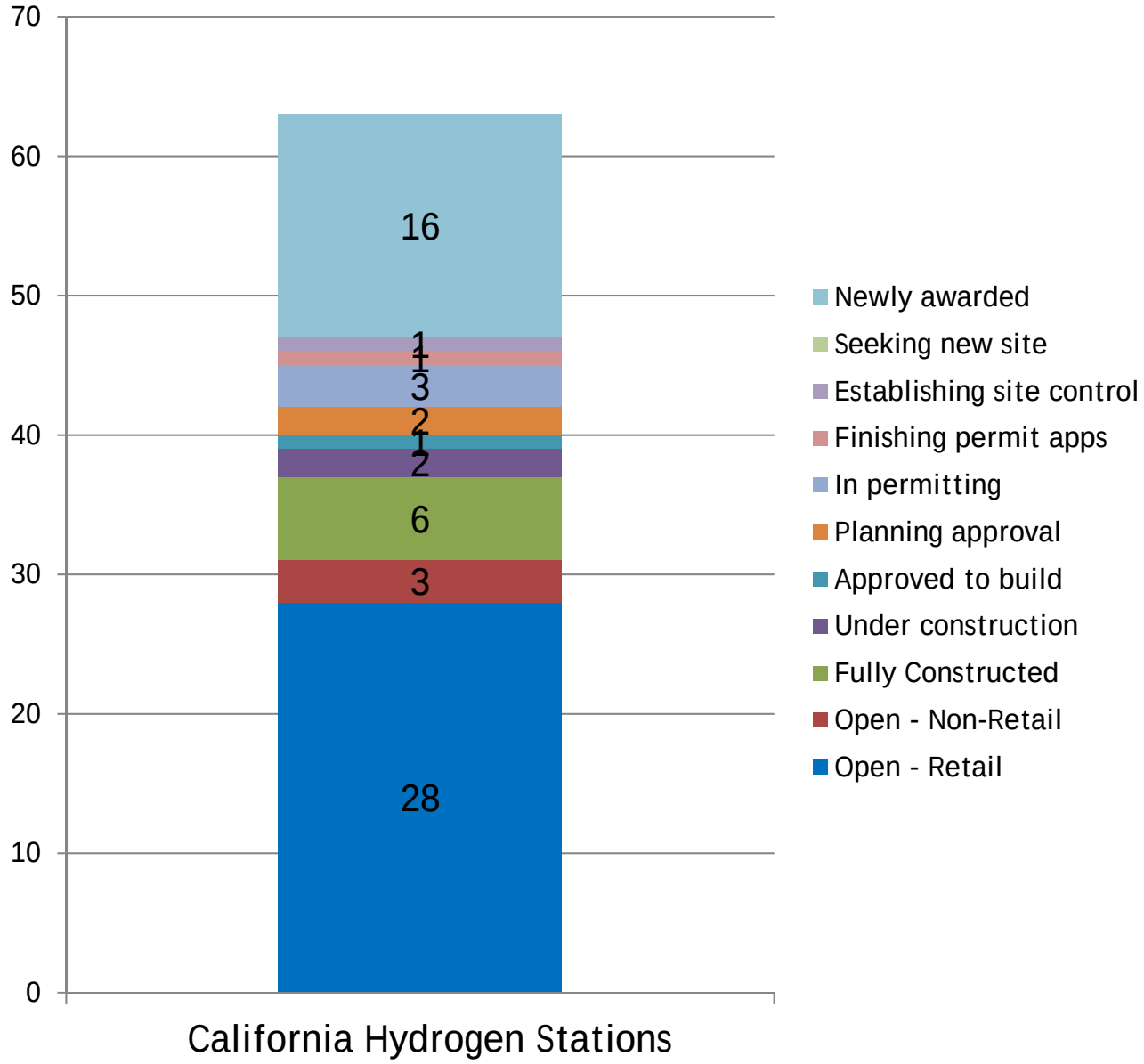


Governor's Vision **2013 ZEV Action Plan** **2016 ZEV Action Plan**

Hydrogen Station Development



Hydrogen Station Development



June 2017

Northern CA Hydrogen Stations

Retail: Open

Campbell - Winchester Blvd
Hayward
Mill Valley
San Jose
Saratoga
South San Francisco
Lake Tahoe-Truckee
West Sacramento

Other: Open

Emeryville – AC Transit
Oakland – AC Transit

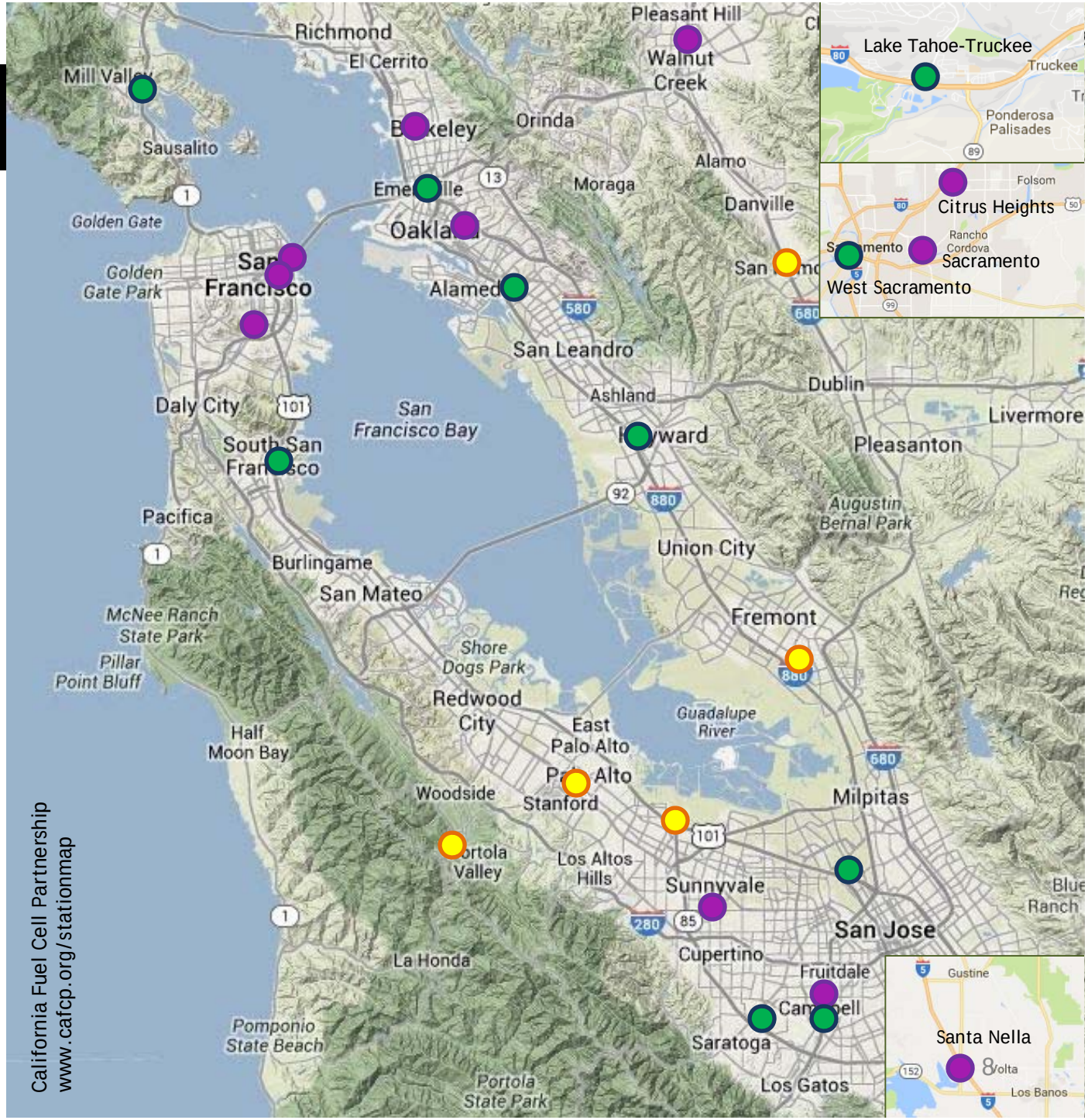
Retail: In Development

Fremont
Mountain View
Palo Alto
*Rohnert Park
San Ramon
Woodside

**Not shown on map*

Proposed**

Berkeley
Campbell - East Hamilton Ave
Citrus Heights
Oakland - Grand Ave
Sacramento
San Francisco - Third St
San Francisco - Harrison St
San Francisco - Mission St
Santa Nella
Sunnyvale
Walnut Creek



June 2017

Southern CA Hydrogen Stations

Retail: Open

Anaheim
Costa Mesa
Del Mar
Diamond Bar
Fairfax-LA
Harris Ranch
Hollywood
La Cañada Flintridge
Lake Forest
Lawndale
Long Beach
Playa Del Rey
Riverside
San Juan Capistrano
*Santa Barbara
Santa Monica - Cloverfield Blvd
South Pasadena
UC Irvine
West LA
Woodland Hills

Other: Open

Burbank
Newport Beach
*Thousand Palms – SunLine Transit

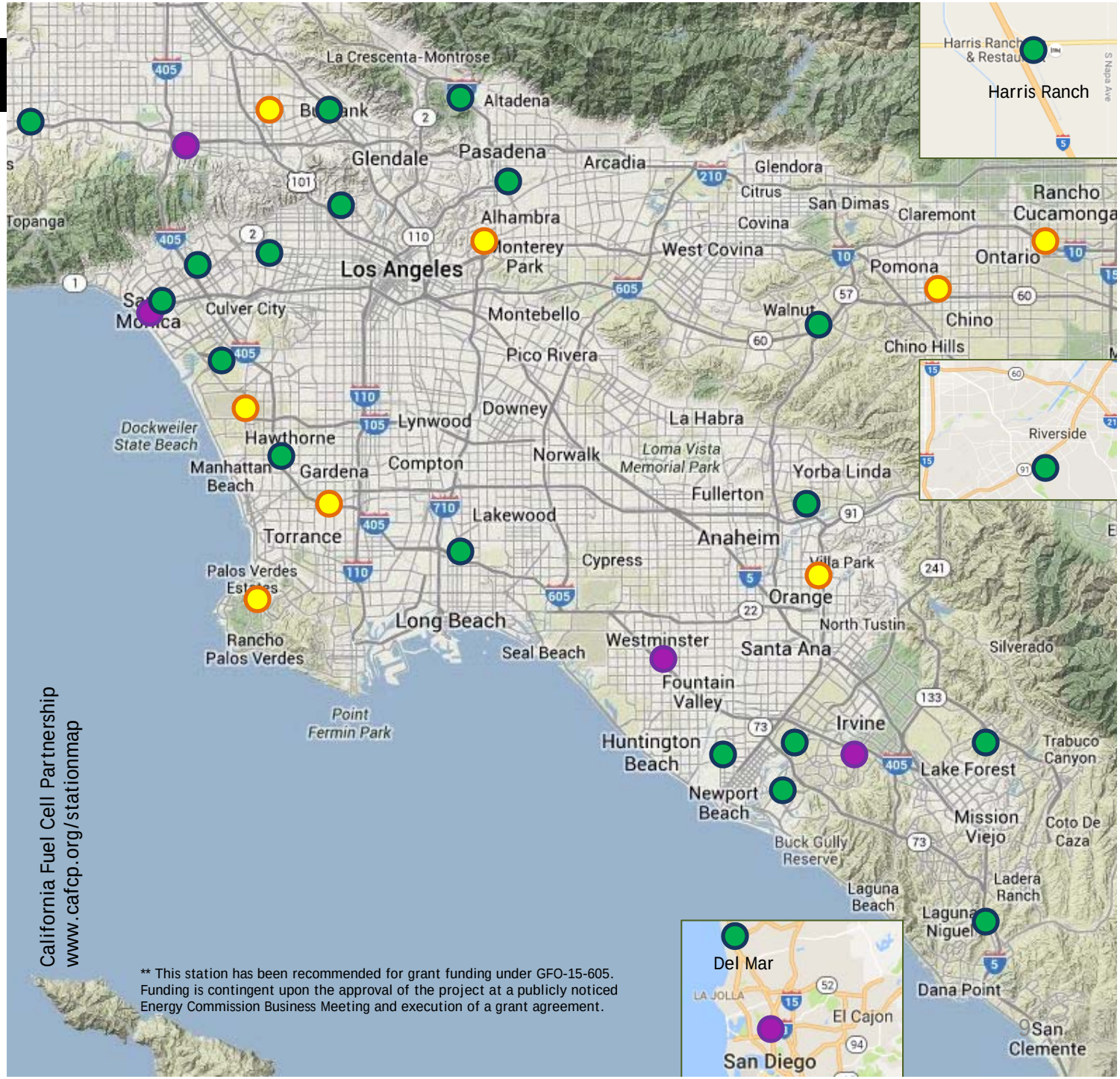
Retail: In Development

Cal State LA
Chino (upgrade)
LAX (upgrade)
North Hollywood
Ontario
Orange
Rancho Palos Verdes
*Thousand Oaks
Torrance

**Not shown on map*

Proposed**

Irvine
Huntington Beach
San Diego
Santa Monica - Lincoln Blvd
Sherman Oaks



** This station has been recommended for grant funding under GFO-15-605. Funding is contingent upon the approval of the project at a publicly noticed Energy Commission Business Meeting and execution of a grant agreement.

DRIVING FOR THE FUTURE

The Facts About FCEVs

Hydrogen fuel cell electric vehicles are paving the way for a zero-emission transportation future and emerging as an important complement to the growing battery electric vehicle market.

0	300+	3-5
tailpipe emissions & quieter to drive than gasoline-fueled cars	Range of miles on a full tank, similar to gasoline-fueled cars	minutes to fill the tank

They're here. And more are coming…

Including GM, Nissan, BMW, Volkswagen, Audi

2,200 FCEVs on the road

- Hyundai leases the Tucson
- Toyota sells and leases the Mirai
- Honda leases the Clarity
- Mercedes-Benz GLC plug-in fuel cell in 2017
  - More automakers will come to market:
  - Audi, BMW, Ford, GM, Lexus, Nissan, Volkswagen

- $5,000 rebate
- HOV sticker
- $15,000 in free fuel

More than cars...

Jennifer Hamilton

HYDROGEN AND FUEL CELLS 101

Hydrogen Uses

The use of hydrogen is not new; private industry has used it safely for many decades. Nine million tons of hydrogen are safely produced and used in the United States every year. 56 billion kg/yr are produced globally. For example, H_2 is used for:

- Petroleum refining
- Glass purification
- Aerospace applications
- Fertilizers
- Annealing and heat treating metals
- Pharmaceutical products

The Air Products and Chemicals hydrogen production facilities in Port Arthur, Texas, is funded by the Energy Department through the 2009 Recovery Act. | Photo credit Air Products and Chemicals hydrogen production facilities.

- Petrochemical manufacturing
- Semiconductor industry
- Hydrogenation of unsaturated fatty acids in vegetable oil
- Welding
- Coolant in power generators

Hydrogen Distribution

- DOT regulated transportation…
- Cryogenic liquid transport
  - -423°F (-253°C)
  - Low pressure (<100 psi)
- Pressurized gas trailers
  - ~2,000-6,500 psi
- Truck, rail, barge and pipeline

Photo: Air Products & Chemicals, Inc.

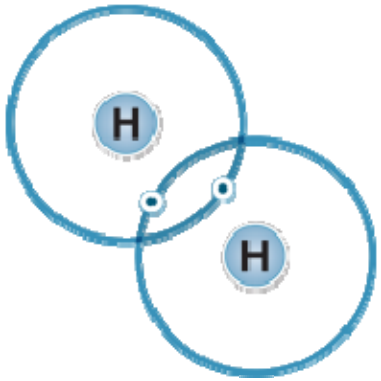
Photo: Ovonics

Photo: Praxair, Inc.

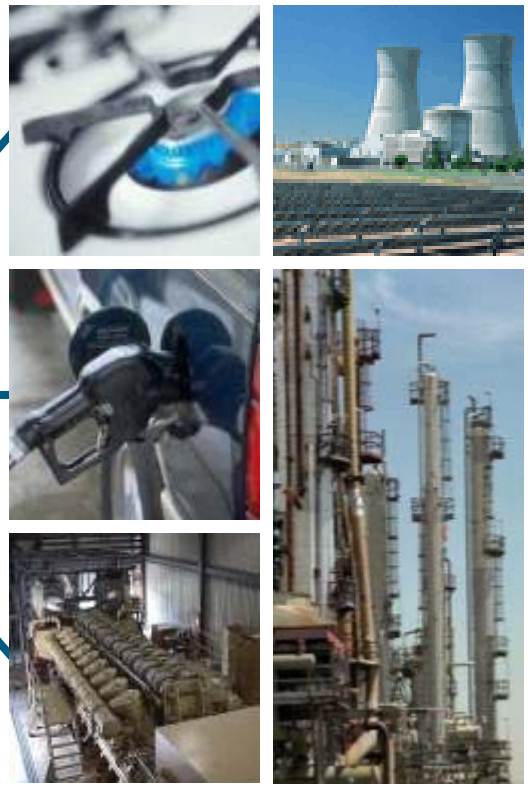
Where Do We Get Hydrogen?

Renewable Sources

Solar, wind, geothermal, hydro, biomass, algae



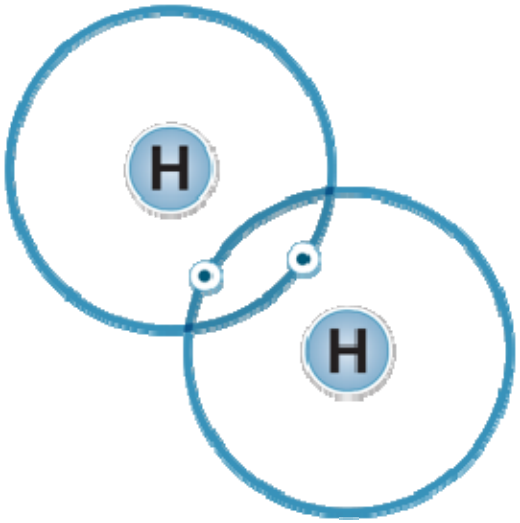
Traditional Sources



Natural gas, gasoline, nuclear, coal

Hydrogen Properties and Behavior

- A gas at ambient conditions
- Hydrogen is a cryogen: exists as a liquid at -423°F (-253°C).
  - Compressing the gas does not liquefy it
  - No liquid phase in a compressed gaseous hydrogen storage tanks
- LH2 storage at relatively low pressure (50 psi)
- Double walled, vacuum insulated tanks with burst disks, vents, and PRDs
- Volumetric ratio of liquid to gas is 1:848
  - Compare water to steam (1:1700)
- Energy content of 1kg of H_2 is approximately equal to 1 gal of gasoline (in BTUs)



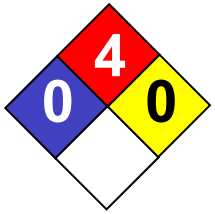
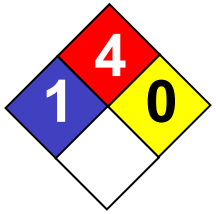
Molecular Hydrogen

Hydrogen Properties: A Comparison

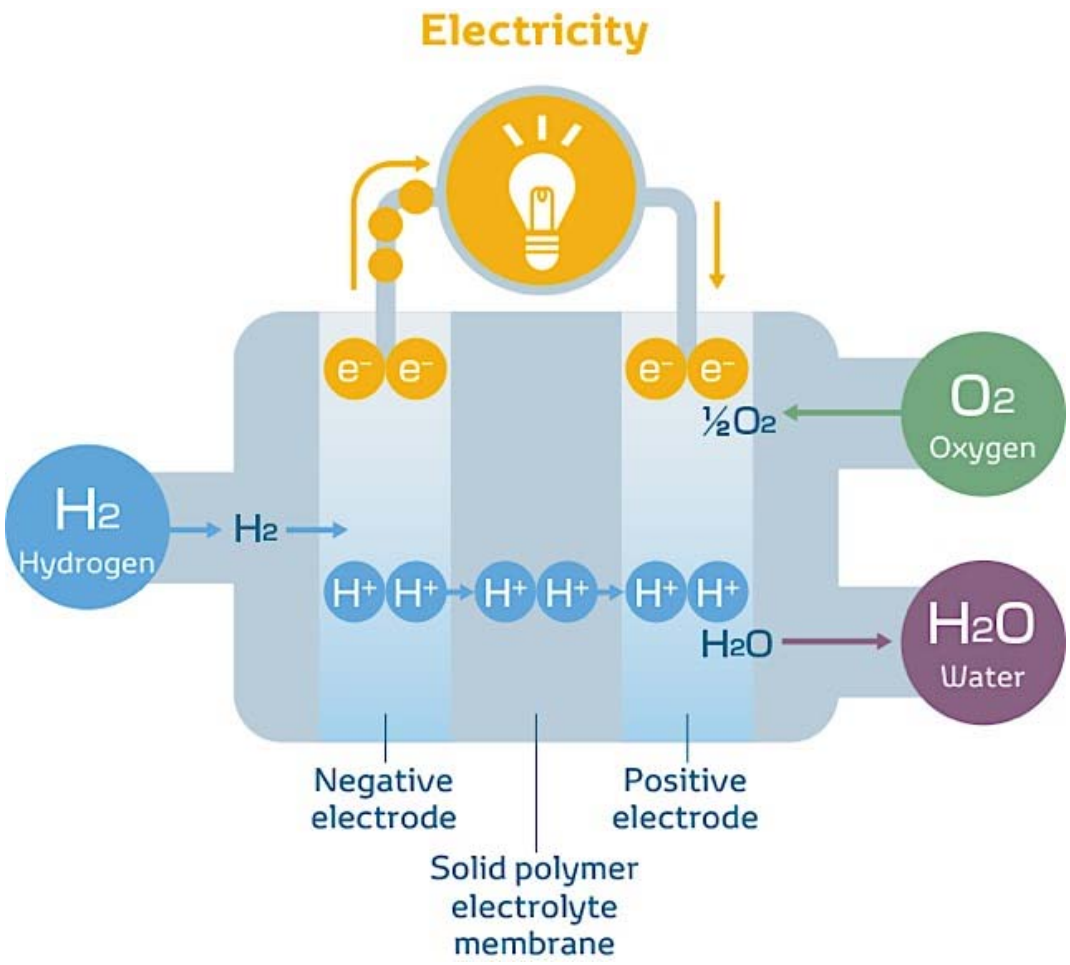
	Hydrogen	Natural Gas	Gasoline
Color	**No**	**No**	**Yes**
Toxicity	**None**	**Some**	**High**
Odor	**Odorless**	**Mercaptan**	**Yes**
Buoyancy Relative to Air	**14X** Lighter	**2X** Lighter	**3.75X** Heavier
Energy by Weight	**2.8X** > Gasoline	**~1.2X** > Gasoline	**43** MJ/kg
Energy by Volume	**4X** < Gasoline	**1.5X** < Gasoline	**120** MJ/Gallon

Source: California Fuel Cell Partnership

Comparison of Flammability

	Hydrogen	Natural Gas	Gasoline
			
Flammability in air (LFL – UFL)	4.1% - 74%	5.3% - 15%	1.4% - 7.6%
Most easily ignited mixture in air	29%	9%	2%
Flame temperature (°F)	4010	3562	3591

How a Hydrogen Fuel Cell Works



How electricity is generated from hydrogen and oxygen in a fuel cell:

1.Hydrogen is supplied to the anode side (negative electrode).

2.Hydrogen molecules activated by the anode catalyst release their electrons.

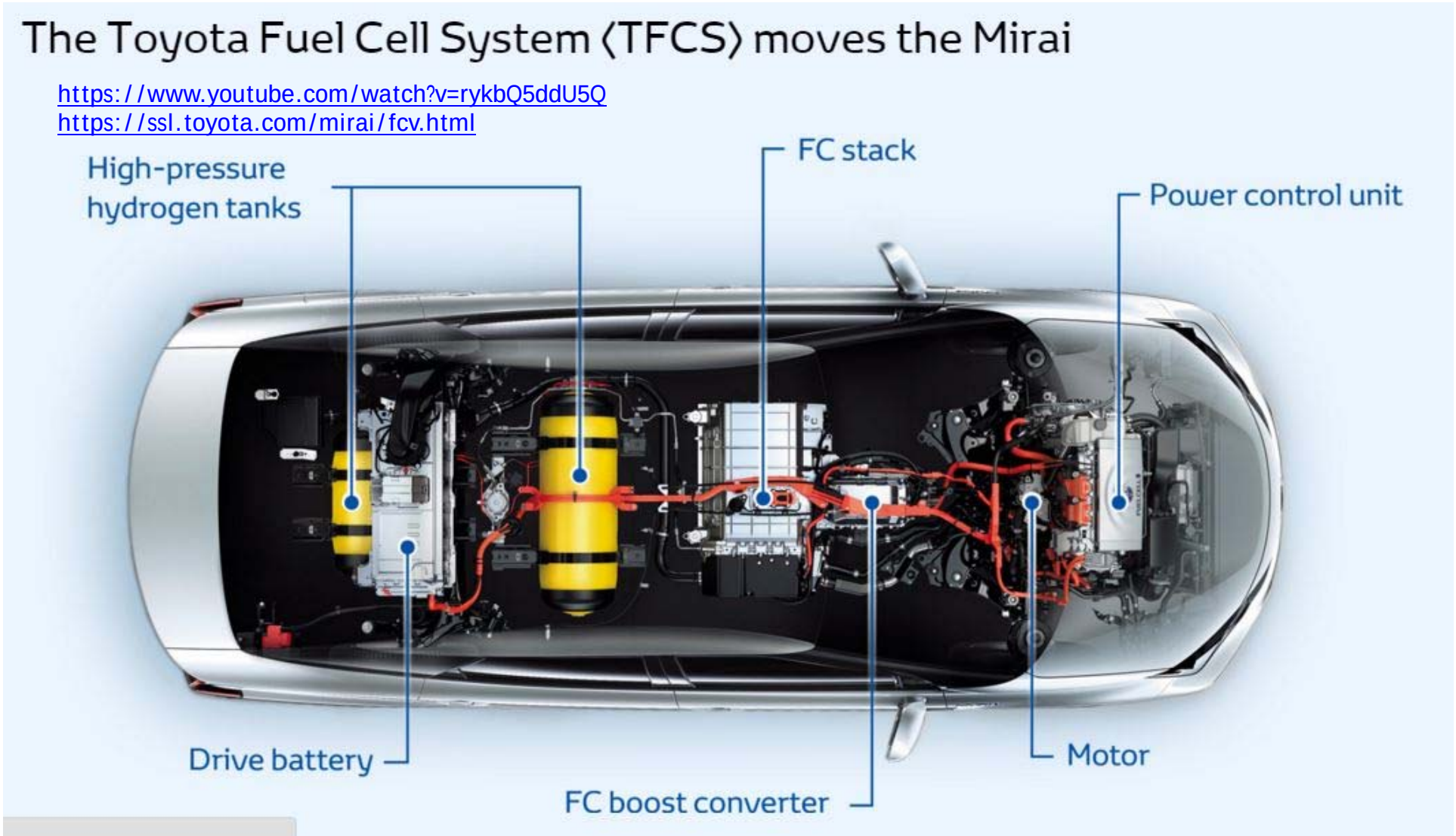
3.The released electrons travel from the anode to the cathode, creating an electrical current.

4.The hydrogen molecules that release electrons become hydrogen ions and move through the polymer electrolyte membrane to the cathode side.

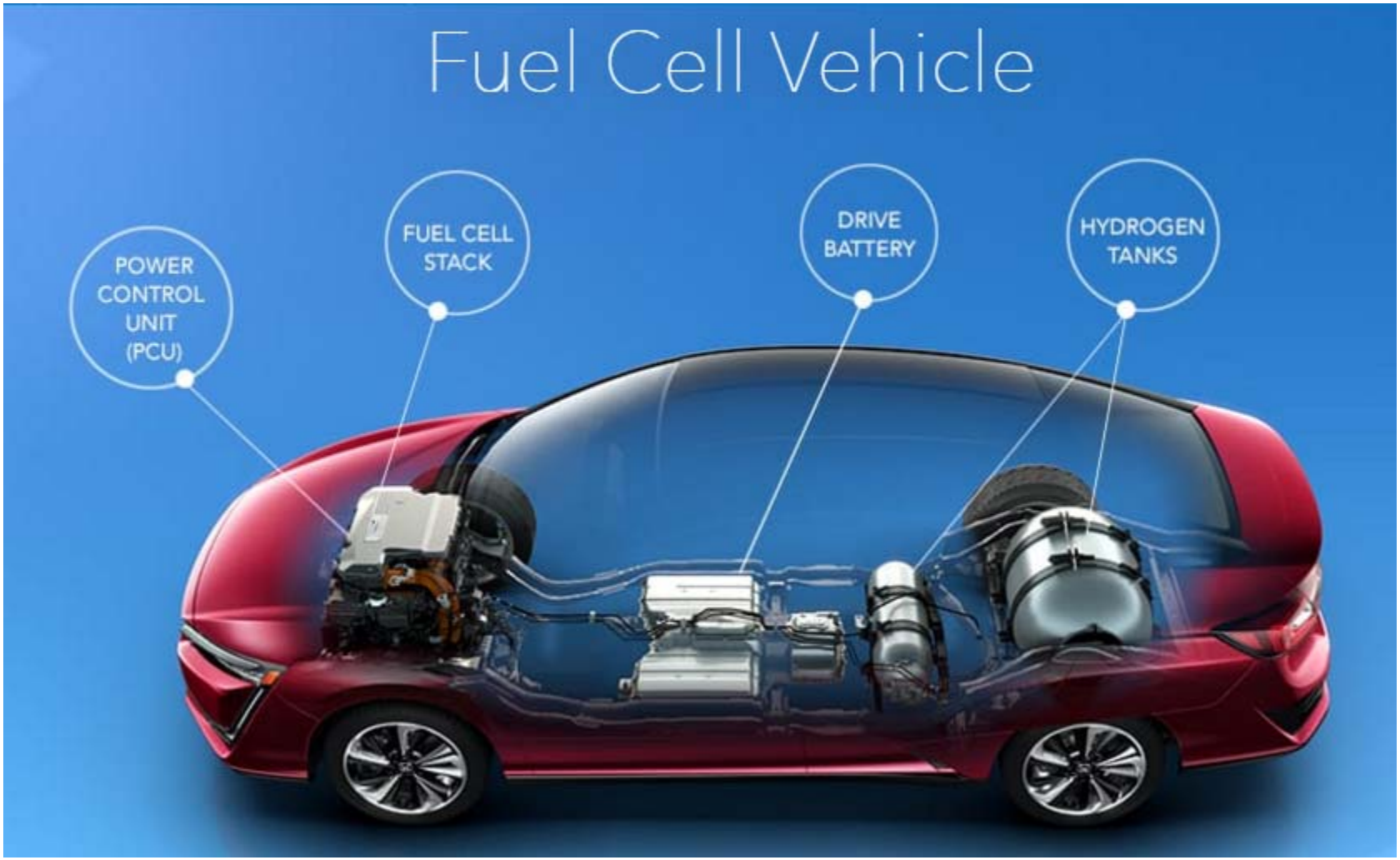
5.The hydrogen ions bond with airborne oxygen and electrons on the cathode catalyst to form water (positive electrode).

http://www.toyota-global.com/

Fuel Cell Vehicles are Electric Vehicles



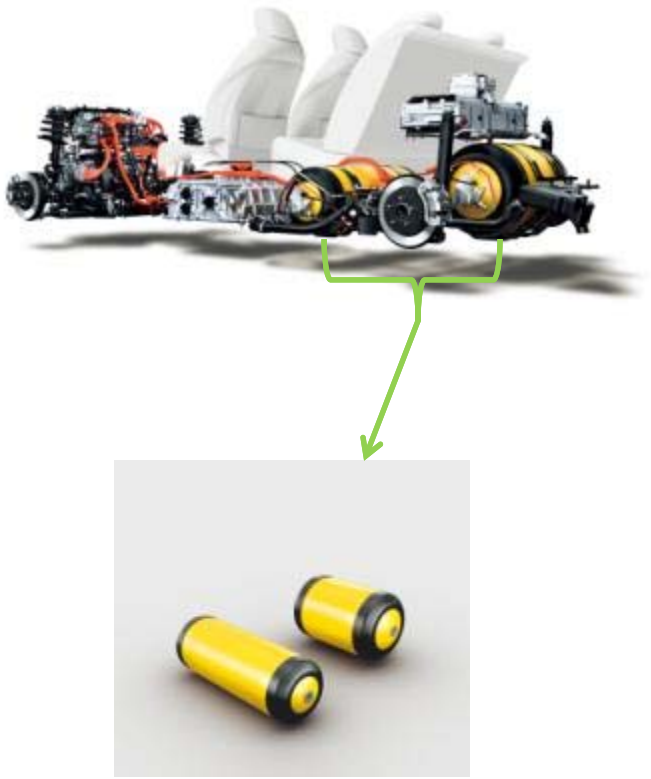
Honda Clarity



http://automobiles.honda.com/Clarity?ef_id=1:1:1&CID=SEARCH_HONDA_Google_FY17_FCV_SHOPPERS

Onboard Hydrogen Storage

- Hydrogen fuel cell vehicles use gaseous hydrogen
- Storage pressure of a full 'tank' is 70 MPa (approximately 10,000 psi)
- Passenger vehicles typically store 4 to 6 kg of hydrogen gas
- Buses with multiple tanks can store as much as 40 to 50 kg of hydrogen gas



Toyota Mirai fuel cell sedan power train, seats, and hydrogen tanks
Source: http://newsroom.toyota.co.jp/en/detail/4198334

High Voltage System

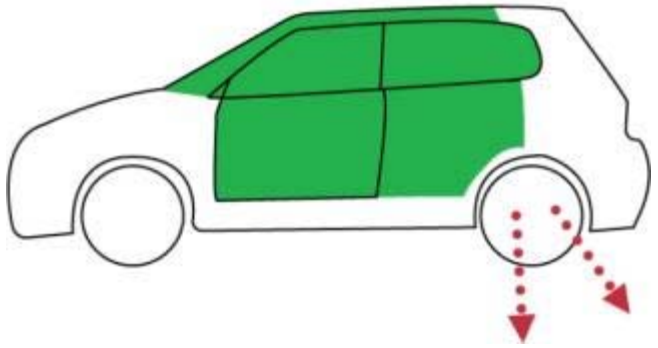
- Same technology as other alt fuel vehicles (gas/electric hybrids)
- Orange high-voltage wiring per SAE
  - Voltage levels greater than 30 VAC or 60 VDC
- Isolated + and – sides (not grounded to the chassis)
- Automatic high voltage system disconnect
  - Inertia switch
  - Ground fault monitoring

Light Duty Vehicle

Transit Bus

Hydrogen Vehicle Safety Systems

- When a leak is detected by hydrogen sensors, solenoid valves close, shutting off the flow of hydrogen, and the vehicle safely shuts down
- When collision sensors activate:
  - Tank solenoid valves close so that hydrogen remains locked in the tank.
  - In FCVs, high-voltage relays open so that the high-voltage battery/capacitors are isolated from the system
- Tank solenoid valves also close when the vehicle is turned off or the power is disrupted
- Tanks have non-reclosing, thermally activated pressure relief devices (TPRDs) -open if the temperature is above 108-110°C



TPRD vent direction

Fuel Isolation in Typical or Normal Operation

In typical operation of turning off the vehicle

- Cuts the 12 volt signal, therefore…
  - Closing the electrically activated solenoid(s) in the fuel storage system
  - Opening the electrically activated relays in the high voltage system
- This isolates the fuel to the tank and high voltage to the battery pack

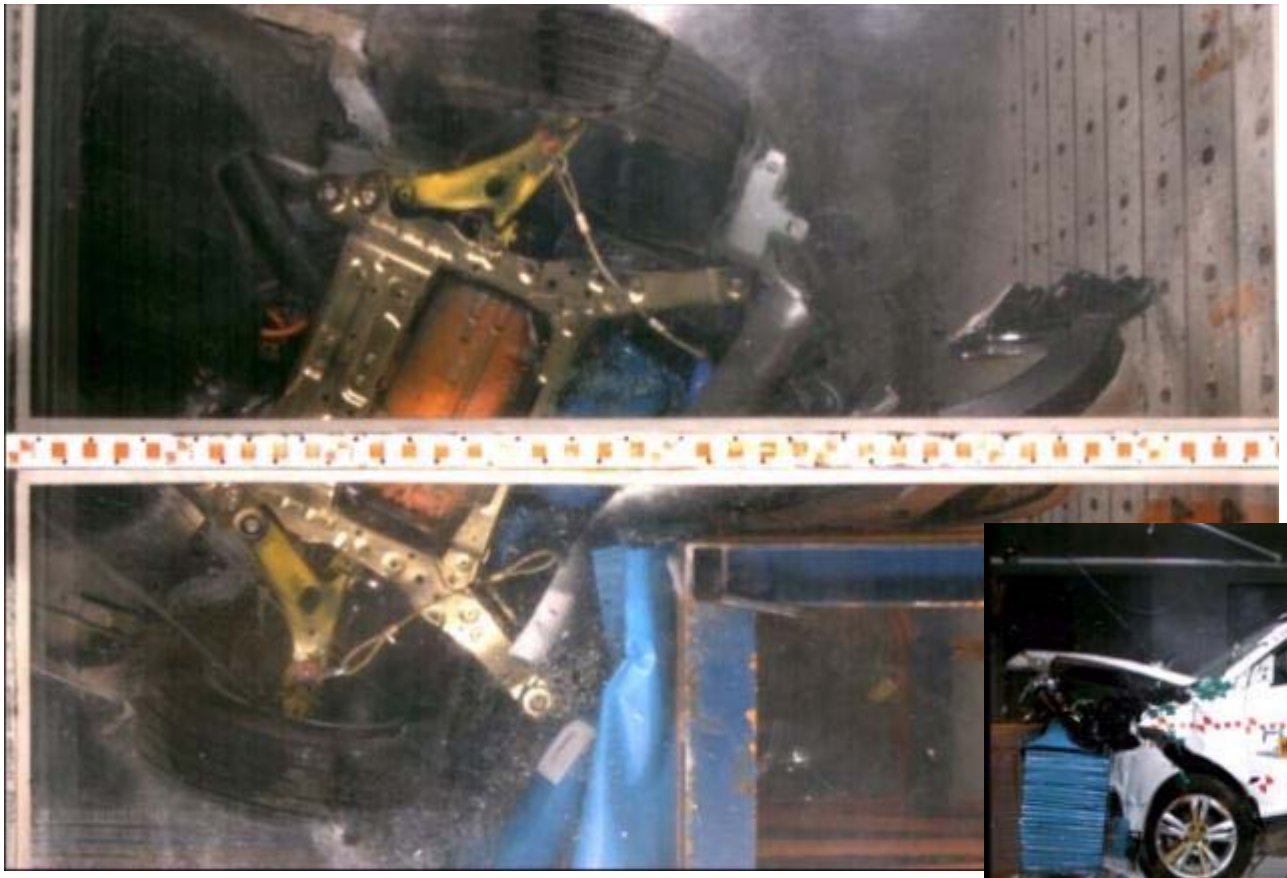
The Smart Entry with push button start begins and ends each drive with a simple touch.

http://automobiles.honda.com/Clarity?ef_id=1:1:1&CID=SEARCH_HONDA_Google_FY17_FCV_SHOPPERS

Compressed Hydrogen Tank Testing

- In accordance with latest proposed hydrogen vehicle tank standards (SAE J2579, ANSI HGV2, GTR 13)
- Tests conducted as part of the design qualification testing for new tanks
- Vent only, no rupture

Hyundai ix35 FCEV- FMVSS 305 and ECE R94- 25s Certification



Courtesy of Hyundai

Typical Station Configurations

- Hydrogen can be delivered or made on site
- Liquid delivered → gaseous H_2
- Gaseous delivered or piped → booster compressed gaseous H_2
- Natural gas → gaseous H_2
- Water + electricity → gaseous H_2

Identifying Stationary Facilities

NFPA 704 Hazard Placards

- Red = Flammability
- Blue = Health
- Yellow = Reactivity
- White = Special Precautions

Gaseous Hydrogen

Liquid Hydrogen

General Station Safety Systems

- Pressure relief systems
  - Burst disks
  - Pressure relief valves/devices (PRV/PRD)
  - Safety vents
- Fire and leak detection systems
  - Telemetric monitoring
  - Hydrogen gas detectors
  - UV/IR cameras
  - Fueling line leak check on nozzle connect

ASME steel and composite stationary storage tubes

General Station Safety Systems

- Design elements
  - Engineering safety margins and analysis (HAZOP, etc.)
  - Hydrogen compatible materials
  - Siting to established regulations
  - Cross-hatched areas for user attention
- Other systems
  - Emergency stops
  - Dispenser hose break-away devices
  - Impact sensors at dispenser
  - Controlled access
  - Excess flow control (fueling)
  - Pre-coolers (-40^{o}F)

Hydrogen Fueling

- Closed-loop design, no leaks or vapors- NFPA 2 integrity checks
- Experienced suppliers and providers: Linde, First Element, Equilon Enterprises LLC, Air Products, Air Liquide, Hydrogen Frontiers, Nel Hydrogen, HTEC**,** and others

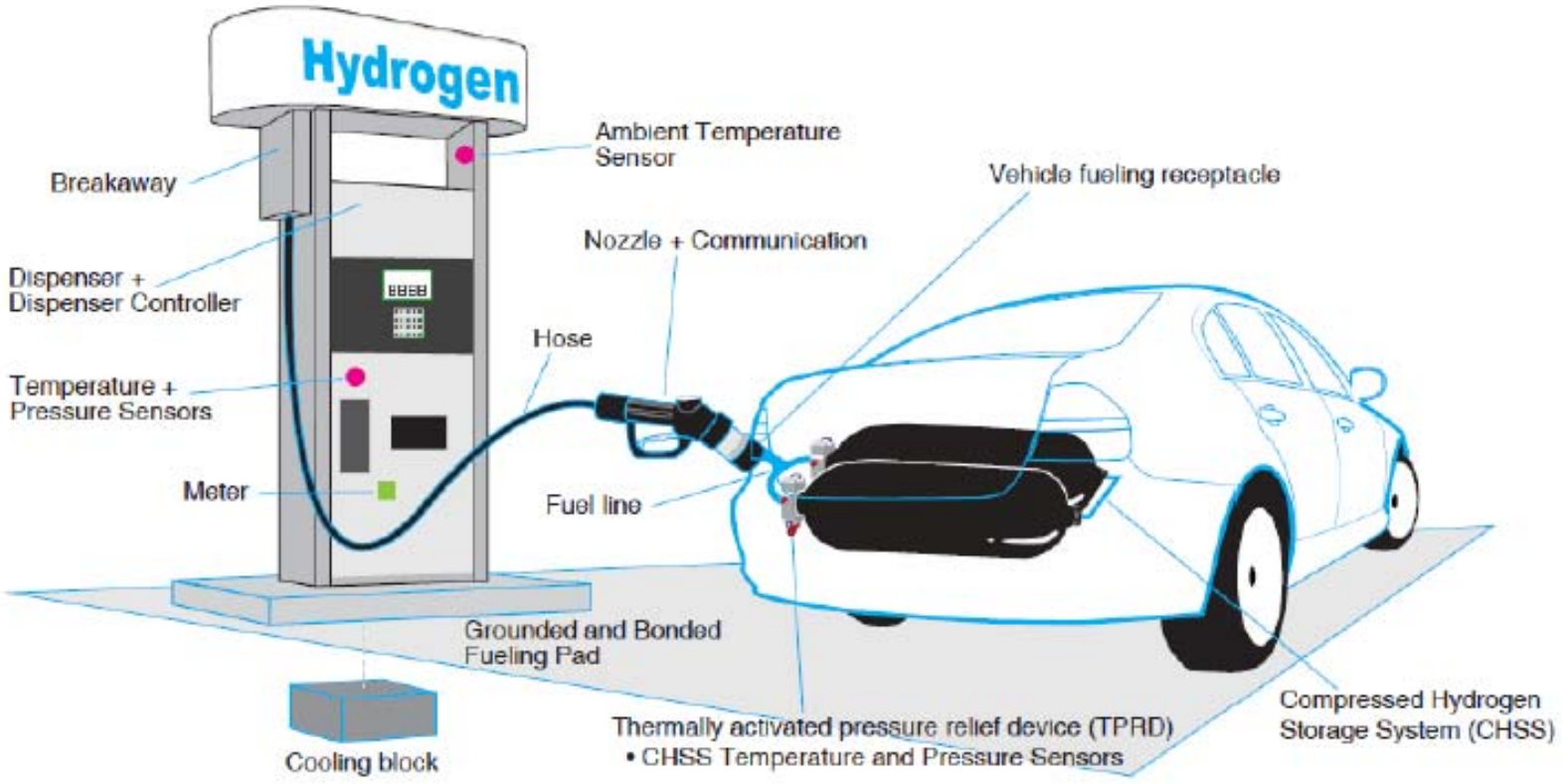
35 MPa Nozzle **(H35)**

Medium/Heavy Duty Fork lifts

70 MPa Nozzle **(H70)**

Light duty passenger vehicles

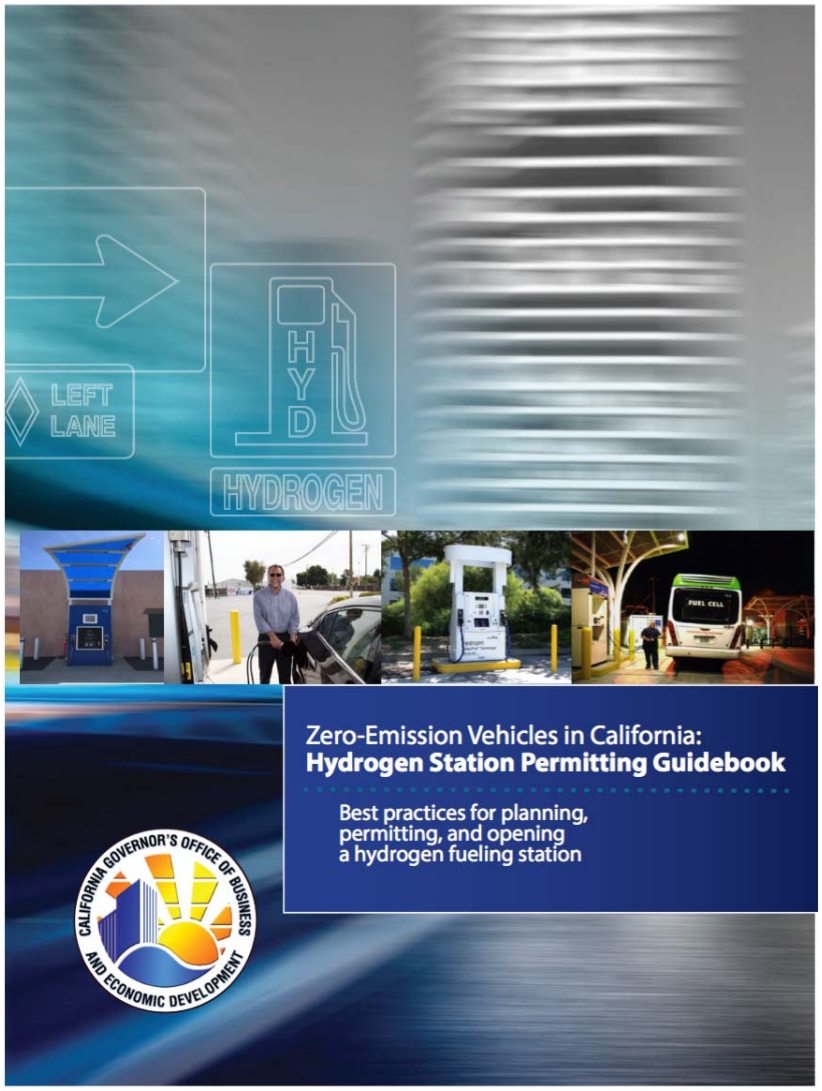
Hydrogen Fueling Diagram



Gia Vacin & Jennifer Hamilton

HYDROGEN PERMITTING, CODES & STANDARDS

H2 Station Permitting Guidebook Overview



http://business.ca.gov/ZEV (on the ZEV infrastructure tab)

- Importance of H2 for transportation in CA
- H2 properties and production
- FCEVs technology and benefits
- H2 station components and H2 sales in CA
- Permitting process
  - Pre-application outreach
  - Planning review
  - Building review
  - Construction
  - Commissioning

AHJ Pre-Application Checklist

- How will the station be supplied to hydrogen?
- How do you expect traffic to flow through the site?
- What codes and standards do you plan to design to?
- How do you plan to meet relevant set-back distances?
- What do you expect the station to look like?
- Have you engaged the local utility?

(Hydrogen Station Permitting Guidebook, Page 3)

Relevant Codes

- Two key codes for H2 station development
  - California Fire Code
  - NFPA 2 (as adopted by reference)

- More complete list of related codes and standards in Appendix A of the Permitting Guidebook

California Environmental Quality Act (CEQA)

- Applies to state and local agencies or private entities that require some discretionary approval
- Addition of hydrogen to existing gasoline stations does not trigger CEQA review
  - Ministerial, non-discretionary action
- Several jurisdictions have filed a categorical exemption or prepared a negative declaration
- CEQA Net lists the CEQA categorical exemptions filed by the California Energy Commission to encumber funds for hydrogen stations

Hydrogen Station Permitting Guidebook

Applicable CUPA program elements

1. Hazardous Materials Business Plan
   - California Health and Safety Code, Division 20, Chapter 6.95, §25500-25519
   - California Code of Regulations, Title 19, Division 2, Chapter 4

   - Applies to hydrogen stations
   - Hydrogen quantities > 200 scf or 55 gallons
     - Hydrogen NOT an EHS per Appendix A, 40CFR Part 355

- Must prepare compliant Business Plan
  - Hazmat inventory
  - Fire Code compliance
  - Consultation with AA
  - ER plans and procedures
  - Training and documentation

Applicable CUPA program elements

6. California Uniform Fire Code (2016, based on 2015 IFC)

- Title 24 CCR Part 9 (CUPA AA jurisdiction)
  - Hazardous Materials Management Plans (HMMP) and Hazardous Materials Inventory Statement (HMIS) Appendix H
- Key sections for fueling stations
  - **Section 2309** Hydrogen Motor Fuel-dispensing And Generation Facilities
  - **Section 2311.7** Repair garages for vehicles fueled by lighter-than air fuels.
  - **Section 50** Hazardous Materials- outdoor MAQ for flammable gas 3000 @ NTP
  - **Section 5303** Compressed Gases, general requirements
  - **Section 55** Cryogenic Fluids
  - **Section 5801.1 Flammable Gases and Flammable Cryogenic Fluids** Scope. The storage and use of flammable gases and flammable cryogenic fluids shall be in accordance with this chapter and **NFPA 55**.
  - **Section 5806.3** Above-ground tanks for liquid hydrogen. Aboveground tanks for the storage of liquid hydrogen shall be in accordance with Sections 5806.3 through 5806.3.2.1.

Non-applicable CUPA program elements

2. CA Accidental Release Program (CalARP)

- Health & Safety Code §25531 et.sec. (19CCR2735-2785)
- Requirements apply to stationary sources with more than one *covered process.*
  - *Covered process is an activity involving a regulated substance present in more than a threshold quantity.*
- Hydrogen station applicability to CalARP
  - Is H2 a regulated substance? Yes
  - What is the threshold quantity? 10,000 pounds
  - How much hydrogen is stored at one time at today's stations? 60 to 2,400 kg (130 to 5,300 pounds)
- CalARP does not apply to:
  - hydrogen stations if the maximum quantity is below 10,000 pounds
  - "*Flammable substances used as fuel or held for sale as a fuel at* a retail facility." 19CCR 2770.4.1

Non-applicable CUPA program elements

3. Underground Storage Tanks
   - Applies to underground storage of liquid and solid hazardous substances
     - All hydrogen stations store gaseous hydrogen above ground
     - All below grade piping conveys gaseous hydrogen
     - Some stations store liquid hydrogen
4. Above Ground Petroleum Storage Act
   - Only applies to petroleum storage
5. Hazardous Waste Treatment, Storage & Disposal
   - No hazardous waste generation associated with hydrogen station operation and maintenance

Jennifer Hamilton

RESOURCES

Hydrogen Tools Portal

A Transformative Step Towards Hydrogen Adoption

CENTRALIZED LOCATION organizes current H_2 resources in one robust location—including many proven tools, with plans for adding future content

FOCUSED CONTENT tailored to the specialized needs of H_2 user groups

RESPONSIVE DESIGN enables H_2 safety work across both desktop and mobile devices

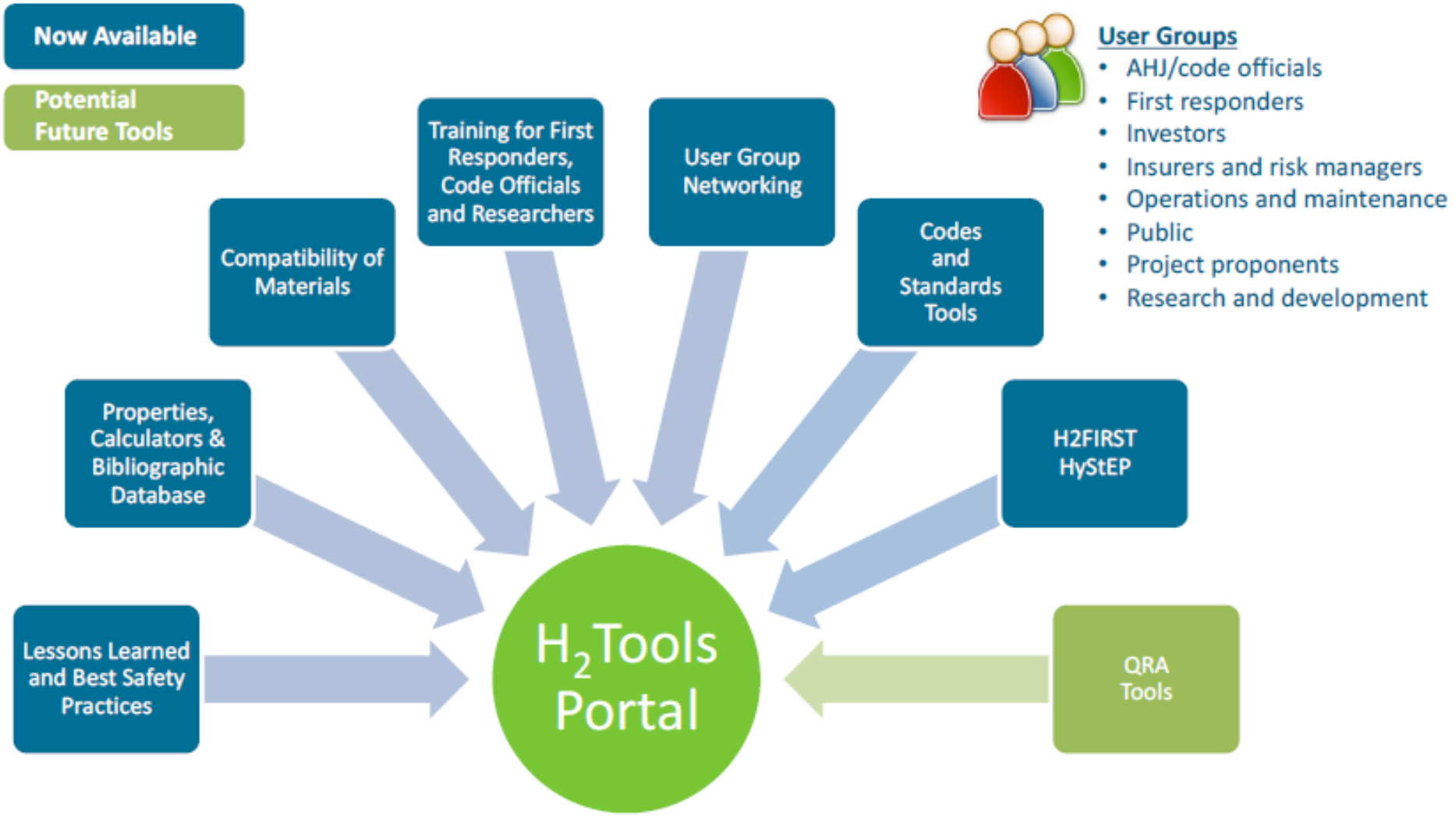
TRUSTED COMMUNITIES fostered through social networking around H_2 subject matter expertise

EXPANDABLE FORMAT built with frequently requested future feature sets in mind

http://h2tools.org

› **Credible** and **reliable** safety information from a **trustworthy** source

H2Tools.org – Consolidating Safety Information



Hydrogen Equipment Certification Guide

A *Hydrogen Equipment Certification Guide* has been released to assist code officials, designers, owners, evaluators and others with the application of the listing and approval requirements pertinent to the design and/or installation of hydrogen equipment as regulated by the model codes.

Gaps Addressed

- In the early market, the availability of systems or equipment that are listed, labeled or certified is limited
- When equipment is not listed or available, "approval" by the code official is required before installation occurs

Benefits Provided

- Enables code users to better apply the requirements where the use of *listed, labeled, certified* or *approved* equipment or methods is required, and to increase awareness and understanding of what the equipment is expected to do
- Increased consistency in the application of requirements with the expectation of an expedited permitting process
- Consistent application of requirements among providers, regardless of hydrogen experience results in a level playing field as the technology emerges

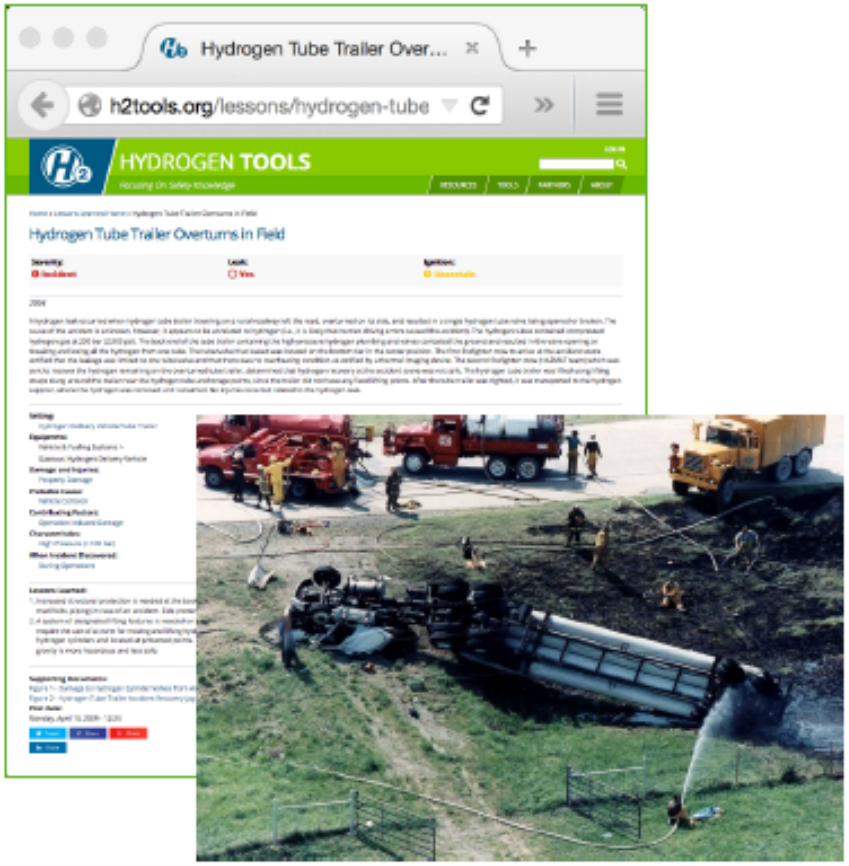
The *Guide* is available at https://h2tools.org/system/files/Hydrogen%20Equipment%20Certification%20Guide_Jan2017.pdf.

H2tools.org/lessons
…capturing the event, focusing on lessons learned

Each safety event record contains

- Description
- Severity (Was hydrogen released? Was there ignition?)
- Setting
- Equipment
- Characteristics (High pressure? Low temperature?)
- Damage and Injuries
- Probable Cause(s)
- Contributing Factors
- Lessons Learned/Suggestions for Avoidance/Mitigation Steps Taken

http://h2tools.org/lessons



Tube Trailer Rollover

Hydrogen Risk Assessment Model

HYDROGEN TOOLS
Focusing on Safety Knowledge

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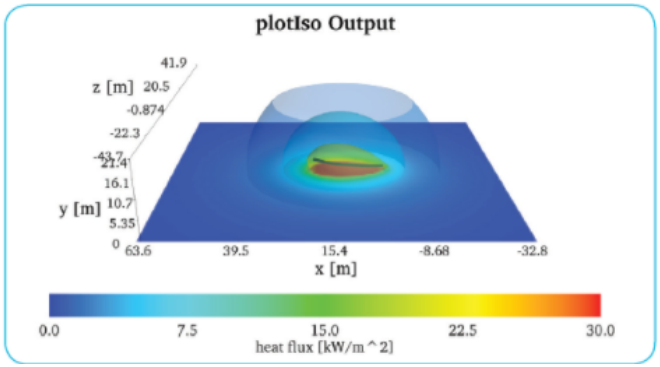
Hydrogen Risk Assessment Model (HyRAM)

H2FC Hydrogen and Fuel Cells Program

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

Developing hydrogen codes and standards is challenging because the relevant models and information span multiple science and engineering disciplines. The HyRAM toolkit integrates state-of-the-art models and data for assessing hydrogen safety. HyRAM provides a common platform for stakeholders conducting quantitative risk assessment and consequence analysis for hydrogen systems. The resulting information provides the scientific basis to ensure code requirements are consistent, logical, and defensible.

HyRAM 1.0 Technical reference manual. Katrina M. Groth, Ethan S. Hecht & John T. Reynolds. Methodology for assessing the safety of Hydrogen Systems: HyRAM 1.0 technical reference manual. SAND2015-10216, Sandia National Laboratories, Albuquerque, NM, November 2015. SAND2015-10216-HyRAM-1.0-Technical-Reference-Manual.pdf



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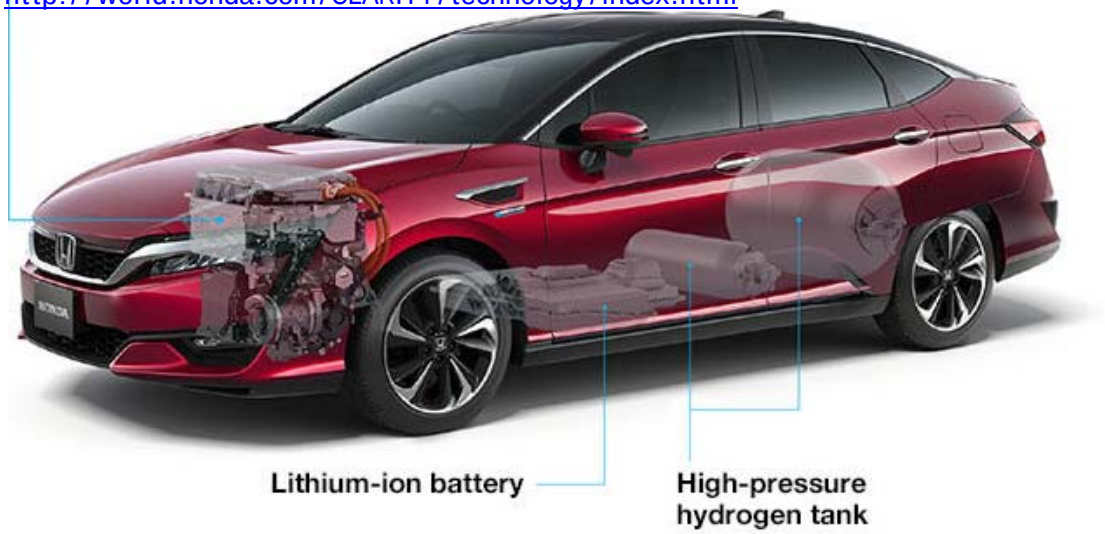
Backup slides

Hydrogen Delivery System

http://world.honda.com/CLARITY/technology/index.html



- Distribution lines contain lower pressures than storage cylinders

- Tank PRDs/TRDs vent directly or are connected to fuel vent line(s)

Mirai cutaway showing H2 storage tanks, courtesy Toyota

Hydrogen Delivery System – Bus

- Bus fuel tanks on roof
- All equipped with PRDs and vent lines
- Larger capacity storage

Hydrogen Sensors Example

* Positions in the illustration are for explanatory purposes only. They do not represent actual system positions.

Image: http://www.nissha.com/english/news/2014/12/12th_1.html

Compressed Hydrogen Tank Testing

High Strain Rate Impact Test

Projectile test of 35 MPa hydrogen tank:

- Objective: penetrate tank while pressurized
- Tank filled with hydrogen to 5,000 psi
- 30 caliber armor piercing bullet, 45° angle
- Simulate a high-strain rate penetration event due to collision

Compressed Hydrogen Tank Testing

Bonfire Test

Bonfire test of 70 MPa hydrogen tank:

- Objective to simulate vehicle fire; entire tank engulfed
  - Test begins with a flame impingement
- Tank filled with hydrogen to 10,000 psi
- Subjected to a propane burner fire, 1.65m long
- PRD activated and hydrogen vented to atmosphere without incident