CENTER FOR Hydrogen SAFETY

Hydrogen for Mobility and Power:

Market, Application, and Safety

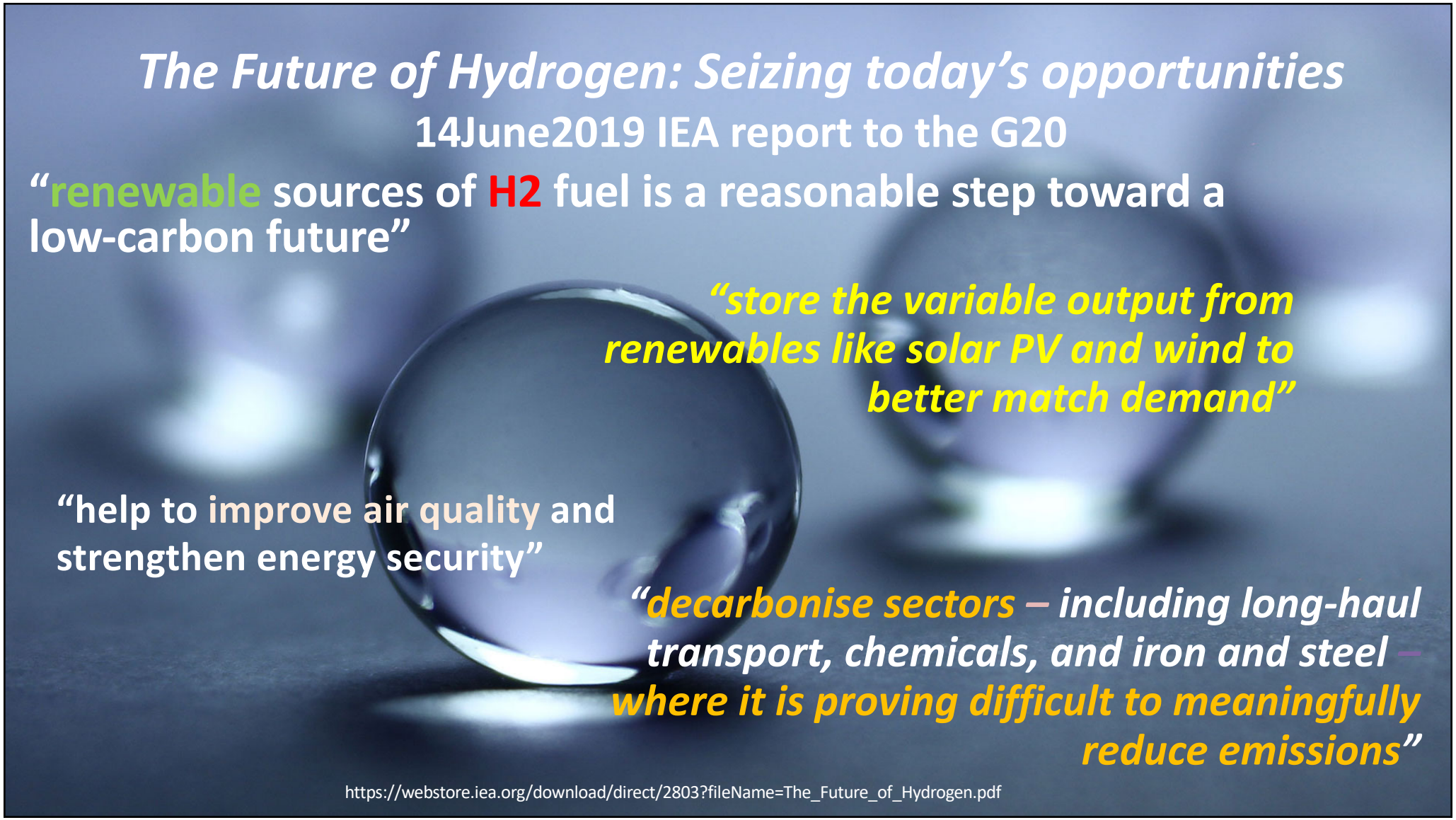
Introducing the

Center for Hydrogen Safety

Nick Barilo
Director, Center for Hydrogen Safety

Larry Moulthrop
Member, Hydrogen Safety Panel

June 2019


The Future of Hydrogen: Seizing today's opportunities
14June2019 IEA report to the G20
"renewable sources of H2 fuel is a reasonable step toward a low-carbon future"
"store the variable output from renewables like solar PV and wind to better match demand"
"help to improve air quality and strengthen energy security"
"decarbonise sectors – including long-haul transport, chemicals, and iron and steel – where it is proving difficult to meaningfully reduce emissions"
https://webstore.iea.org/download/direct/2803?fileName=The_Future_of_Hydrogen.pdf

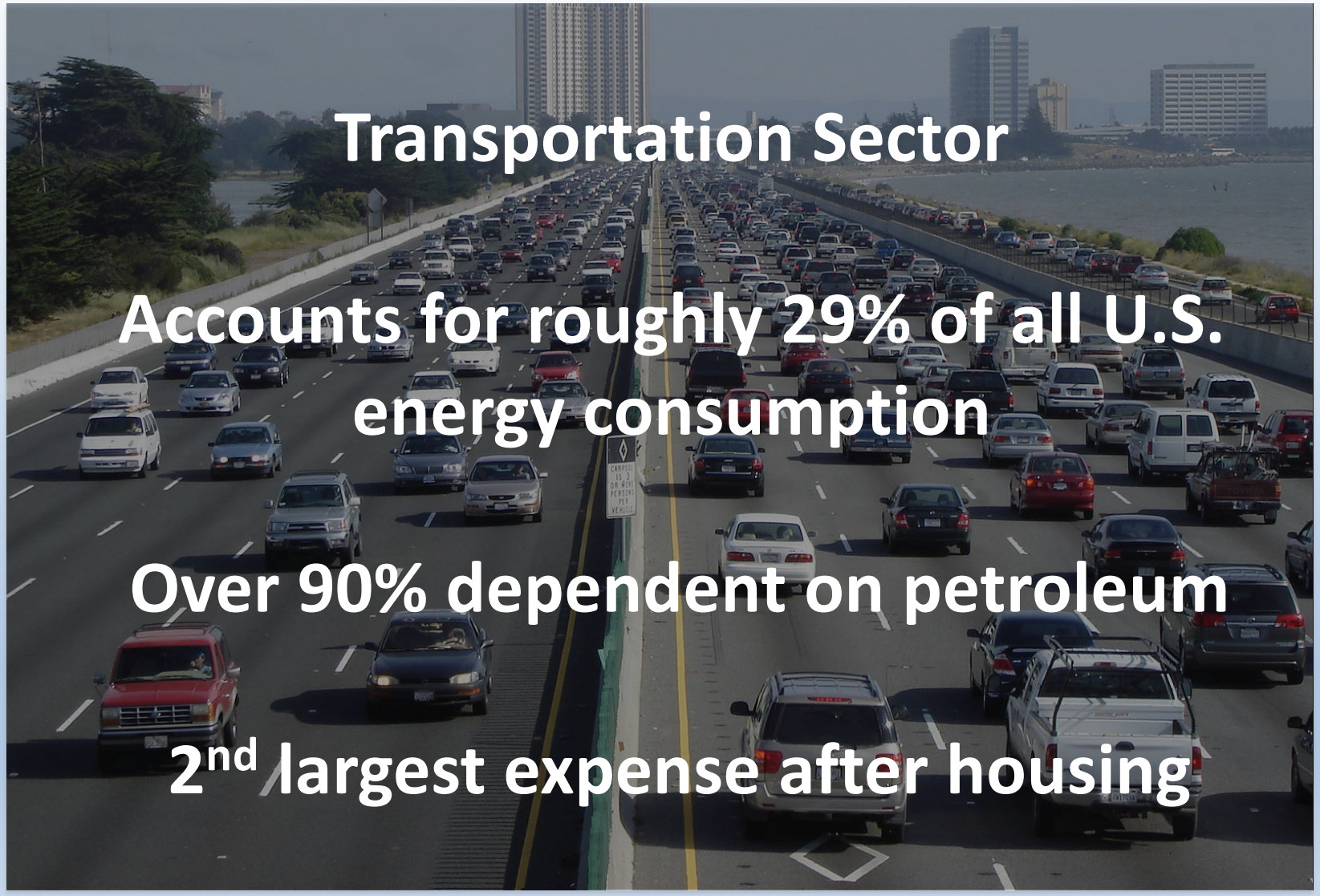
Energy Consumption by Sector

Industry ~ 32%

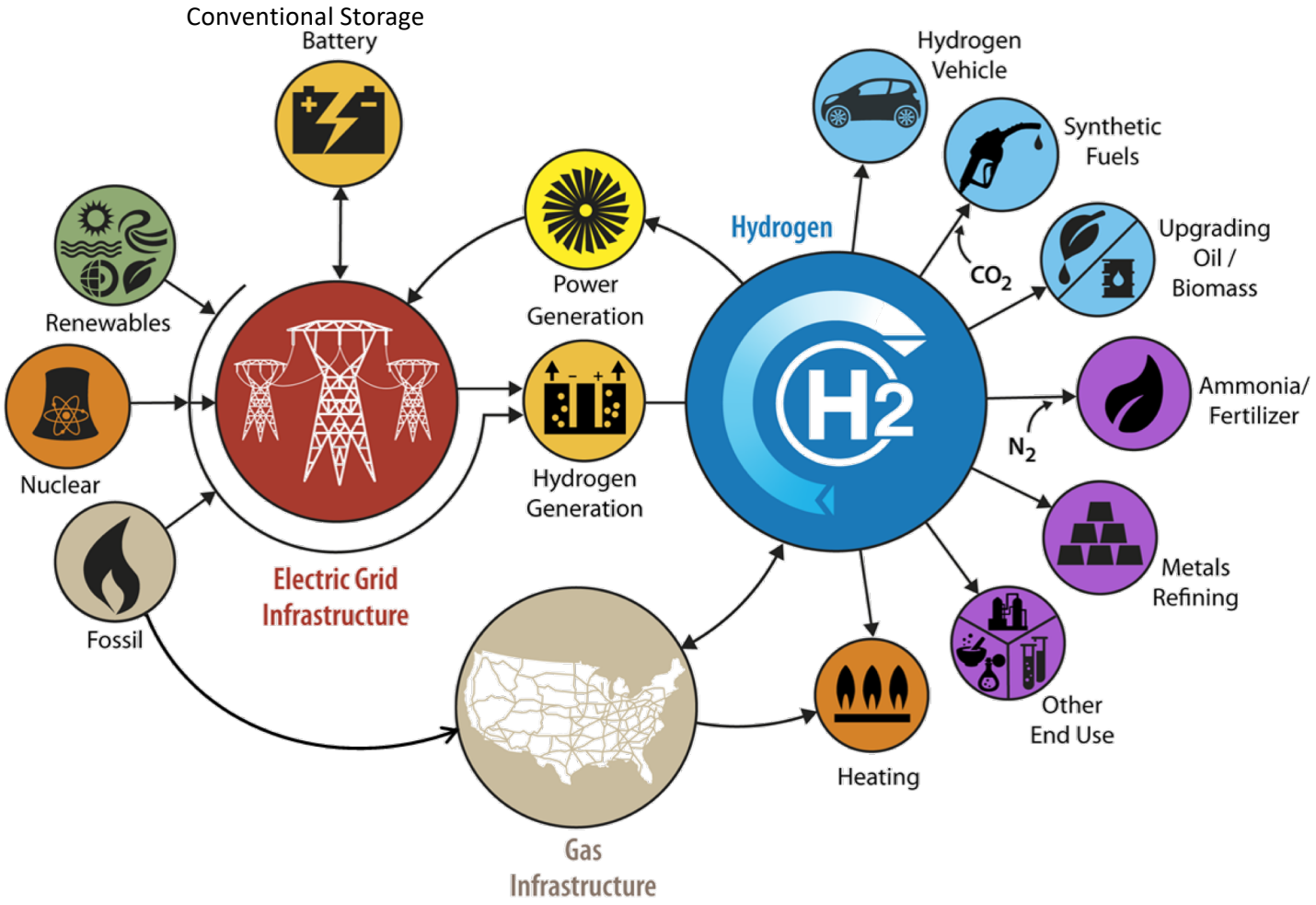
Residential ~ 20%

&

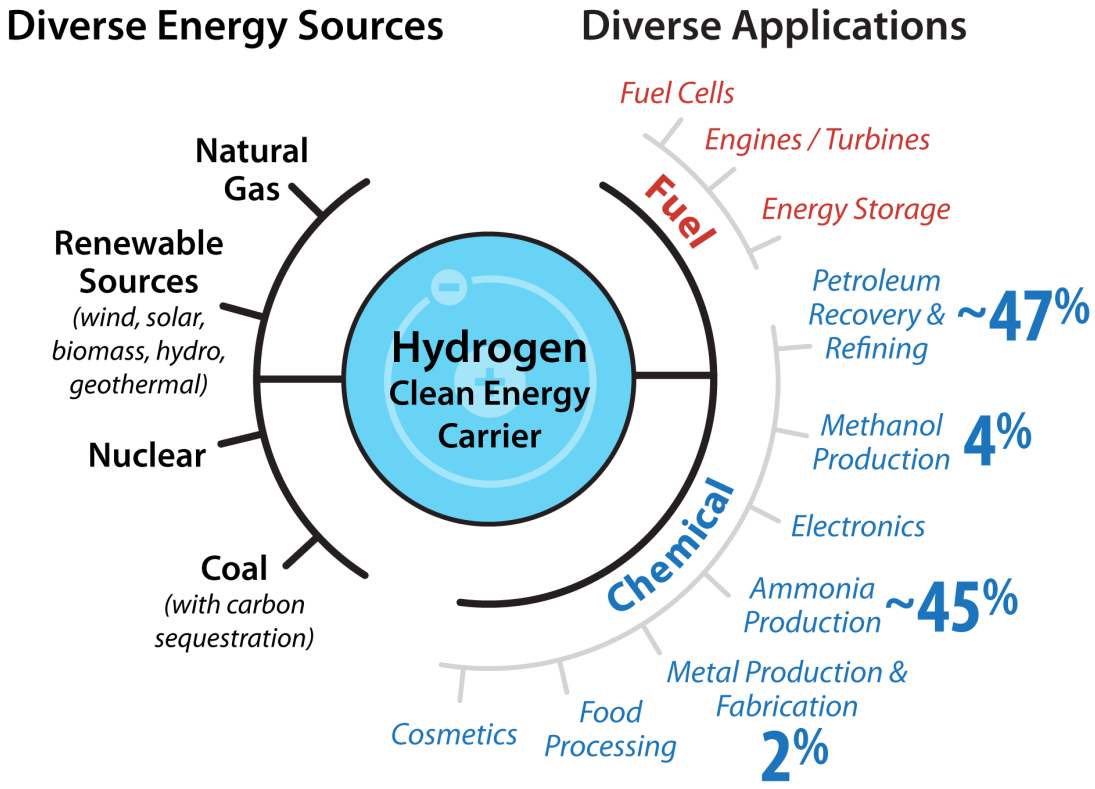
Commercial Buildings ~19%


Transportation Sector
Accounts for roughly 29% of all U.S. energy consumption
Over 90% dependent on petroleum
2nd largest expense after housing

The Goal… H_2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



Hydrogen – A Clean, Flexible Energy Carrier



*H_2 services all energy sectors AND improves **Energy Security** and **Domestic Economy***

*Industry has used H_2 **safely** for **over a century**!*

Source: DOE, NREL, Hydrogen and Fuel Cell Program

Why Hydrogen as mobility Fuel?

- Most abundant element in the universe
- Excellent energy carrier
- Ultra-low/Zero emissions
- Economically competitive
- Safe and secure
  - *More than 100 years of industrial use*
  - *Can be used as safely as gasoline*
  - *Domestically produced from a variety of sources*

H2 fuel dispenser
(Photo :California Fuel Cell Partnership)

Fuel Cells in Use, U.S.

Material handling equipment

>25,000 operating/ordered in 26 US states

Fuel cell (FC) technology proves more efficient, lower operating cost and less warehouse space vs. batteries

Stationary power

>240 MW total installed, 43 states

High-temp FCs reform natural gas/biogas to H_2 internally, providing combined heat and power, critical reliability

Backup critical power

41 US states, >8500 installations

Telecommunications towers, railroad switching and signal stations, government facilities, and utility networks use FC for critical backup

(Plug Power)

(Bloom Energy/Walmart)

(Plug Power)

- State of the States: Fuel Cells in America 2016, 7th Edition (https://tinyurl.com/mrj8spu)
- The Business Case for Fuel Cells: Delivering Sustainable Value (http://www.fchea.org/s/2016-Business-Case-dwcy.pdf)
- http://www.cleanegroup.org/wp-content/uploads/Fuel-Cells-for-Resilient-Power-Case-Studies-2015.pdf
- Market Transformation (Devlin) , 2017 DoE EERE FCTO AMR

Fuel Cells for Resiliency - Seamless Load Transfer & Backup Power

October 2012 Hurricane Sandy

- All 23 fuel cells in the impacted areas remained operational during the storm

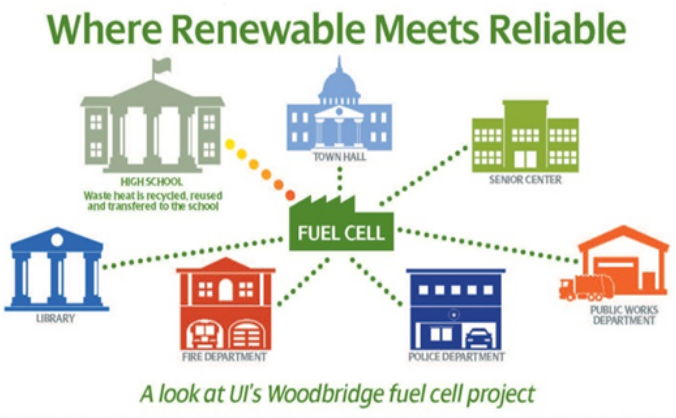
CT October 2011 Winter Storm Alfred

- South Windsor, CT High School serves as community shelter
- Whole Foods Market avoids costly food spoilage
- CT Juvenile Training Facility operates continuously

San Diego, CA September 2011 Blackout

- Albertsons Supermarket remains open for business
- Perishable inventory protected

Fuel Cells in Utility Microgrids



Town of Woodbridge, Connecticut

- Fuel cell microgrid supplies grid and maintains power during outages for 6 critical town buildings
- 2.2 MW system provides heat to a local high school
- FCE fuel cell operating since January 2017

New Jersey	Category	Commercial Deployments	Government Deployments	Initiatives/ Incentives/Funding
	Fuel Cell Vehicles			
	Hydrogen Stations			
	Fuel Cell Buses			
	Material Handling Equipment	✓		
	Other Fuel Cell Vehicles			
	Large Stationary Fuel Cells	✓		✓
	Small Stationary Fuel Cells	✓	✓	

H2 FCEV fueling stations:

Lodi, Whippany NJ stations part of northeast states FCEV hydrogen fueling corridor

H2 Fuel Cell material handling forklifts:

- 180+ Wakefern Food/Newark Farmers Market warehouse
- 25+ FreezPak Logistics/Cataret cold storage

Multiple stationary fuel cell installations for primary and resilient power, including:

- AT&T -- 2 MW in Middletown, 600 kW in Freehold, and 700kW in Trenton
- Verizon -- 2 MW at Basking Ridge headquarters
- Walmart -- Mays Landing, Washington Township, Williamstown, Woodbury retail stores
- FAA Teterboro Remote Transmitter Receiver

CENTER FOR Hydrogen SAFETY

Source: DOE FCTO 2017 State of the States (*numbers may be higher today*)

Maryland	Category	Commercial Deployments	Government Deployments	Initiatives/ Incentives/Funding
	Fuel Cell Vehicles			
	Hydrogen Stations			
	Fuel Cell Buses			
	Material Handling Equipment	✓	✓	
	Other Fuel Cell Vehicles			
	Large Stationary Fuel Cells		✓	
	Small Stationary Fuel Cells		✓	

- **60+ FCV forklifts at a Whole Foods / Landover**
- **80+ FCV forklifts at U.S. Postal Service National Distribution Center in Capitol Heights**
- **1.6 MW MC fuel cell supplies power to Fort Meade / National Security Agency (NSA)**

Source: DOE FCTO 2017 State of the States (*numbers may be higher today*)

Real World Applications – In the U.S.

Photo Credit: UPS

Fuel cell delivery and parcel trucks starting deliveries in CA and NY

Photo Credit: FedEx

First fuel cell tow truck fleet at airport in Memphis

World's first fuel cell for maritime ports in Hawaii

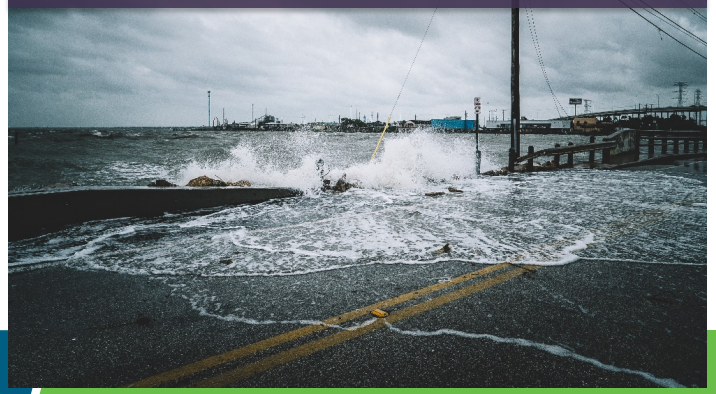
Photo Credit: Sandia National Laboratories

Real World Applications – In the U.S.

Industry demonstrates heavy duty fuel cell trucks

Fuel cell buses in California surpass 19M passengers

Fuel cells provided backup power during Hurricane Sandy in the U.S. Northeast



Fuel cells used to power new World Trade Center in NYC

Real World Applications – Abroad

World's first 4-seater fuel cell plane takes off at German Airport

Photo Credit: Christoph Schmidt/dpa via AP and phys.org.

Fuel cell cab fleet launched in Paris, France

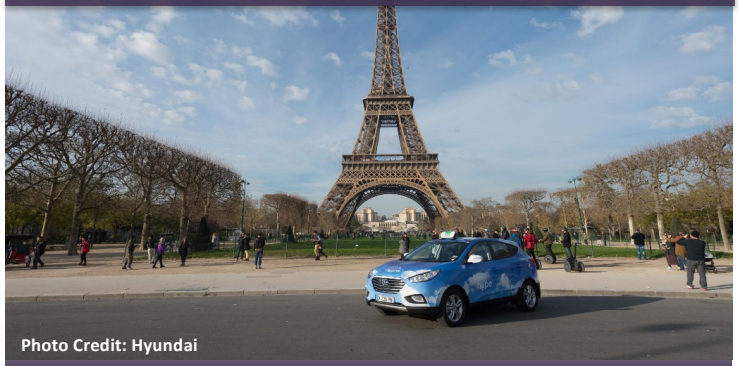


Photo Credit: Hyundai

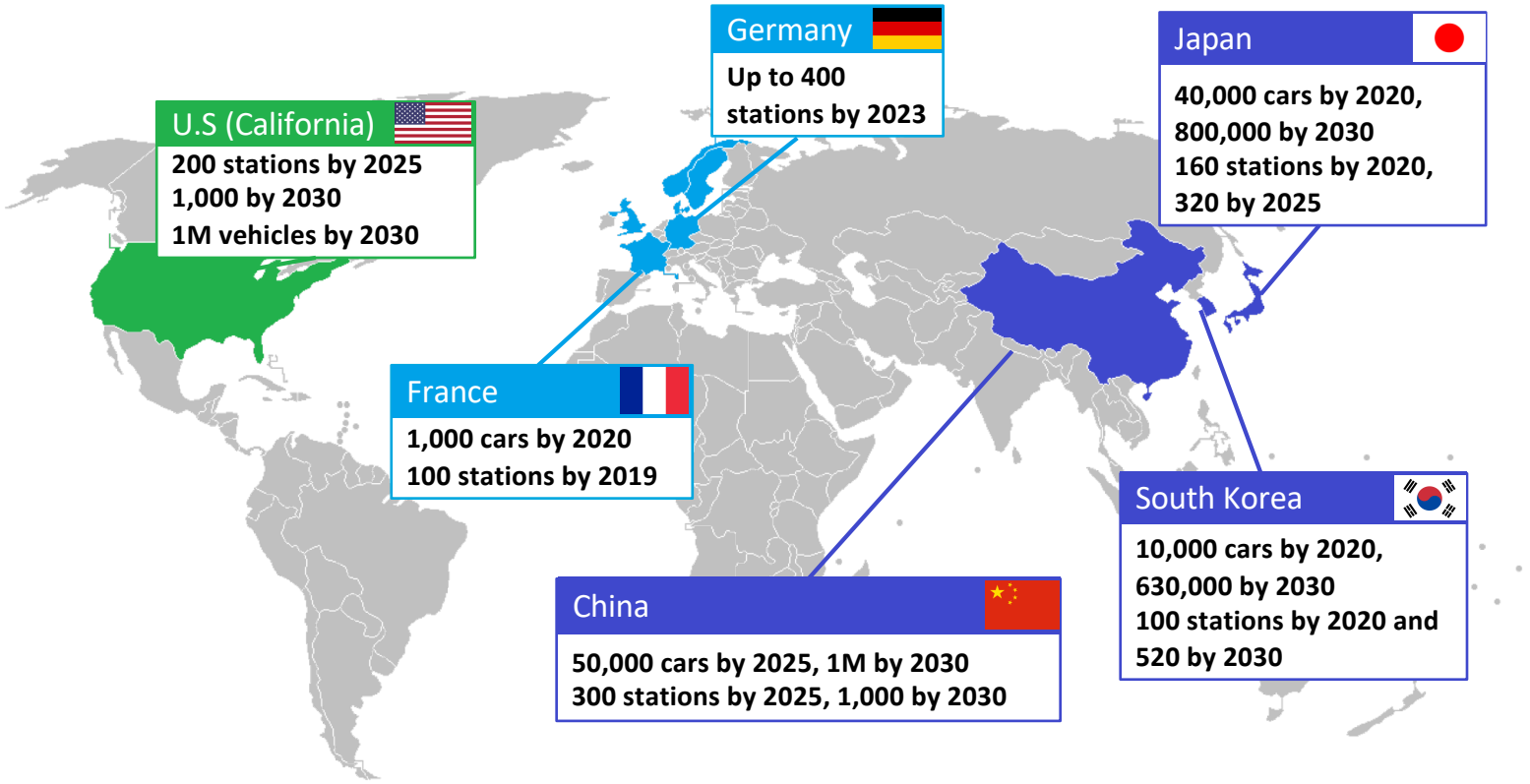
A town in Fukuoka, Japan running on hydrogen

Photo Credit: Fukuoka Pref.

World's first hydrogen fuel cell train in Germany

Photo Credit: Hydrogenics and Alstom

Increased International FCEV Activity

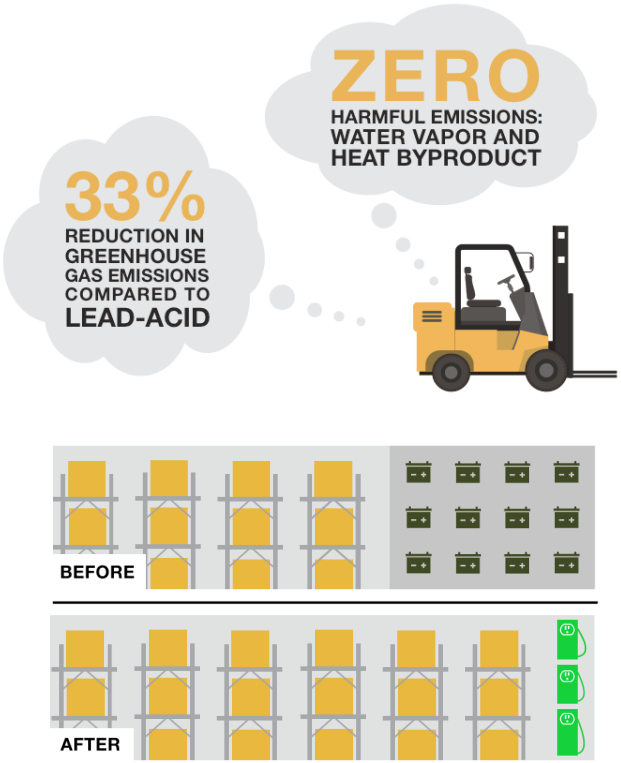


Source: DOE Fuel Cell Technologies Office, August 2018

Material Handling – H_2 FCV Success Story

> 25,000 operating/ordered HFC fork trucks in 26 US states/19M fuelings

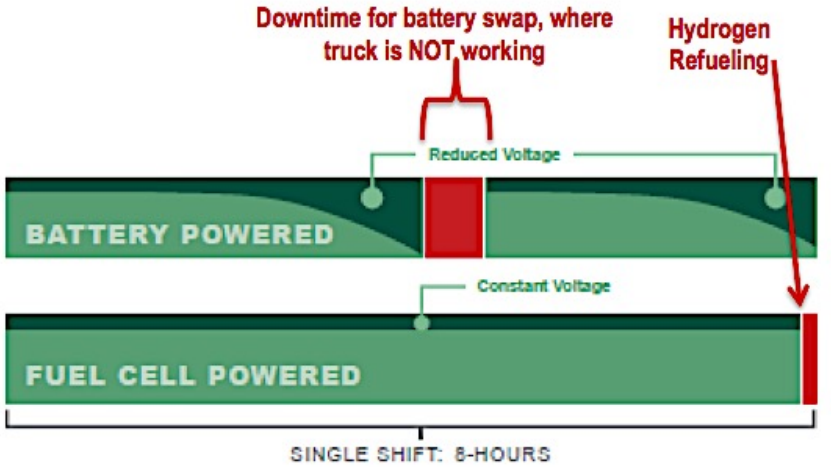
- **Amazon** buying 23% of FC maker Plug Power and adding *PEM* fuel cell forklifts into many distribution operations
- **USPS** using 80 FC in Capital Heights, Maryland material handling fleet
- In planning or use by *Ace Hardware, Coca-Cola, FedEx, Home Depot, Newark Farmer's Market, Kroger, Lowe's, Proctor & Gamble, Sysco, Walmart, Wegmans, Honda, Volkswagen*, *BMW,* and more
- **Space saving** H_2 infrastructure takes much less space than a battery room, recouping valuable warehouse storage space



FC Powered Industrial Trucks Can Do More Work

	Lead-acid battery	H_2 fuel cell pack
Recharge	~20 min swap to charge room	<5 min H_2 fueling by operator
Work	voltage decay => power loss	Constant FC voltage = max. power

FC retrofit truck at inside H_2 fueling station



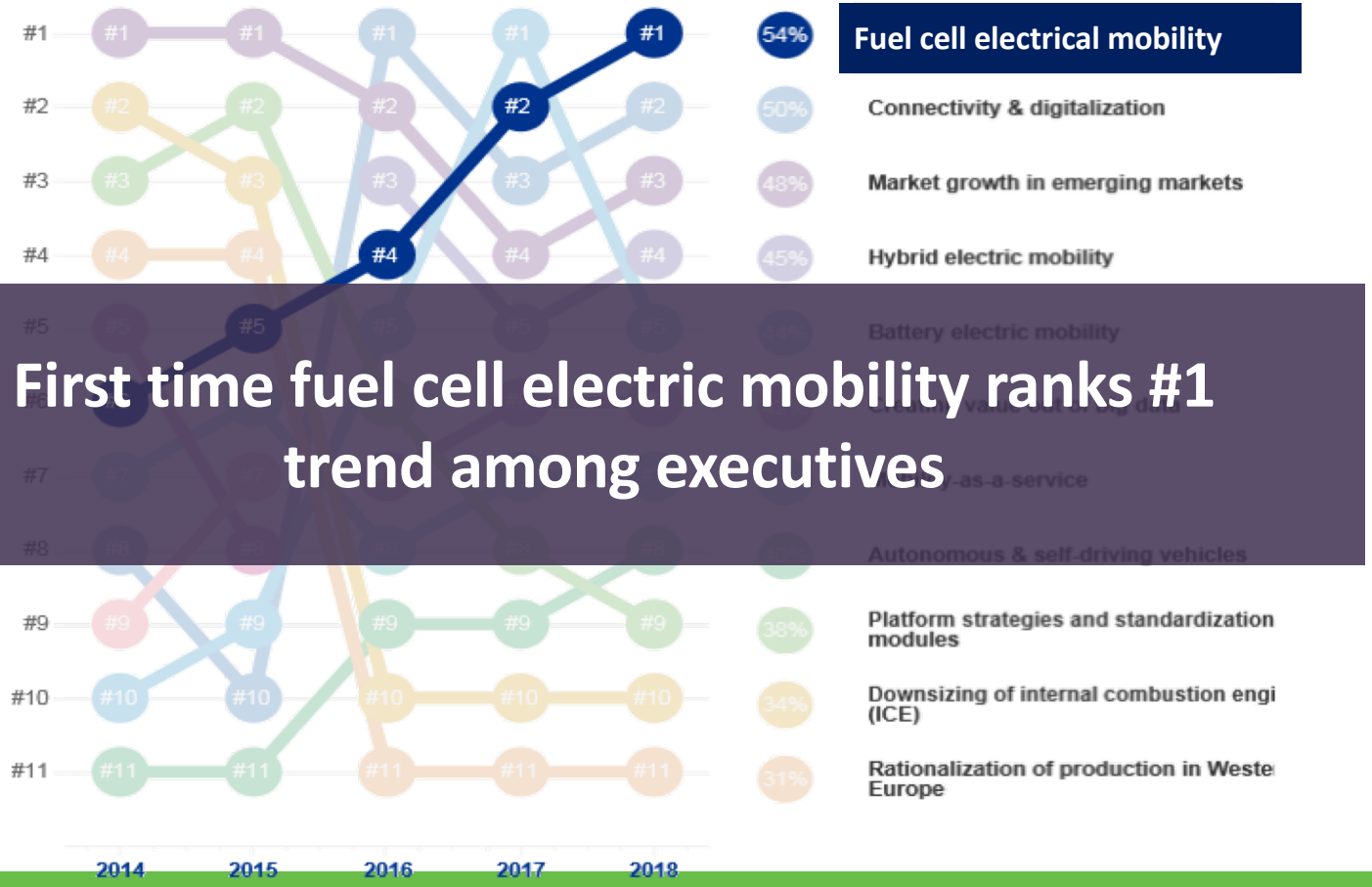
BMW regained > 156 hours of lost productivity over three-shift operation, saving > $65 million annually

(Courtesy of Air Products and Chemicals, Inc.)

Why Fuel Cell Vehicles (FCV)?

Video Source: Toyota
https://h2tools.org/sites/default/files/barilo/Intro_GameChanger.mp4

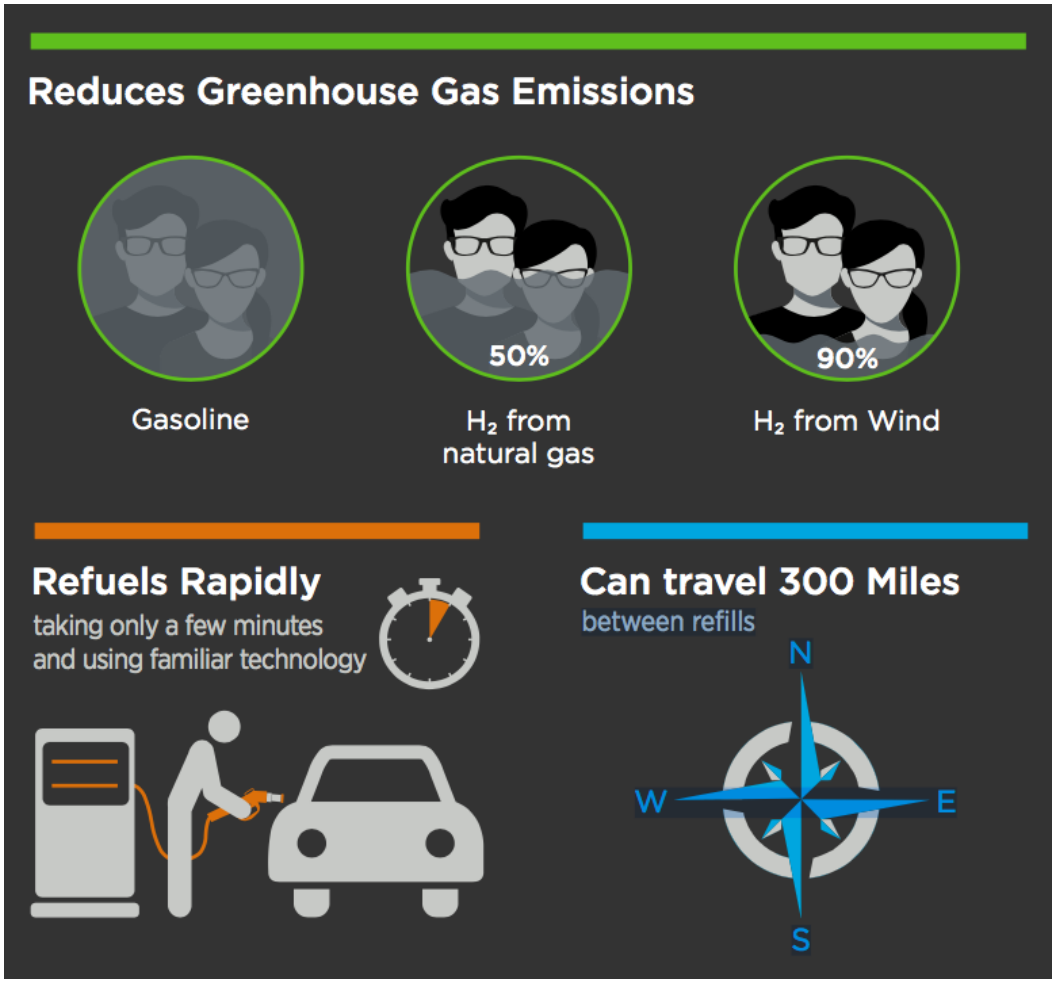
Automotive Executives Survey Results



First time fuel cell electric mobility ranks #1 trend among executives

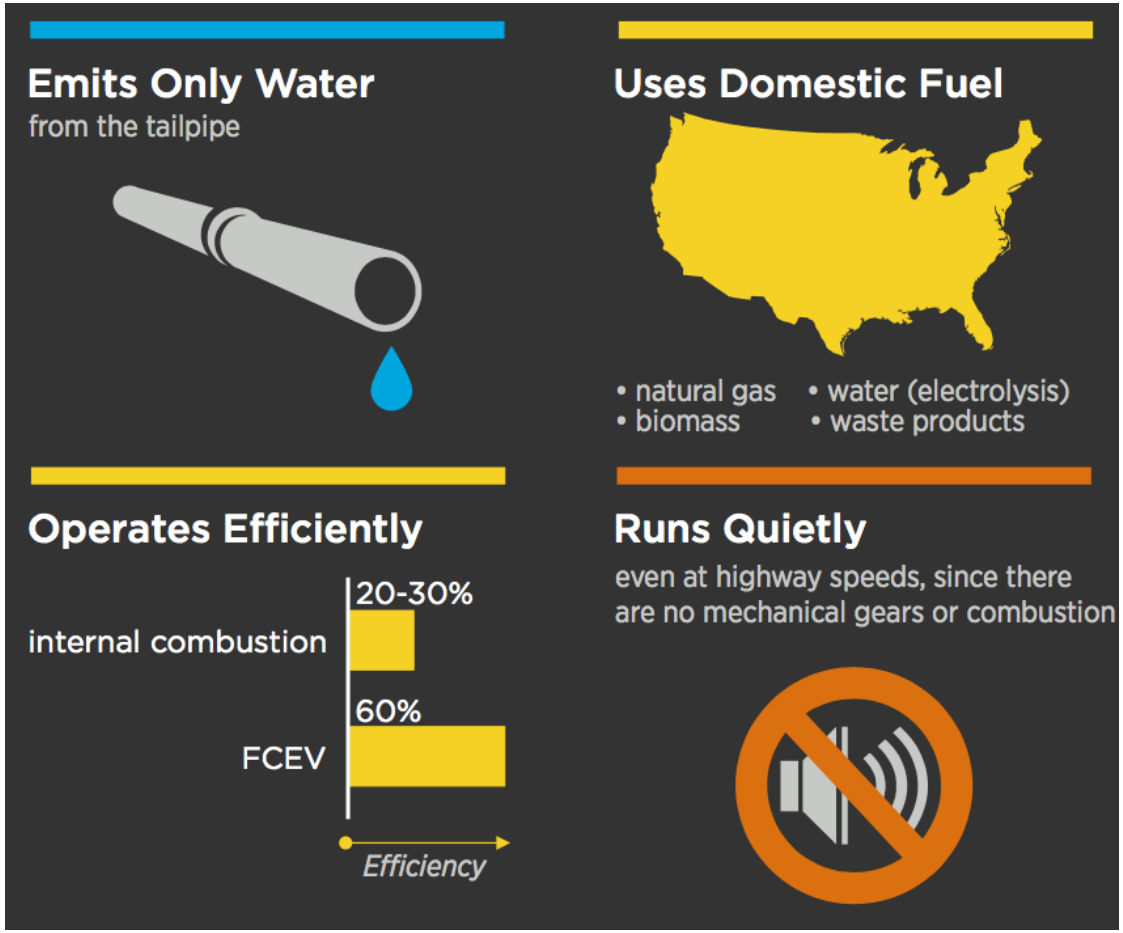
Source: KPMG Global Automotive Executive Survey 2018

Benefits of the FCEV



Source: US Department of Energy, Fuel Cell Technologies Office

Benefits of the FCEV



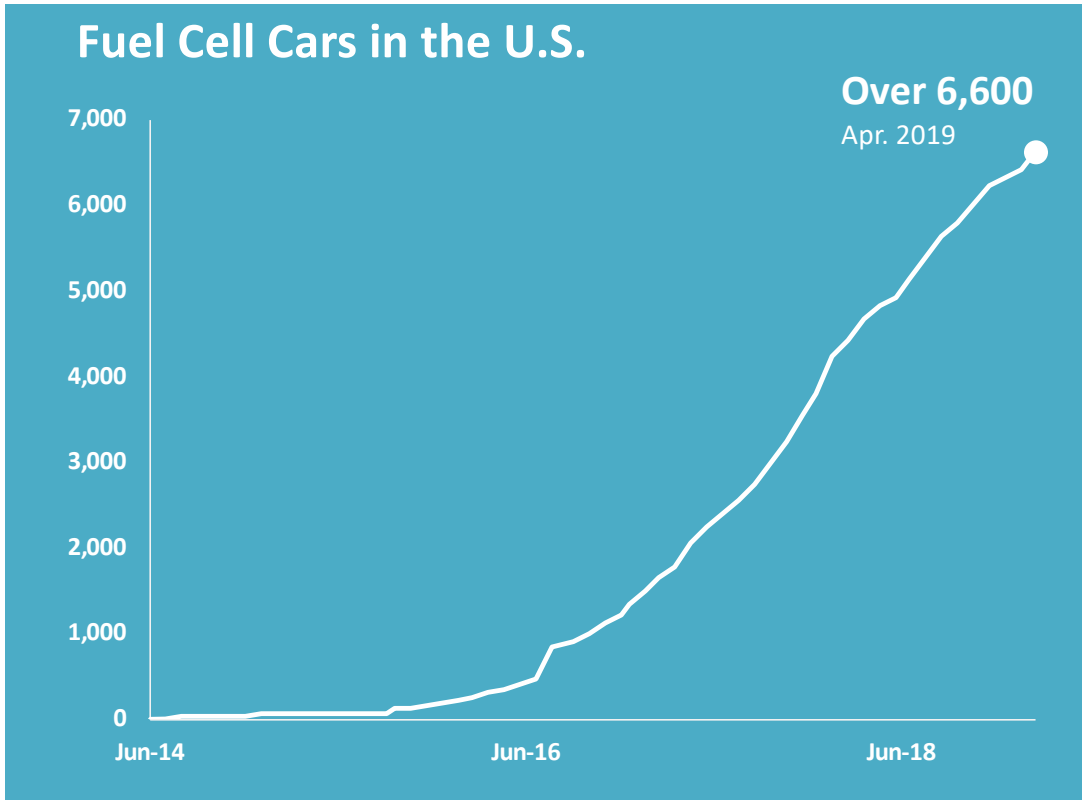
Source: US Department of Energy, Fuel Cell Technologies Office

Benefits of the FCEV

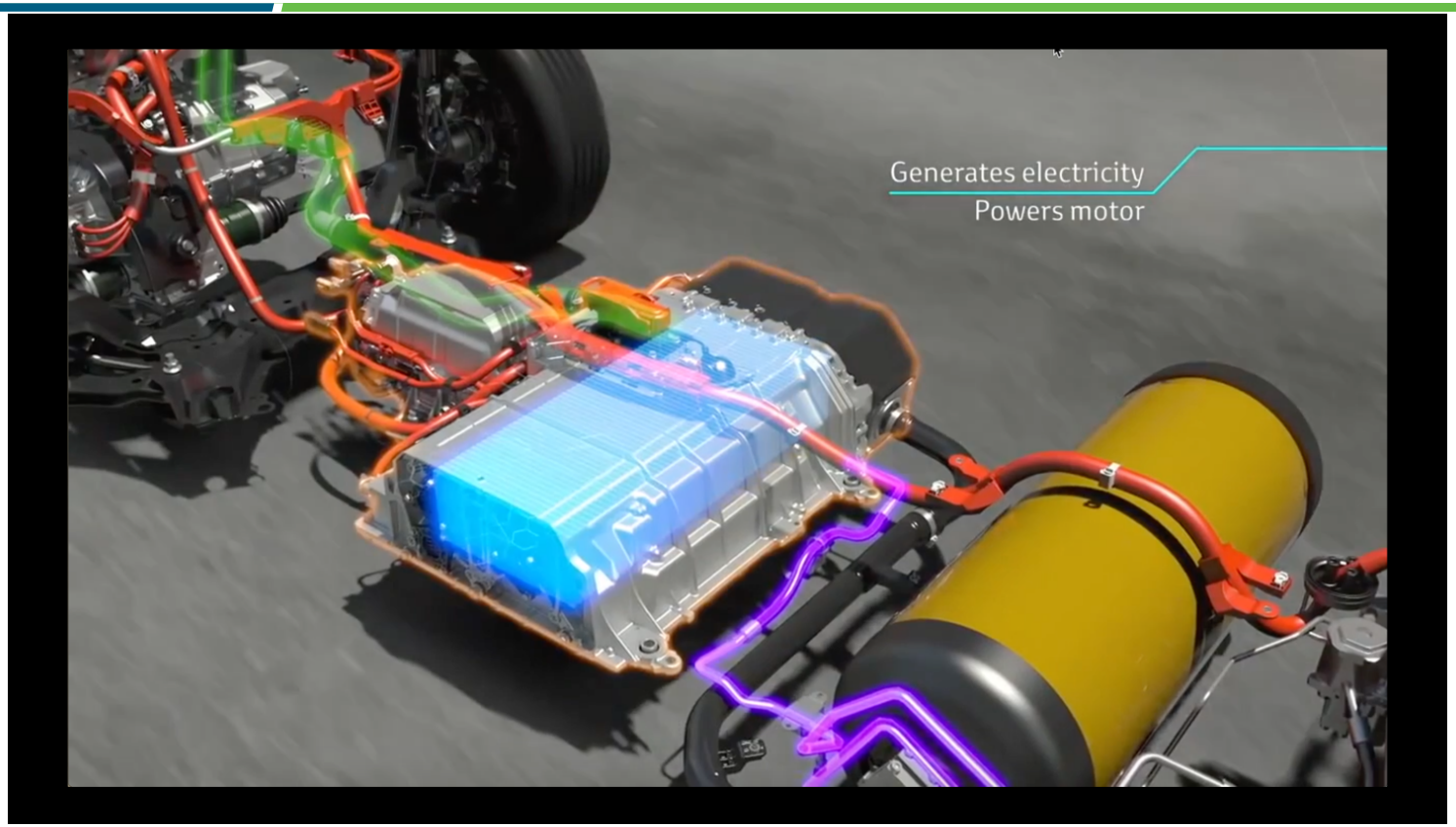
Scales Up Easily

as fuel cells can be added to the stack to increase power

Fuel Cell Passenger Vehicles Status



How a Fuel Cell Works in an FCEV

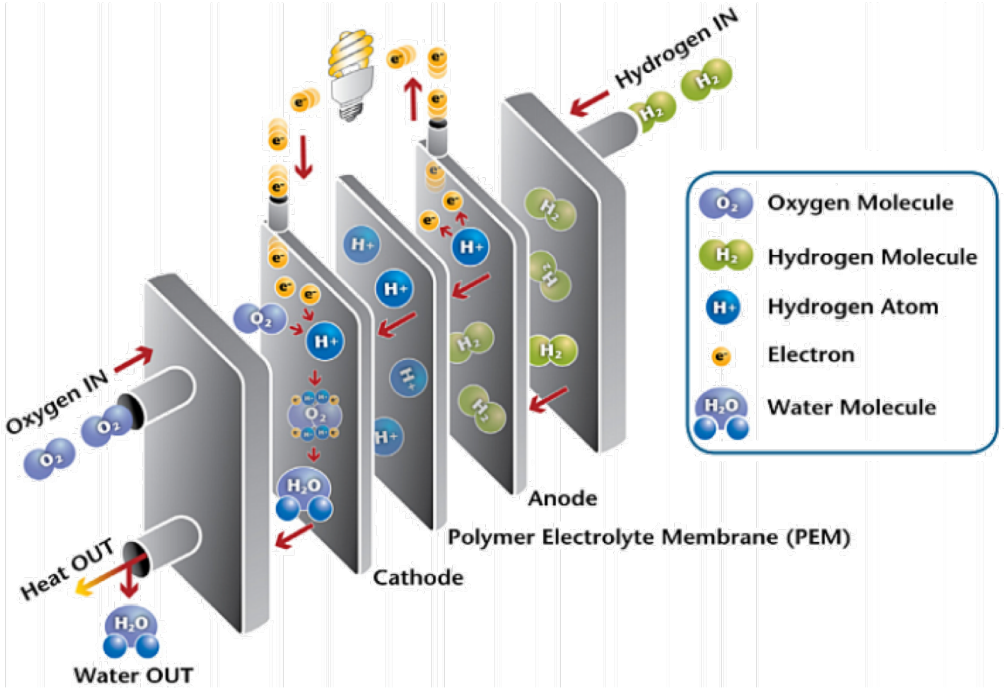


Source: Toyota

Video download URL:
https://h2tools.org/sites/default/files/barilo/Fuel_Cell_Animation.mp4

Fuel Cells 101 : PEM Fuel Cell

Relies on an *electrochemical* reaction



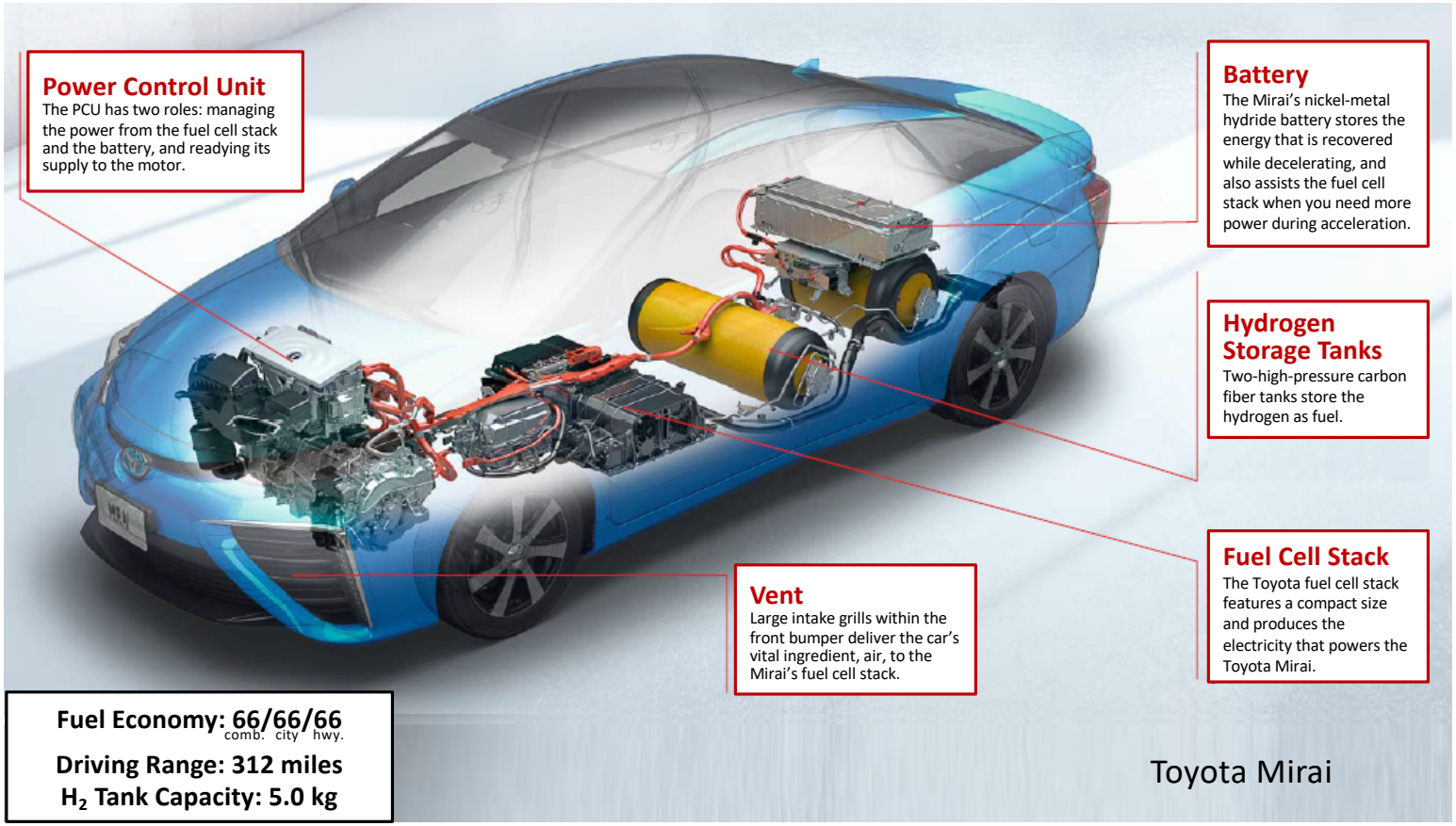
Anode side
(an oxidation reaction):
$2H_2 \Rightarrow 4H^+ + 4e^-$

Cathode side
(a reduction reaction):
$O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$

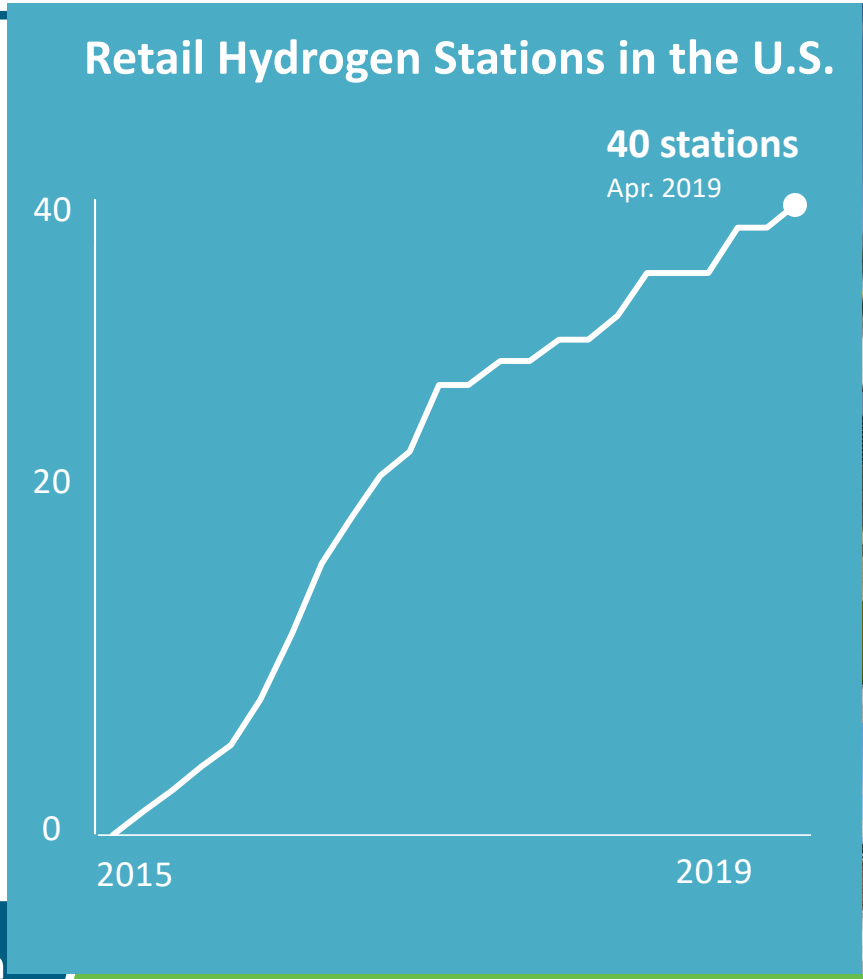
Net reaction
(the "redox" reaction):
$2H_2 + O_2 \Rightarrow 2H_2O$

Produces electricity without combustion

Example of a Commercially Available FCEV

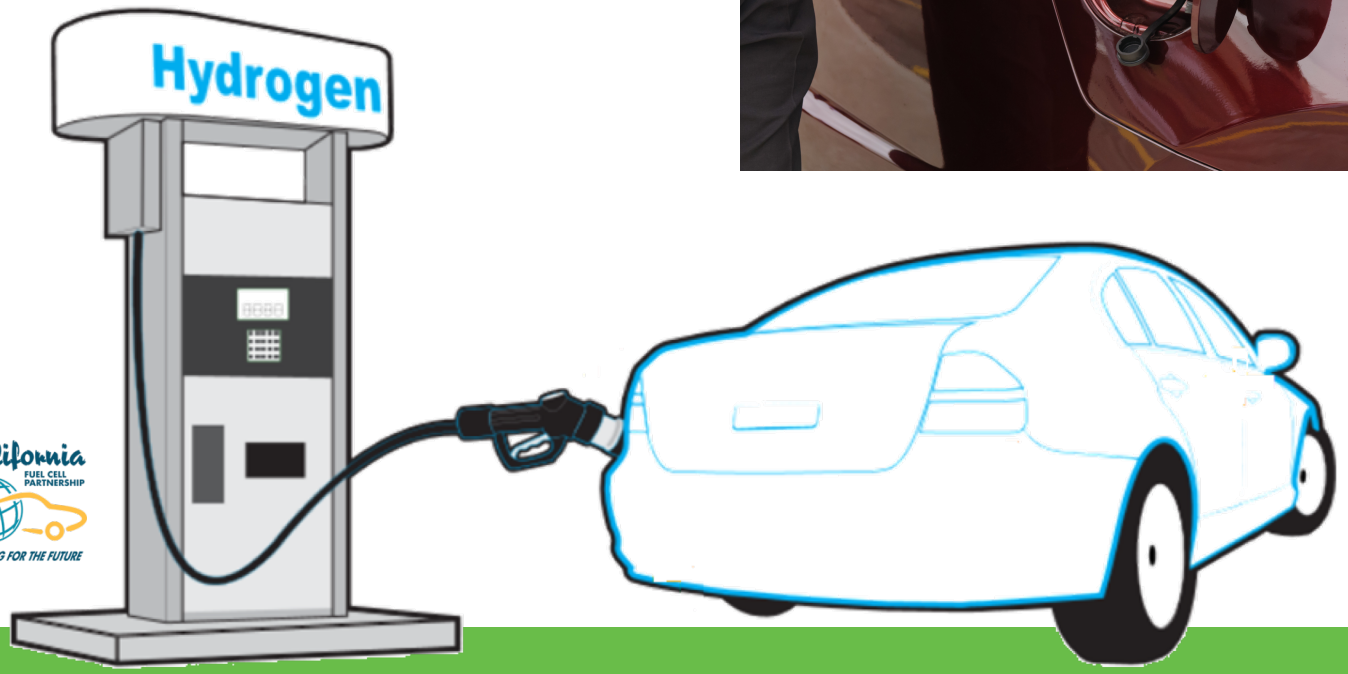


US Hydrogen Public Fueling Infrastructure Status



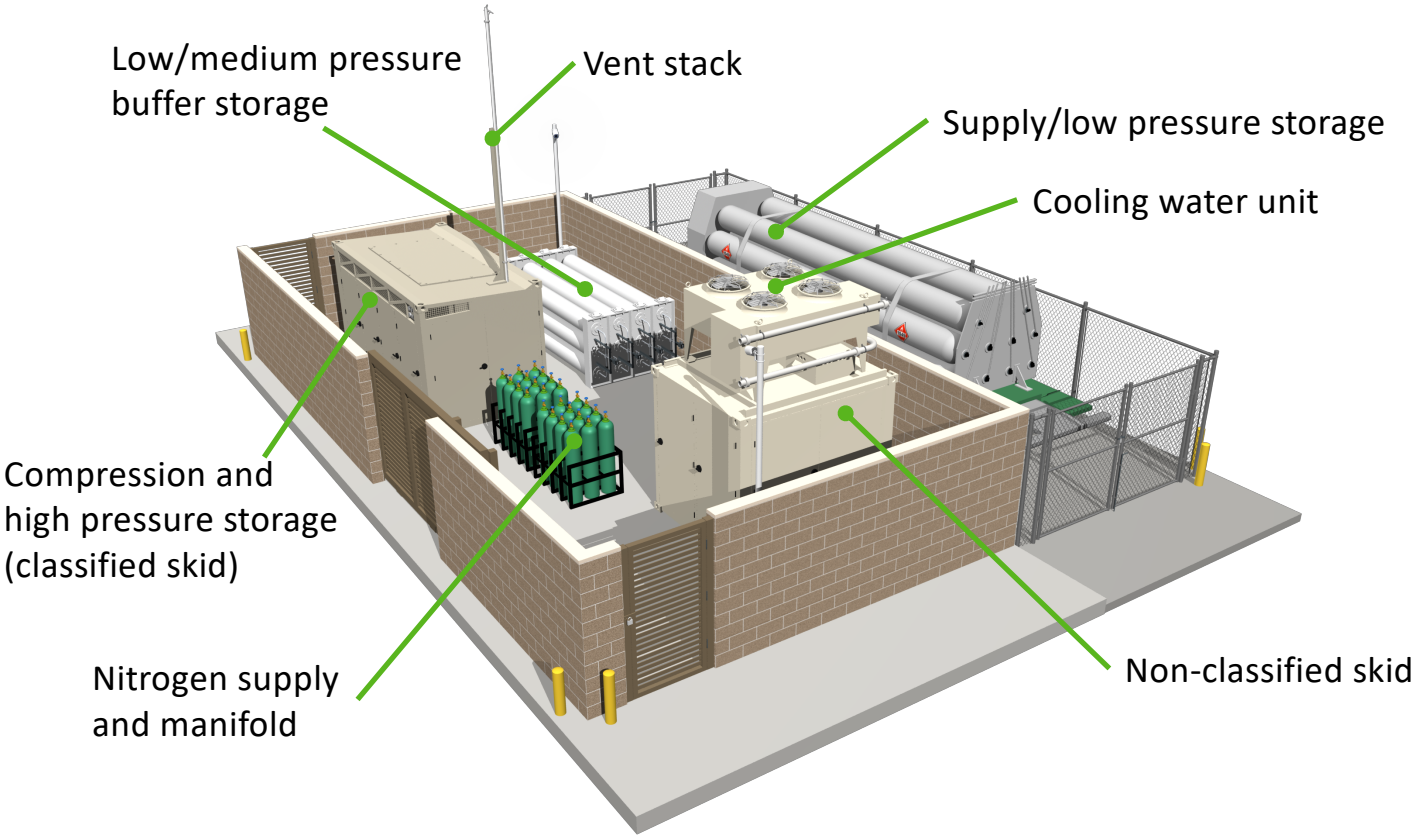
What does hydrogen refueling look like?

- Takes minutes
- Similar dispenser to gasoline
- Safe and familiar process



Example FCV Gaseous H_2 Station Configuration

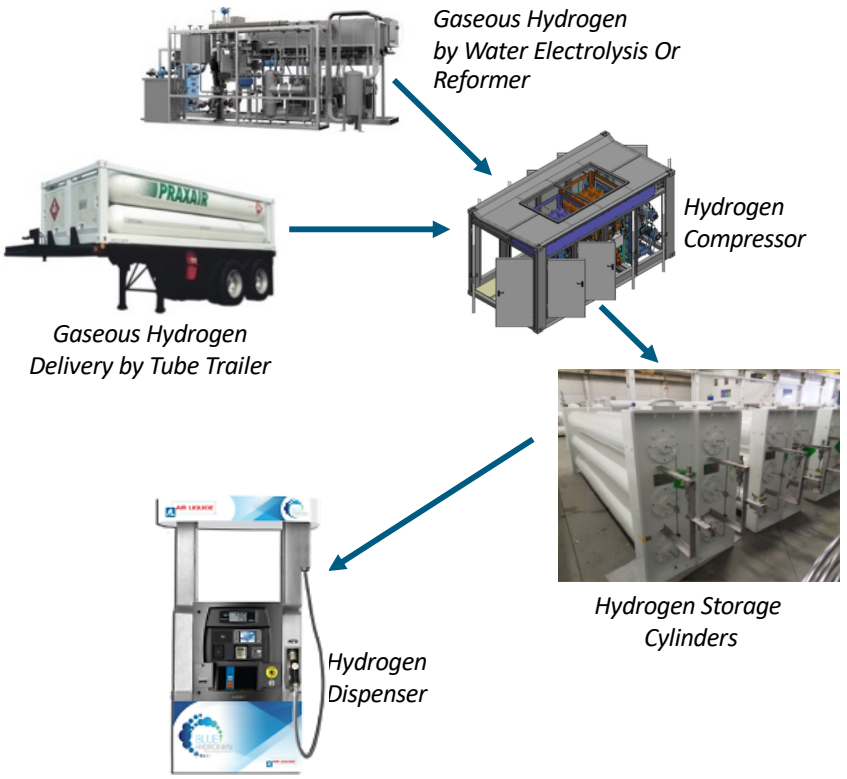
Gaseous Hydrogen Storage System Layout (Typical)



Source: Air Liquide

Gaseous Hydrogen Storage

- Delivered to fueling station by trailer, or generated onsite
- Compressed and stored onsite in cylinders
- Piped to dispenser for fueling vehicles



Liquid Hydrogen Delivery

Liquid hydrogen can be delivered to the fueling station by tanker truck, as is shown for this hydrogen and gasoline station

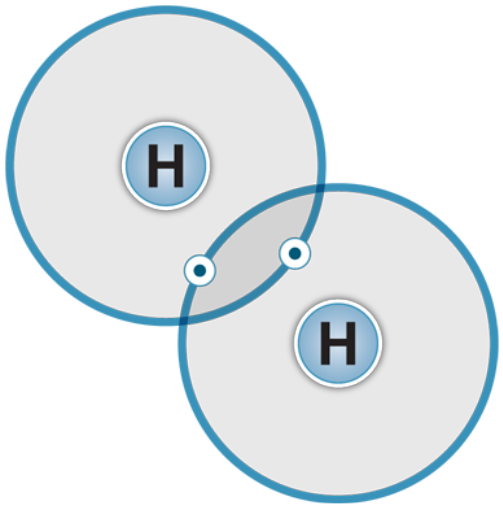
Fueling dispenser & canopy

Photos: California Fuel Cell Partnership and Linde.

Source: Ivys Energy Solutions

Hydrogen Properties and Behavior

- **Gas** at ambient conditions
  - Rises and disperses rapidly (14x lighter than air)
  - Flammable range 4-75% in air
- **Liquid** at -423°F (-253°C) – a *cryogen*
  - LH_2 stored at 50 psi in vacuum insulated tanks
  - No liquid phase in compressed gas H_2 storage
- **Energy content comparison** :
  - 1 kg of hydrogen ~ 1 gallon gasoline
  - 33.3 kWh/kg hydrogen vs. 32.8 kWh/gal gasoline



Molecular Hydrogen Model:
2 protons (H+) sharing 2 electrons (e-)

Hydrogen Properties: *A Comparison*

	Hydrogen Gas	Natural Gas	Gasoline
Color	No	No	Yes
Toxicity	None	Some	High
Odor	Odorless	Yes (mercaptan)	Yes (benzene)
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

Properties of Hydrogen

Description

- Colorless, odorless, tasteless

General Properties

- Flammable
- Non-irritating, nontoxic, asphyxiant
- Non-corrosive
- Lightest gas, buoyant, can escape earth's gravity

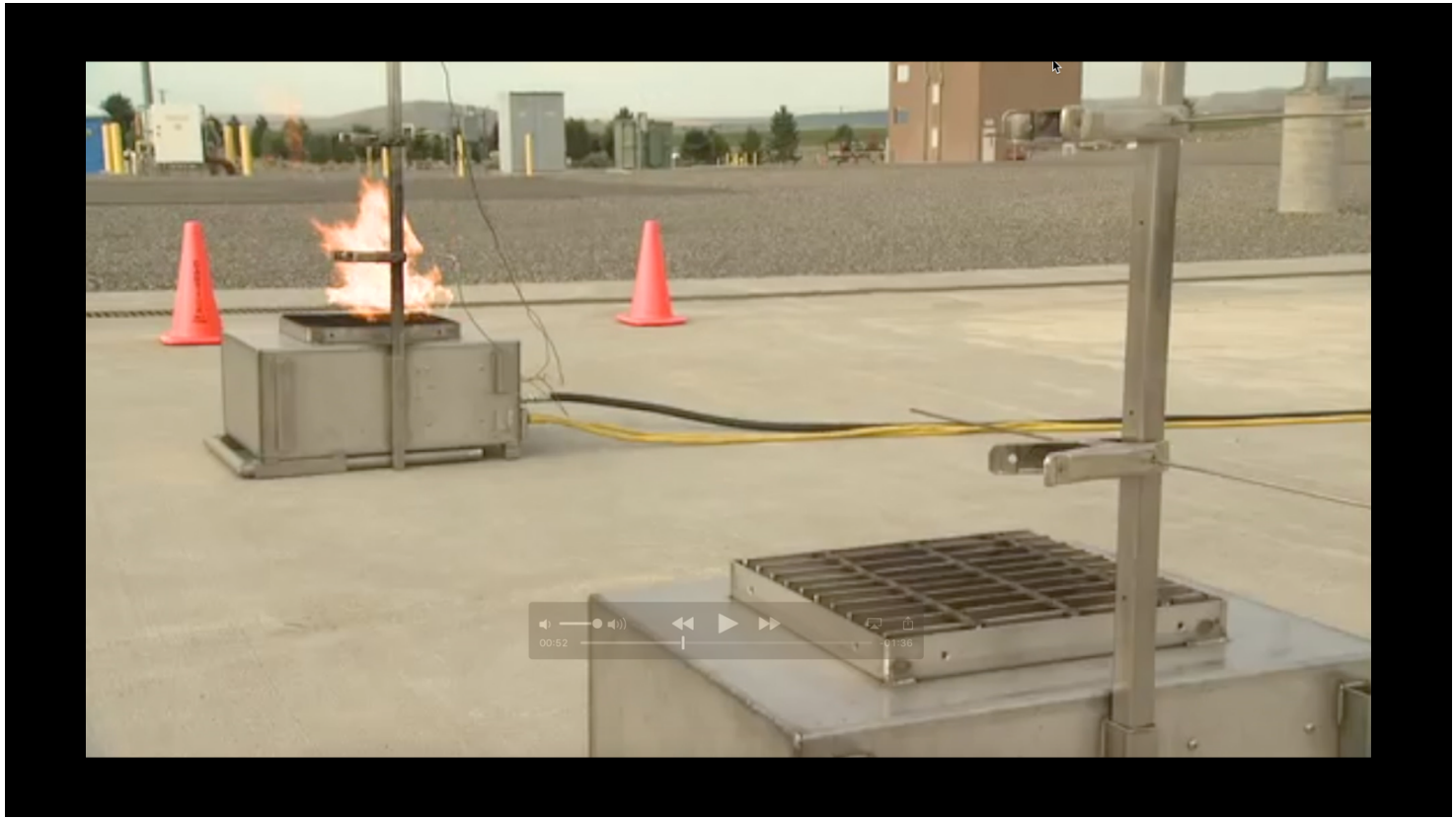
Physical Properties

- GH_2 density @ NTP — 0.0838 kg/m^3 (1/15th air)
- GH_2 specific gravity — 0.0696 (Air = 1.0)
- Viscosity — 33.64 x 10^{-3} kg/m hr (1/2 air)
- Diffusivity — 1.697 m^2/hr (4x NG in air)
- Thermal Conductivity — 0.157 kcal/m hr K (7 x air)

Potential Hazards

- Combustion
- Pressure hazards
- Low temperature
- Hydrogen embrittlement
- Exposure and health

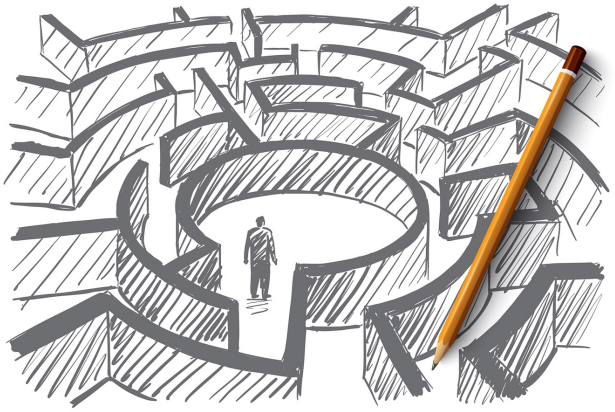
Demonstration of Hydrogen Flames



Video download URL:
https://h2tools.org/sites/default/files/barilo/BurnDemo.mp4

Enabling Widespread Success: Addressing Safety

- Safety issues must be addressed for successful hydrogen technology acceptance and deployment
- Safety issues can be a ‘deal breaker’
- Hydrogen technology stakeholders may not be able to identify and effectively address all safety issues
- Stakeholders benefit from an independent and experienced hydrogen safety review resource involved in early design and safety planning activities



The Safety Basics

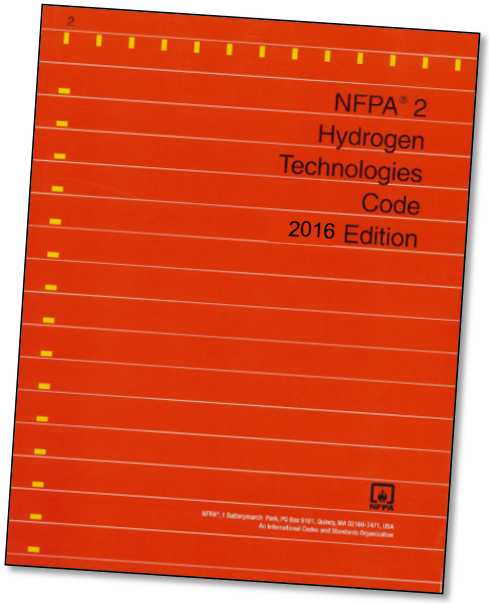
Hydrogen safety, like all flammable gas, relies on these key safety considerations:

- Eliminate hazards or define mitigation measures
- Ensure system integrity
- Provide proper ventilation to prevent accumulation
- Manage discharges
- Detect and isolate leaks
- Train personnel

Fuel cell backup power connected to a data center

Critical Infrastructure H_2 Codes & Standards

International Fire Code (IFC)



NFPA 2 Hydrogen Technologies Code

Hydrogen Safety Resources

Hydrogen Safety Panel (HSP)

- Identify Safety-Related Technical Data Gaps
- Review Safety Plans and Project Designs
- Perform Safety Evaluation Site Visits
- Provide Technical Oversight for Other Program Areas

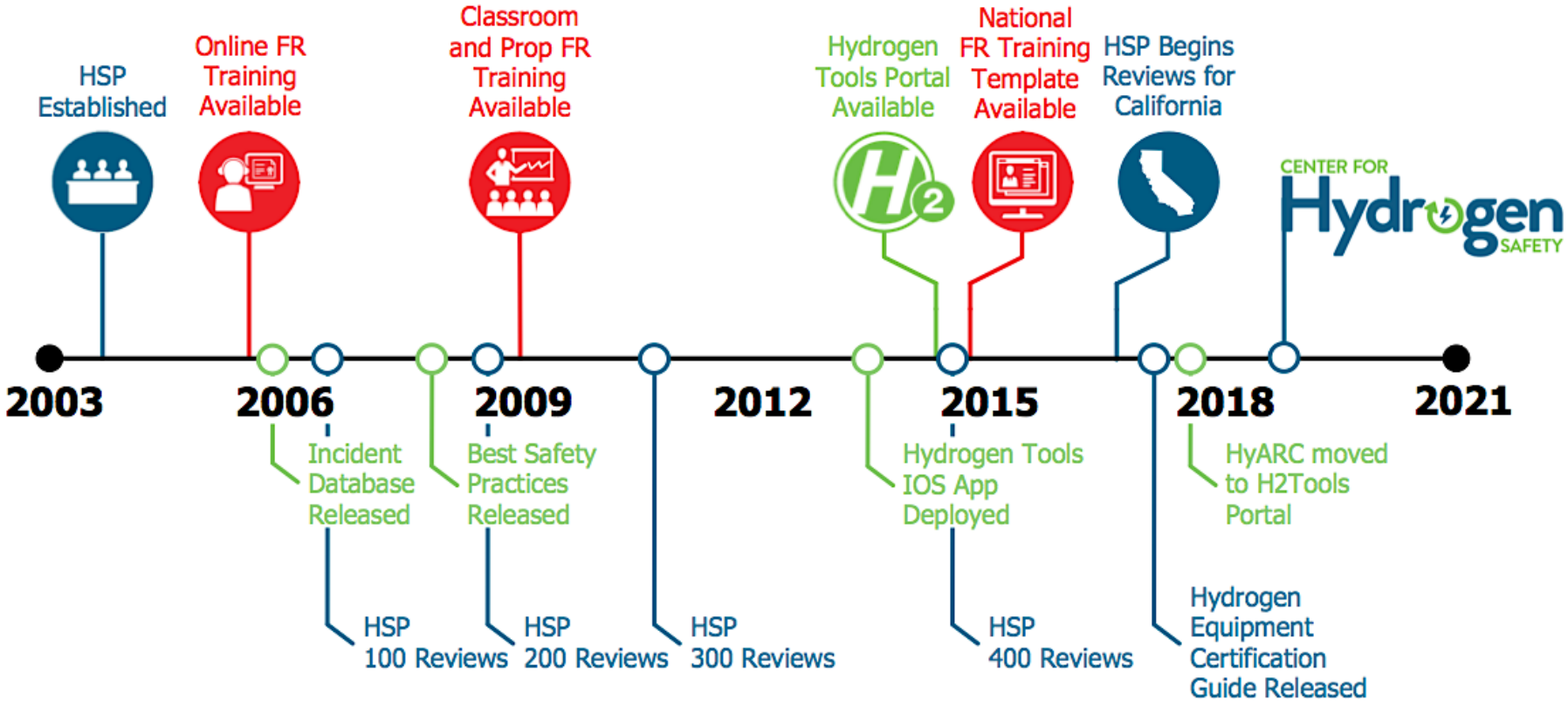
Hydrogen Tools *Web Portal* (*http://h2tools.org*)

- Hydrogen Facts, Training, Forums, HyARC Tools
- Hydrogen Lessons Learned, Best Practices, Workspaces

Emergency Response Training Resources

- Online Awareness Training
- Operations-Level Classroom/Hands-On Training
- National Hydrogen and Fuel Cell Emergency Response Training Resource

Project Timeline



Hydrogen Tools

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

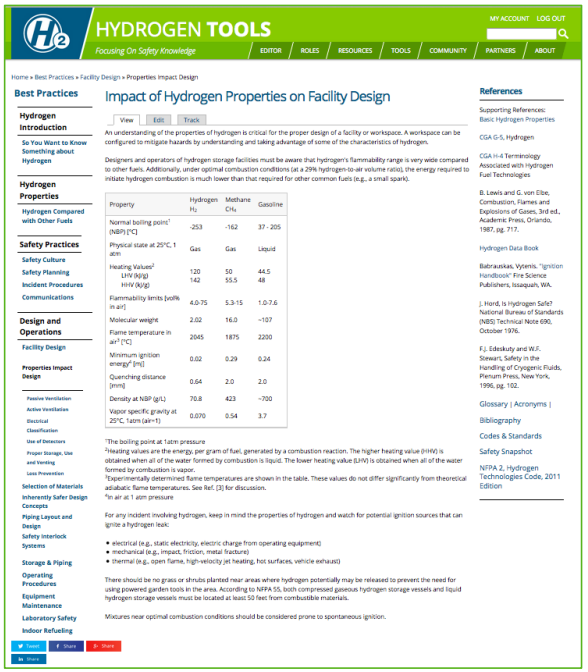
*http://**h2tools**.org*

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

CENTER FOR Hydrogen SAFETY

H2tools.org/bestpractices
…Sharing Experience, Applying Best Practices

- Introduction to Hydrogen
  - So you want to know something about hydrogen?
- Hydrogen Properties
  - Hydrogen compared with other fuels
- Safety Practices
  - Safety culture
  - Safety planning
  - Incident procedures
  - Communications
- Design and Operations
  - Facility design considerations
  - Storage and piping
  - Operating procedures
  - Equipment maintenance
  - Laboratory safety
  - Indoor refueling of forklifts



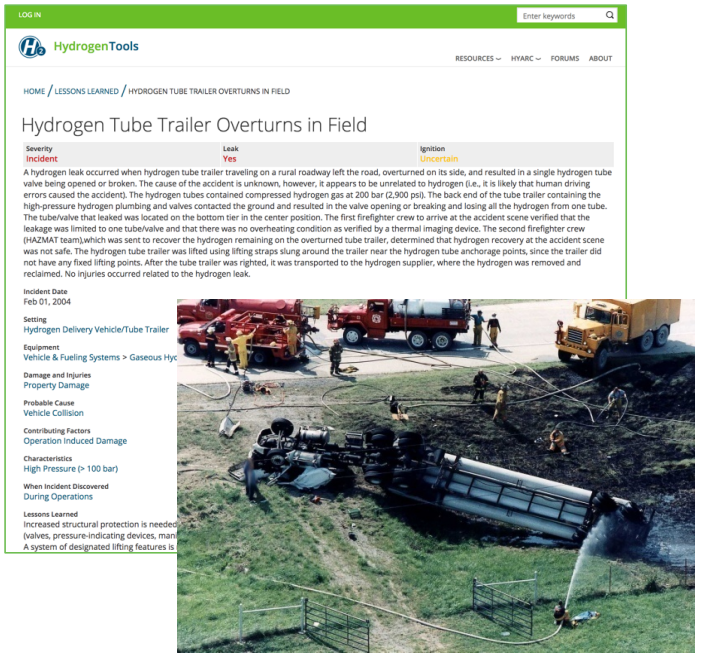
Safety events from "H2incidents.org" illustrate what can go wrong if best practices are not followed.

URL: http://h2tools.org/bestpractices

…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



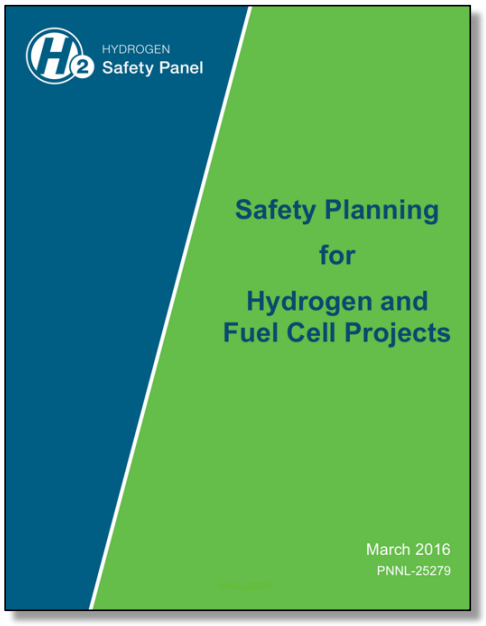
Tube trailer rollover

URL: http://h2tools.org/lessons

Guidance for Safety Planning of H_2 Projects

Safety planning should be an integral part of the design and operation of an H_2 system.

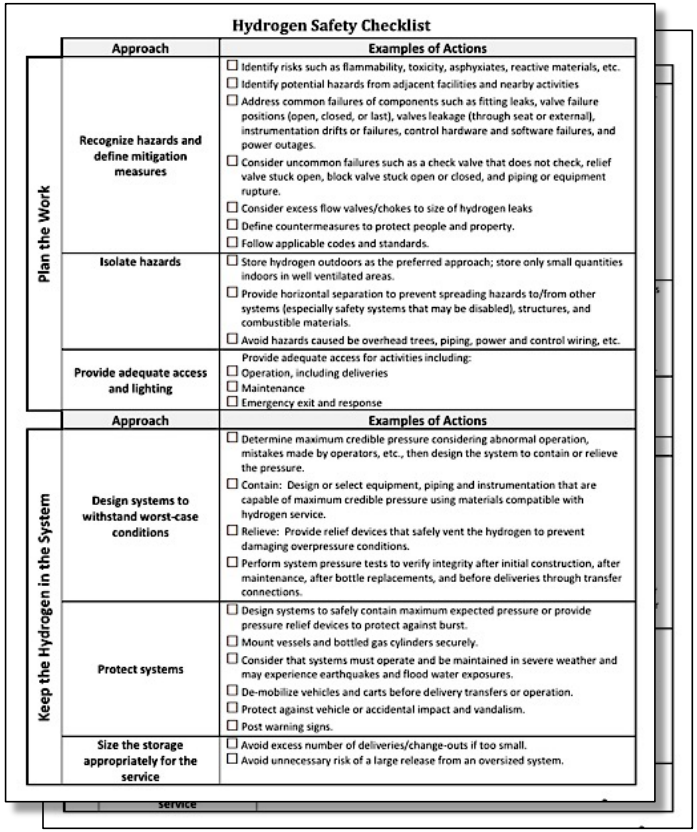
- Originally developed by the HSP for the U.S. Department of Energy in 2005
- The document provides information on safety practices for hydrogen and fuel cell projects
- The project safety planning process is meant to help identify risks and avoid potential hydrogen and related incidents.
- This document can aid in generating a good safety plan that will serve as a guide for the safe conduct of all work related to the development and operation of hydrogen and fuel cell equipment.



URL: https://h2tools.org/hsp/reviews

Hydrogen Safety Considerations Checklist

- Intended users
  - Those developing designs for hydrogen systems
  - Those involved with the risk assessment of hydrogen systems.
- While fairly inclusive, it is not possible to include all variables that need to be considered
- A hazard analysis process should include
  - Personnel who are familiar with applicable codes and standards
  - Team members with expertise in the technical aspects of the specific project



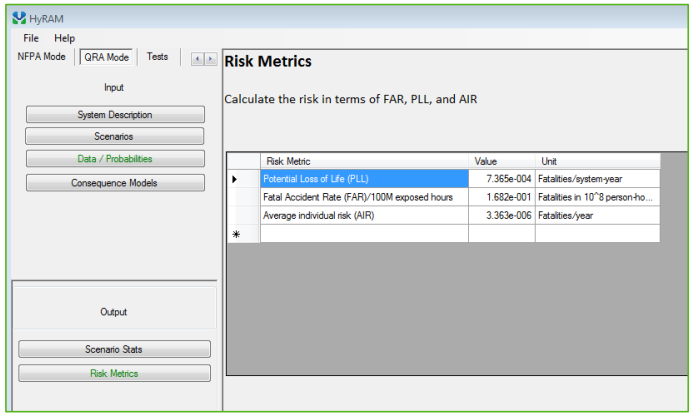
Hydrogen Safety Checklist

	Approach	Examples of Actions
Plan the Work	Recognize hazards and define mitigation measures	☐ Identify risks such as flammability, toxicity, asphyxiates, reactive materials, etc. ☐ Identify potential hazards from adjacent facilities and nearby activities ☐ Address common failures of components such as fitting leaks, valve failure positions (open, closed, or last), valves leakage (through seat or external), instrumentation drifts or failures, control hardware and software failures, and power outages. ☐ Consider uncommon failures such as a check valve that does not check, relief valve stuck open, block valve stuck open or closed, and piping or equipment rupture. ☐ Consider excess flow valves/chokes to size of hydrogen leaks ☐ Define countermeasures to protect people and property. ☐ Follow applicable codes and standards.
	Isolate hazards	☐ Store hydrogen outdoors as the preferred approach; store only small quantities indoors in well ventilated areas. ☐ Provide horizontal separation to prevent spreading hazards to/from other systems (especially safety systems that may be disabled), structures, and combustible materials. ☐ Avoid hazards caused be overhead trees, piping, power and control wiring, etc.
	Provide adequate access and lighting	Provide adequate access for activities including: ☐ Operation, including deliveries ☐ Maintenance ☐ Emergency exit and response
	Approach	**Examples of Actions**
Keep the Hydrogen in the System	Design systems to withstand worst-case conditions	☐ Determine maximum credible pressure considering abnormal operation, mistakes made by operators, etc., then design the system to contain or relieve the pressure. ☐ Contain: Design or select equipment, piping and instrumentation that are capable of maximum credible pressure using materials compatible with hydrogen service. ☐ Relieve: Provide relief devices that safely vent the hydrogen to prevent damaging overpressure conditions. ☐ Perform system pressure tests to verify integrity after initial construction, after maintenance, after bottle replacements, and before deliveries through transfer connections.
	Protect systems	☐ Design systems to safely contain maximum expected pressure or provide pressure relief devices to protect against burst. ☐ Mount vessels and bottled gas cylinders securely. ☐ Consider that systems must operate and be maintained in severe weather and may experience earthquakes and flood water exposures. ☐ De-mobilize vehicles and carts before delivery transfers or operation. ☐ Protect against vehicle or accidental impact and vandalism. ☐ Post warning signs.
	Size the storage appropriately for the service	☐ Avoid excess number of deliveries/change-outs if too small. ☐ Avoid unnecessary risk of a large release from an oversized system.

URL: https://h2tools.org/sites/default/files/HydrogenSafetyChecklist.pdf

Quantitative Risk Assessment

- Developed toolkit to enable integrated probabilistic and deterministic modeling
  - Relevant H_2 hazards (thermal, mechanical)
  - Probabilistic models (traditional QRA models) & H_2-specific component data
  - H_2 phenomena (gas release, heat flux, overpressure)
- Variable Users
  - High level, generic insights (e.g., for C&S developers, regulators)
  - Detailed, site-specific insights (e.g., for AHJs, station designers)
- Currently, two interfaces (views):
  - **"QRA mode"** and **"Physics mode"**
  - Planned "performance-based design" mode for targeted analyses



HyRAM
HYDROGEN RISK ASSESSMENT MODELS

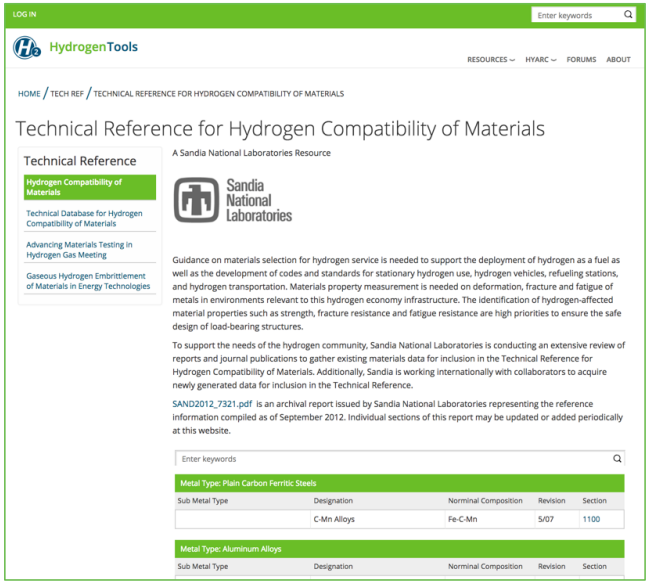
First-of-its-kind software tool for integrating H_2 consequence models w/ QRA models
Includes behavior models & data developed through FY12

URL: http://hyram.sandia.gov

Technical Reference for Hydrogen Compatibility of Materials

Consists of material specific chapters (as individual PDF files) summarizing mechanical-property data from journal publications and technical reports

- Plain Carbon Ferritic Steels
- Low-Alloy Ferritic Steels
- High-Alloy Ferritic Steels
- Austenitic Steels
- Aluminum Alloys
- Copper Alloys
- Nickel Alloys
- Nonmetals



H_2 Fueling Station Permitting Videos

Permitting Hydrogen Fueling Stations Part One

Permitting Hydrogen Fueling Stations Part Two: Planning and Building Considerations

Permitting Hydrogen Fueling Stations Part Three: Fire Department Regulations

Permitting Hydrogen Fueling Stations Part Four: Annual Inspections

- Gives AHJs, Project Developers, and other interested parties a quick orientation in permitting hydrogen fueling stations.
- Provides basic background information on hydrogen technologies followed by a description of the permitting process including an overview of key codes and standards.
- Contains interviews with code officials, emergency responders, and technical experts as well as footage of hydrogen stations.

Videos available at https://h2tools.org/videos

Introducing the Hydrogen Safety Panel (HSP)

Experienced, Independent, Trusted Expertise

The HSP promotes safe operation, handling, and use of hydrogen

- Formed in 2003
- 14 members with **400+ years** combined experience
- **Hydrogen safety reviews** – hydrogen fueling, auxiliary power, backup power, CHP, portable power, and lab R&D
- White papers, reports, and guides
- Provides support on the application of hydrogen codes and standards
- **H_2 safety knowledge shared through the H_2 Tools Portal** (h2tools.org)

Some of the fire officials and hydrogen experts that comprise the Hydrogen Safety Panel (25th meeting, 2019, New Orleans, LA)

Hydrogen Safety Panel: Objective and Activities

The purpose of the HSP is to share the benefits of extensive experience by providing suggestions and recommendations pertaining to the safe handling and use of hydrogen.

Objective: Enable the safe and timely transition to hydrogen technologies by:

- Participating in hydrogen projects to ensure safety is adequately considered
- Providing expertise and recommendations to stakeholders and assisting with identifying safety-related gaps, best practices and lessons learned

HSP Membership

The HSP is a multidisciplinary team of engineers, code officials, safety professionals, equipment providers, and testing and certification experts. The Panel provides guidance for hydrogen projects and facilities, including design and process safety reviews, support/review of risk analyses, onsite safety presentations, and training.

Name	Affiliation
Nick Barilo, Manager	Pacific Northwest National Laboratory
Richard Kallman, Chair	City of Santa Fe Springs Fire Dept. (retired)
Harold Beeson*	WHA International, Inc.
Ken Boyce	UL
David Farese	Air Products and Chemicals
Donald Frikken	Becht Engineering
Livio Gambone	Nikola Motors
Aaron Harris	Air Liquide
Chris LaFleur	Sandia National Laboratories
Miguel Maes	NASA-JSC White Sands Test Facility
Larry Moulthrop	Proton OnSite (retired)
Spencer Quong*	Toyota Motor Corporation
Gary Stottler*	GM (retired)
Tom Witte	Witte Engineered Gases
Robert Zalosh	Firexplo

* New members 2019

Impact of the HSP

- Serves as a non-regulatory, objective, and neutral resource
- Sees the "big picture"
  - Shares learnings
  - Identifies gaps
- Can help reduce costs
  - Over-engineering resulting in unnecessary features
  - Delayed approvals
  - Missed safety considerations/features
- A group with diverse experience can:
  - Respond with a balanced solution to questions, problems, and issues
  - Aid in avoiding repeating costly mistakes among disparate project proponents
  - Help project proponents avoid industry-impacting incidents
  - Help establish stakeholder and public confidence

Since 2003

506
Reviews

345
Projects

>100
Presentations

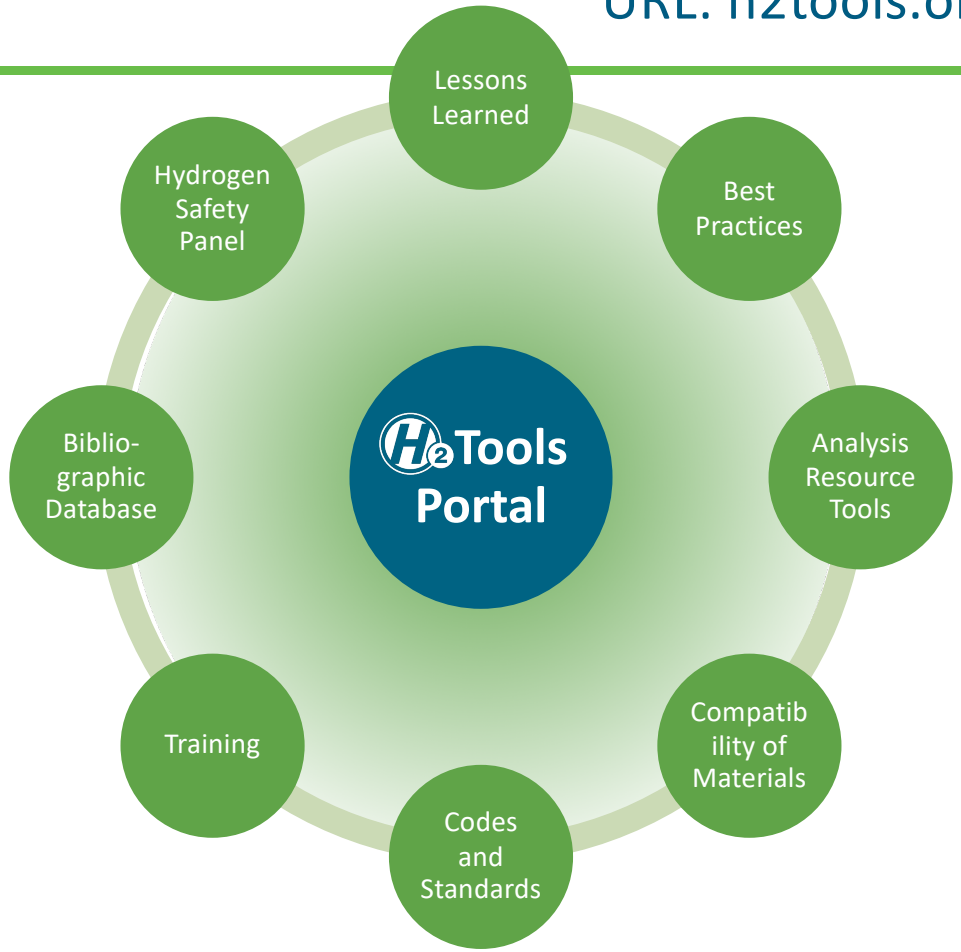
12
Guides

HydrogenTools

URL: h2tools.org

Significant hydrogen safety resources in one location

The goal of the Portal is to support implementation of the practices and procedures that will ensure safety in the handling and use of hydrogen in a variety of fuel cell applications. The portal brings together and enhances the utility of a variety of tools and web-based content on the safety aspects of hydrogen and fuel cell technologies to help inform those tasked with designing, approving or using systems and facilities, as well as those responding to incidents.



Involvement in Hydrogen Fueling Station Rollouts

Contracted by the California Energy Commission (CEC) to support the construction of new hydrogen fueling stations through the following services

- Provided guidance for preparing safety plans
- Participated in pre-award safety consultation for applicants
- Reviewed safety plans submitted by 12 applicants to California's GFO-605
- Provided comments to the CEC in support of award decisions
- Follow-up interviews and stations tours were conducted in March 2017 to identify safety learnings from station deployments

Supporting Rollout of Hydrogen Technologies

Connecticut Center for Advanced Technologies (CCAT) CY18-19

- The objectives include:
  - Raising awareness of the HSP among state/local officials and project developers
  - Establishing working relationships with key state and local organizations to enable seamless incident response and development of safety lessons learned
  - Identifying types of projects that would benefit from HSP involvement
  - Identifying methods to facilitate outside organizations paying for HSP

California Energy Commission CY19-21

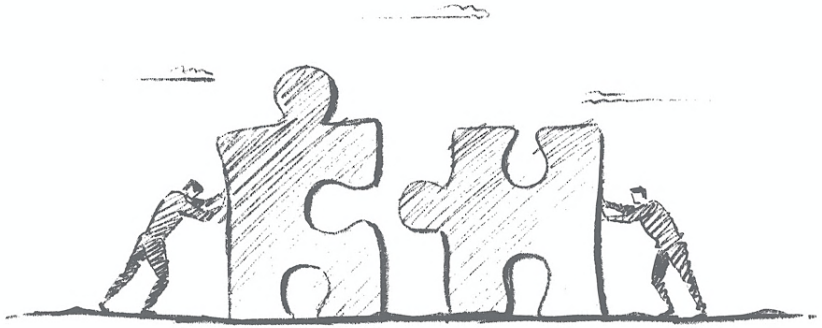
- Activities will be performed in support of the California fueling structure infrastructure including renewable hydrogen production facilities
  - Provide safety planning webinars and consultations
  - Review funding opportunity applicant safety plans
  - Participate in funded project design reviews
  - Perform site safety reviews
  - Provide outreach to code officials and stakeholders
  - Review hydrogen incidents
  - Conduct post startup project team interviews

Learnings from these activities are brought back to California, DOE, and the hydrogen community

Building Blocks

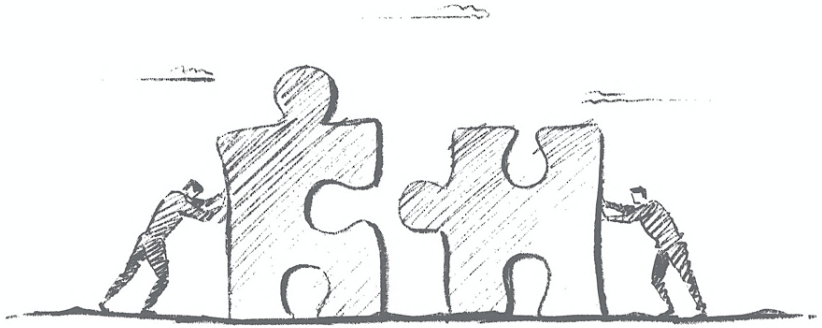
While hydrogen has been used safely in industrial applications for nearly a century, a substantial expansion of its use as a fuel involves a wider and more diverse group of stakeholders

- **Communication of hydrogen specific safety guidance** will be critical to the success of hydrogen as a part of the global energy transition
- Establishing and communicating best practices **from a trusted, independent safety resource** is a valuable part of the hydrogen safety ecosystem



Building Blocks

While hydrogen has been used safely in industrial applications for nearly a century, a substantial expansion of its use as a fuel involves a wider and more diverse group of stakeholders

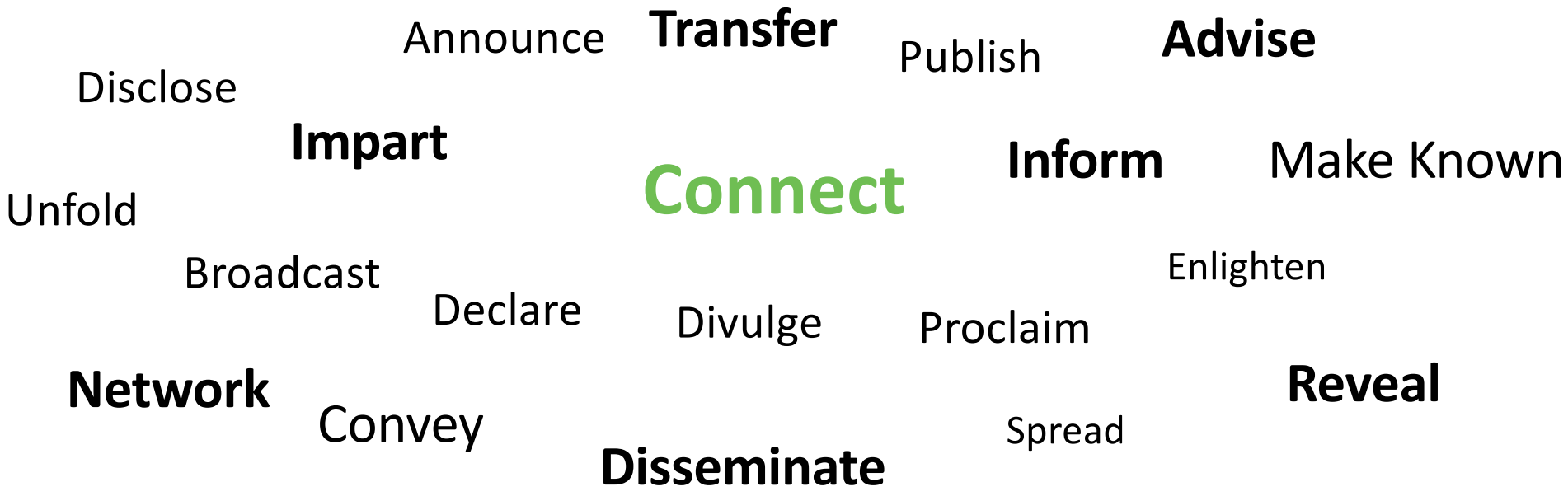


A fundamental need…

Communication of hydrogen specific safety guidance from a trusted, independent safety resource

Our Greatest Need, and **Our Greatest Opportunity…**

… communicating knowledge to enable the safe and timely transition to hydrogen and fuel cell technologies



Future Direction and Sustainability

Streamlined access to HSP

AIChE* has partnered with PNNL to establish a Center for Hydrogen Safety (CHS). CHS will expand the HSP's access to new customers by:

- **Making the HSP more readily available to industry, state, and federal government agencies (national and international)**
- **Enabling less cumbersome/time-consuming contracting efforts**

PNNL will transfer its first responder hydrogen safety training resources to AIChE to enable broader access to online and in-person training resources (with continued subject matter support from PNNL and CaFCP)

** AIChE is the world's leading organization for chemical engineering professionals, with more than 60,000 members from more than 110 countries. AIChE has the breadth of resources and expertise to support industries or emerging areas, such as hydrogen and fuel cell technologies.*

Safely Fueling Our Future…

…by building and enabling a global community

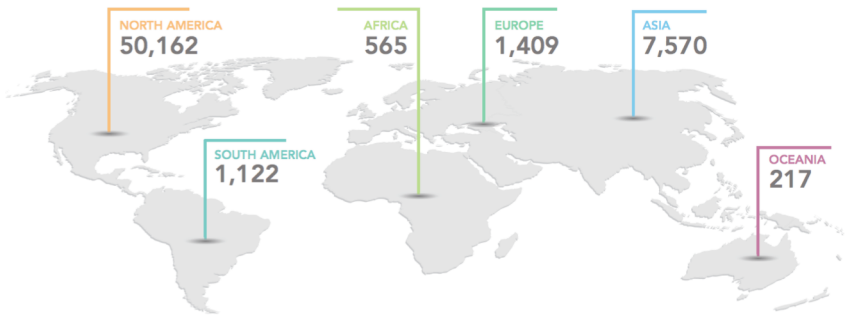
CENTER FOR Hydrogen SAFETY

An AIChE Technical Community • A Global Resource On Hydrogen Safety

AIChE
The Global Home of Chemical Engineers

60,000+ TOTAL MEMBERS

110 COUNTRIES



- A global, neutral and nonprofit resource
- Supports and promotes the safe handling and use of hydrogen across industrial and consumer applications in the energy transition
- Provides assurance that groups of experts have a common communication platform with a global scope to ensure safety information, guidance and expertise is available to all stakeholders

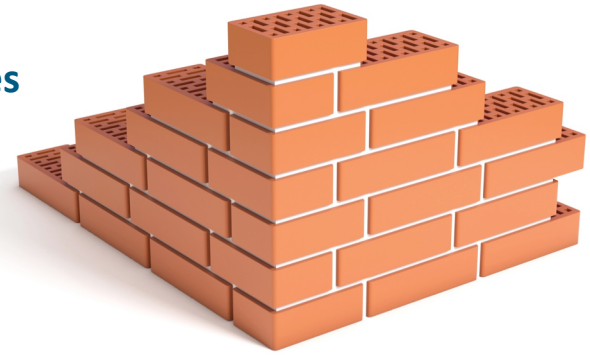
Safely Fueling Our Future…

…by building on a strong foundation of resources built through collaboration

CENTER FOR Hydrogen SAFETY

Safety Knowledge Resources

- Hydrogen Tools Web Portal
- Hydrogen Lessons Learned
- Best Safety Practices



First Responder Training Resources

- Online Awareness Training
- Operations-Level Classroom Training
- National Training Resource

Hydrogen Safety Panel

- Reviews Projects and Facilities
- Identifies Gaps and Shares Learnings

Pacific Northwest NATIONAL LABORATORY

AIChE

2003 2006 2009 2012 2015 2018 2021

Membership Levels and Benefits

Membership Levels

- Government ($25K USD/per year)
- Large Industry ($15K USD/per year)
- Small Industry ($5K USD/per year)
- National Laboratory ($5K USD/per year)
- University ($2K USD/per year)
- Executive Board ($50K USD/per year)

Membership Benefits

PROJECT/FACILITY SUPPORT
- Design Reviews
- Hazard Analysis Support
- Facility/Site Safety Reviews

NETWORKING
- Hydrogen Safety Conferences
- Workshops and Task Groups

TRAINING & EDUCATION
- First Responders
- Researchers
- Technicians

OUTREACH
- Stakeholders
- Code Officials
- Community Events

Training and Education Resources

Coming soon…

Online Training
- First Responders
- Researchers
- Technicians

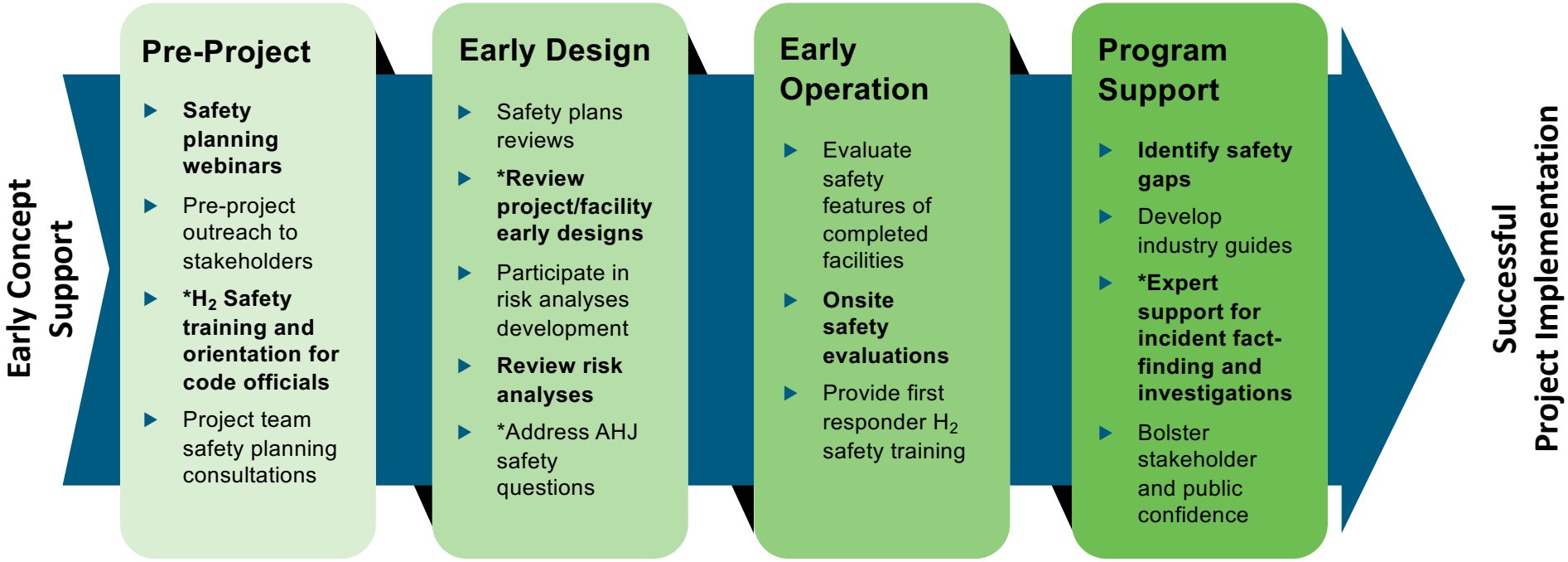
Focused Webinars
- Project Safety and Safety Planning
- Researchers
- Technicians
- Others (based on customer needs)

Information Materials
- First Responders
- Public (anticipated in 2020)

Language Support
- English
- French (late 2019)
- Dutch (current First Responder)
- Japanese (legacy First Responder)

Support for the Safe Implementation of Hydrogen Technologies

Activities that can Benefit from Project/Facility Support



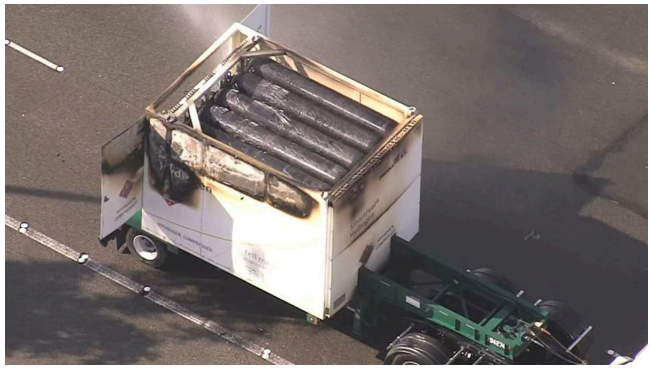
* Support for AHJ and code officials can bridge the gap for inexperienced staff, facilitate faster approvals, support a greater confidence in project safety and provide more technically justified safety features or alternate means and methods

Incident Response Resources

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

Member-only resources

- An online site sharing timely information on incidents, causes and final public reports developed by either CHS or third-parties
- Hydrogen and fuel cell technology safety fact sheets for a variety of audiences
- A guide to quickly identify what resources are available to help with your investigation and fact-finding activities



Picture source: NBC Los Angeles

Safety Conferences

CENTER FOR Hydrogen SAFETY

Connecting a Global Community

Fall 2019

October 14-15, 2019 • Sacramento, CA

Spring 2020

March/April 2020 • East Asia

Fall 2020

September 2020 • Germany

Impact of Membership

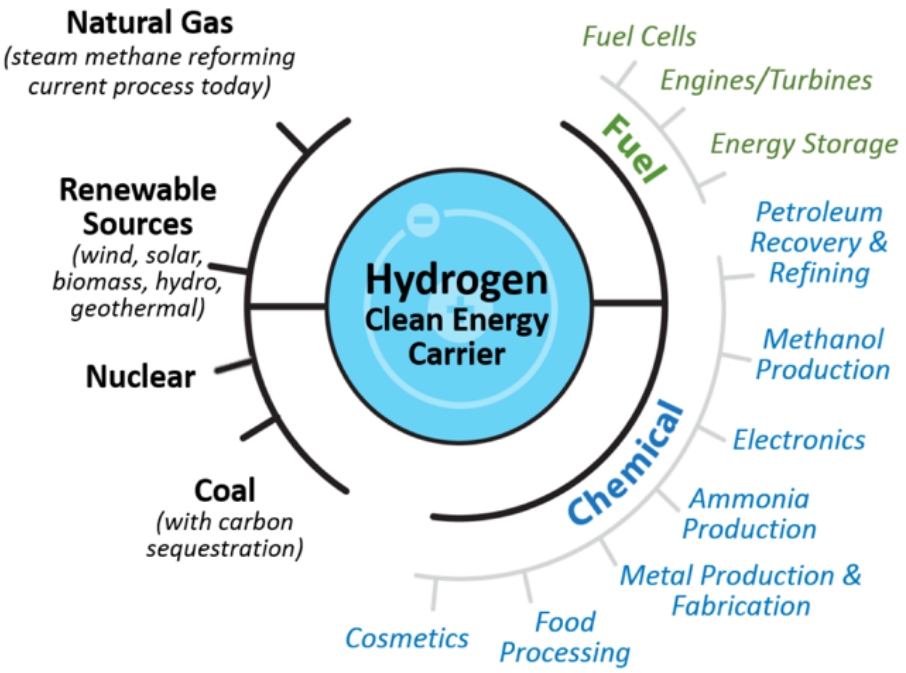
Membership will:

- Demonstrate that safety is a fundamental principal for those deploying the technology
- Ensure that neutral and trustworthy hydrogen safety resources will be sustained and have global impact
- Ensure safety is not a significant impediment to stakeholder and public acceptance of hydrogen technologies

CHS will facilitate a safe and timely transition to hydrogen and fuel cell technologies, contribute to stakeholder and public acceptance of hydrogen technology, and help assure the safe operation of hydrogen facilities

Concluding Thoughts

- The future will likely see an increase in the use of hydrogen and fuel cell technologies
- Because hydrogen as a fuel is still relatively new, best methods of handling, storage, transport, and use may not be well understood by participants
- Safe practices for production, storage, distribution, and use of hydrogen are essential for deployment of hydrogen and fuel cell technologies
- The Center for Hydrogen Safety, HSP and Hydrogen Tools portal (http://h2tools.org) are available to help project participants to understand and apply safe practices for successful use



Value Proposition for Utilizing the CHS/HSP

Critical assets and expertise enable the safe and timely transition to hydrogen and fuel cell technologies

- Protect public investment – Utilize the Center for Hydrogen Safety (CHS), a NY based resource, to ensure public money is utilized for safe facilities
- Reduce soft costs for government agencies and stakeholders
  - Expedite permitting, titling, approvals from local authorities
  - Greater accessibility and reduced costs to utilize the PNNL HSP for state and industry organizations
- Facilitate broader stakeholder and public acceptance of hydrogen technology and facilities
  - Outreach and engagement of stakeholders
  - Educational materials

Our growing list of

Members and Strategic Partners

DECHEMA
Gesellschaft für Chemische Technik und Biotechnologie e.V.

SCEJ
The Society of Chemical Engineers, Japan

PLUG POWER

Rocket Company ™
ASTRA

HySUT

TRUE ZERO
FirstElement

Air Liquide

PROTIUM

SHELL

ALAKAI TECHNOLOGIES

AIR PRODUCTS

UL

STATE OF CALIFORNIA ENERGY COMMISSION

Pacific Northwest NATIONAL LABORATORY

WASHINGTON STATE UNIVERSITY

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

HySA Infrastructure
Hydrogen South Africa

Executive Board

AIChE

Air Liquide

STATE OF CALIFORNIA ENERGY COMMISSION

hySafe
INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY

SHELL

Strategic Partners

Hydrogen Council

California FUEL CELL PARTNERSHIP
DRIVING FOR THE FUTURE

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

Thanks for Your Attention!

My Contact Information:

Nick Barilo, P.E.

Director of the Center for Hydrogen Safety, AIChE
P.O. Box 999, MSIN K7-76
Richland, WA 99352 USA
Tel: 509-371-7894
nickb@aiche.org
http://www.aiche.org/chs
http://h2tools.org