U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

U.S. Department of Energy Hydrogen and Fuel Cell Technology Overview

Dr. Sunita Satyapal, Director – DOE Hydrogen and Fuel Cells Program

FC EXPO 2020

Tokyo, Japan – February 26, 2020

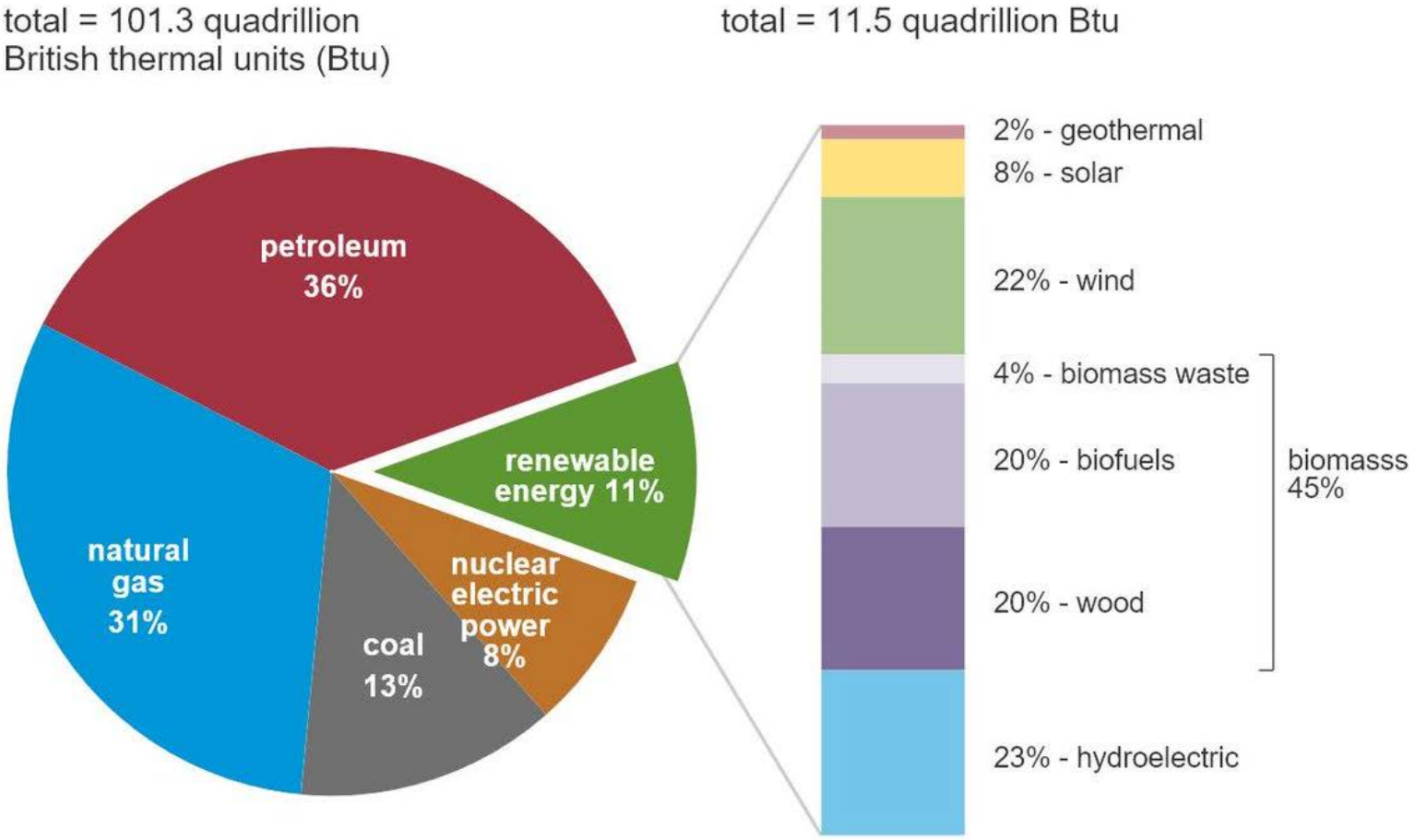
International Partnership for Hydrogen and Fuel Cells in the Economy

Accelerating Hydrogen and Fuel Cells Progress Through Global Collaboration

Sunita Satyapal – IPHE Chair
Toshiyuki Shirai – IPHE Vice Chair
Tim Karlsson – Executive Director, IPHE Secretariat

U.S. Energy Portfolio

U.S. primary energy consumption by energy source, 2018



Note: Sum of components may not equal 100% because of independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2019, preliminary data

Energy Consumption by Sector

Industrial ~ 32%

Residential (20%) & Commercial (19%)

Transportation ~ 29%


CARPOOL
HS 2
OR MORE
PERSONS
PER
VEHICLE

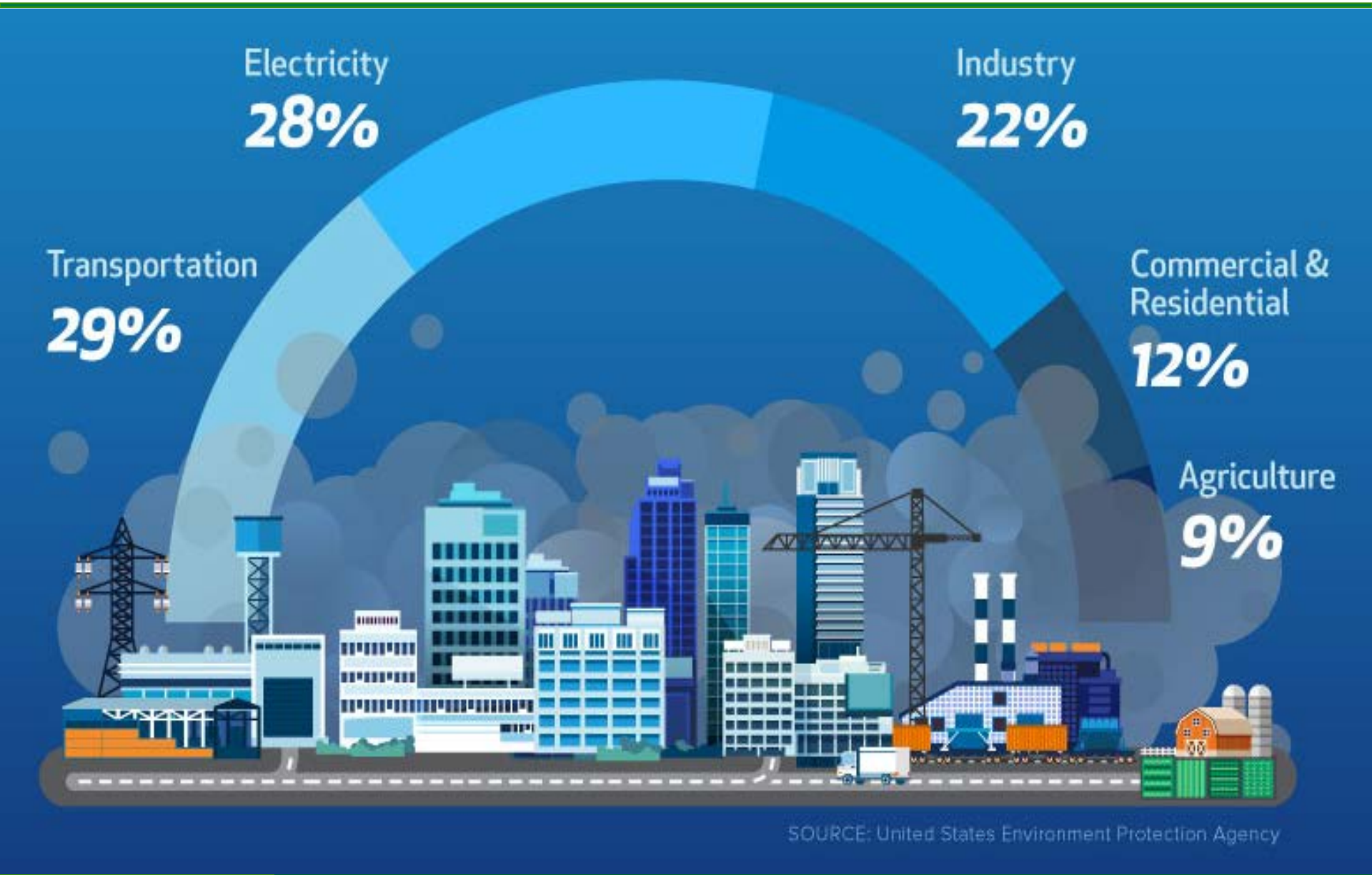
Transportation Sector

90% dependent on petroleum

85% of use is from on-road vehicles

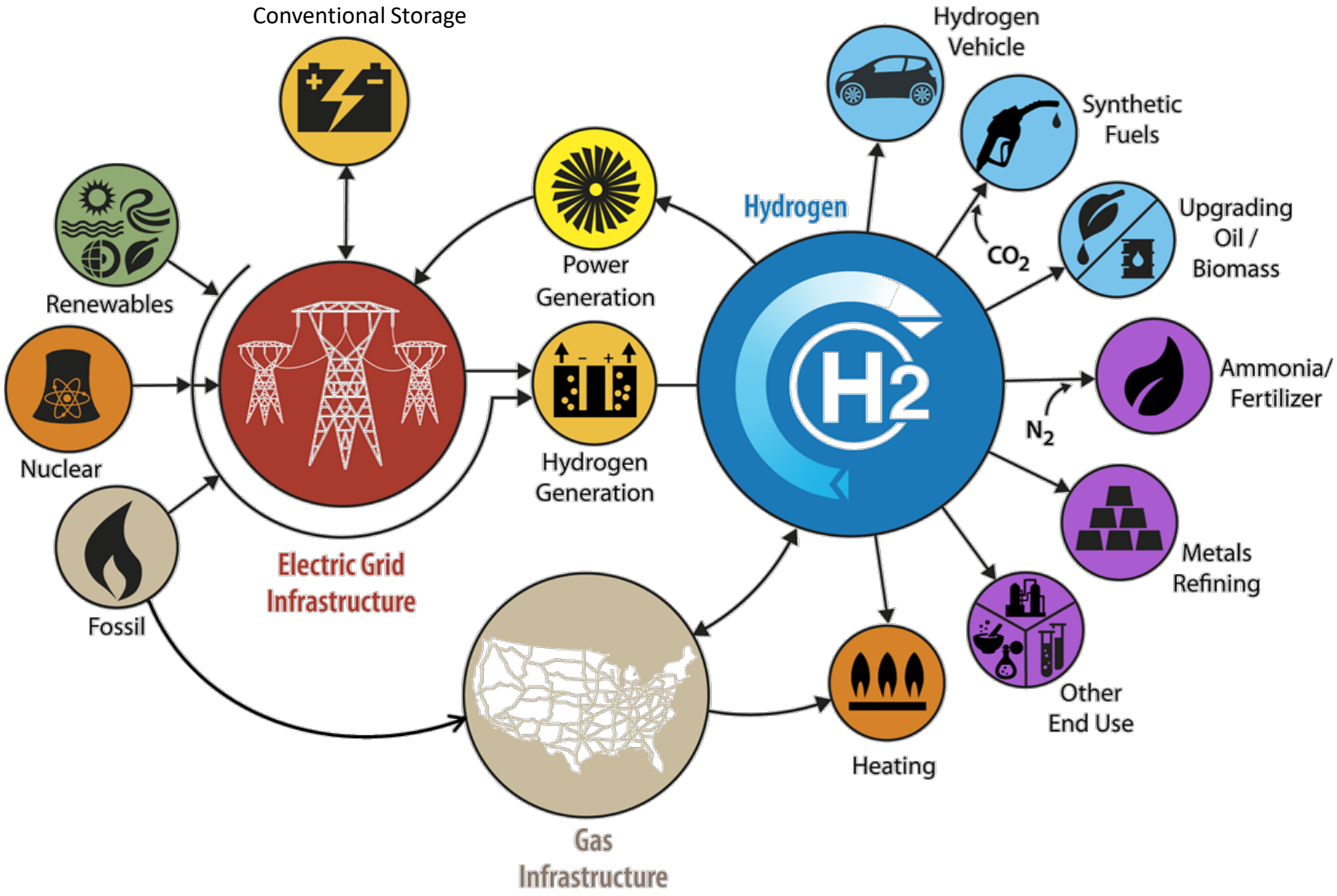
2nd largest expense after housing

U.S. Emissions by Sector




H_2 is one part of an all-of-the-above energy portfolio and can impact all sectors
H2

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



U.S. legislation guiding hydrogen and fuel cell research and development activities

U.S. Energy Policy Act (2005) Title VIII on Hydrogen

Authorizes U.S. DOE to lead a comprehensive program to enable commercialization of hydrogen and fuel cells with industry.

Includes broad applications: Transportation, utility, industrial, portable, stationary, etc.

Program to date

$100M to $250M per year

100 to 200+ projects per year

>100 organizations & extensive collaborations

Includes RD&D on:

H_2 production, delivery, storage, utilization (including fuel cells)

Crosscutting: Analysis, systems development/integration, safety, codes and standards, education & outreach

Progress

Snapshot of Hydrogen and Fuel Cells Applications in the U.S.

Examples of Applications

>500MW
Stationary Power

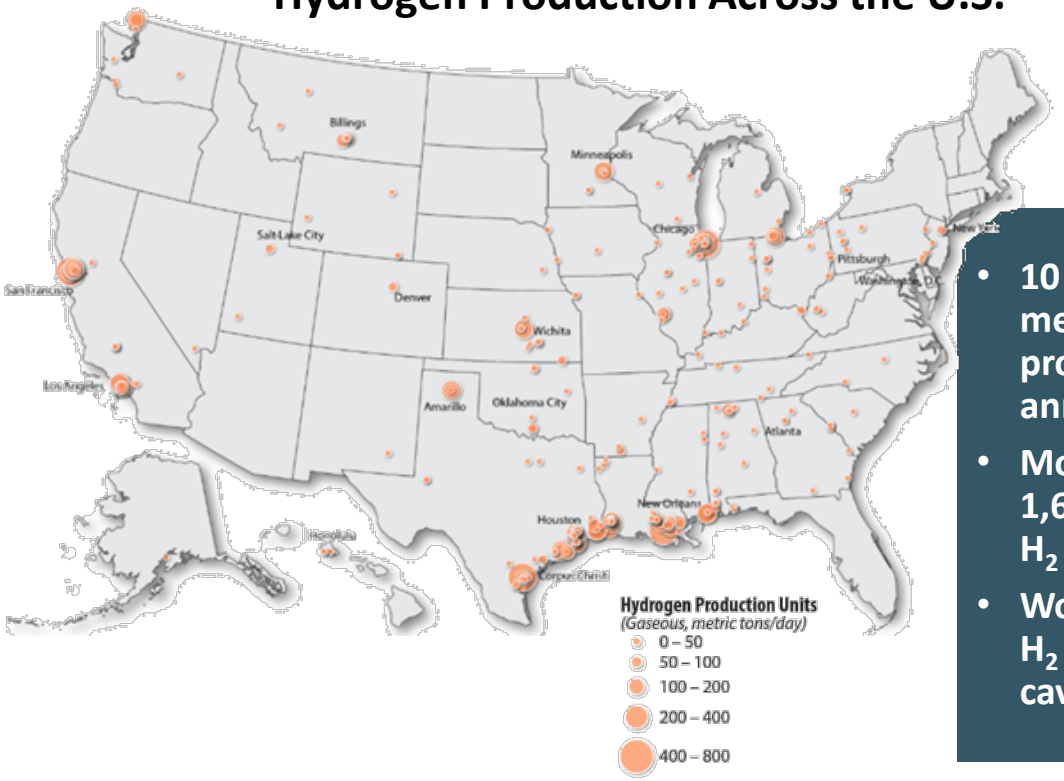
>30,000
Forklifts

>30
Fuel Cell Buses

>45
H_2 Retail Stations

>8,300
Fuel Cell Cars

Hydrogen Production Across the U.S.



- 10 million metric tons produced annually
- More than 1,600 miles of H_2 pipeline
- World's largest H_2 storage cavern

Hydrogen Stations: Examples of Plans Across States

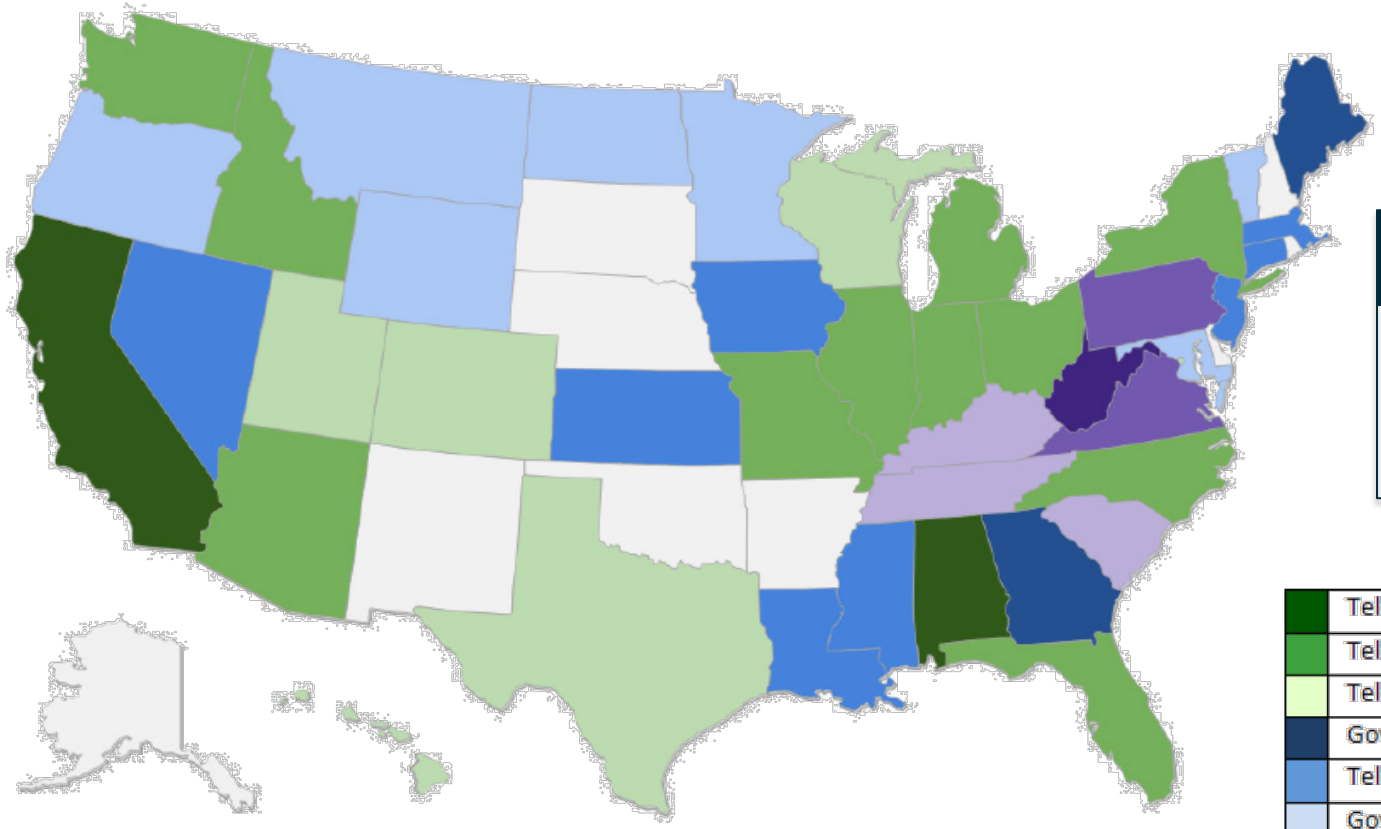
California
200 stations planned - CAFCP goal

Northeast
12 – 20 stations planned

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others with interest

Fuel cells operating all over the U.S.

Fuel cells used for backup power in more than 40 states



Over 500MW

in stationary fuel cell power installed

Telecom, Government, Railroad, Utility sites
Telecom, Government, Railroad sites
Telecom and Government sites
Government, Railroad, Utility sites
Telecom sites
Government sites
Railroad sites
Utility sites
Government and Railroad sites
Telecom and Railroad sites

Over 8,000 backup power units

deployed or on order

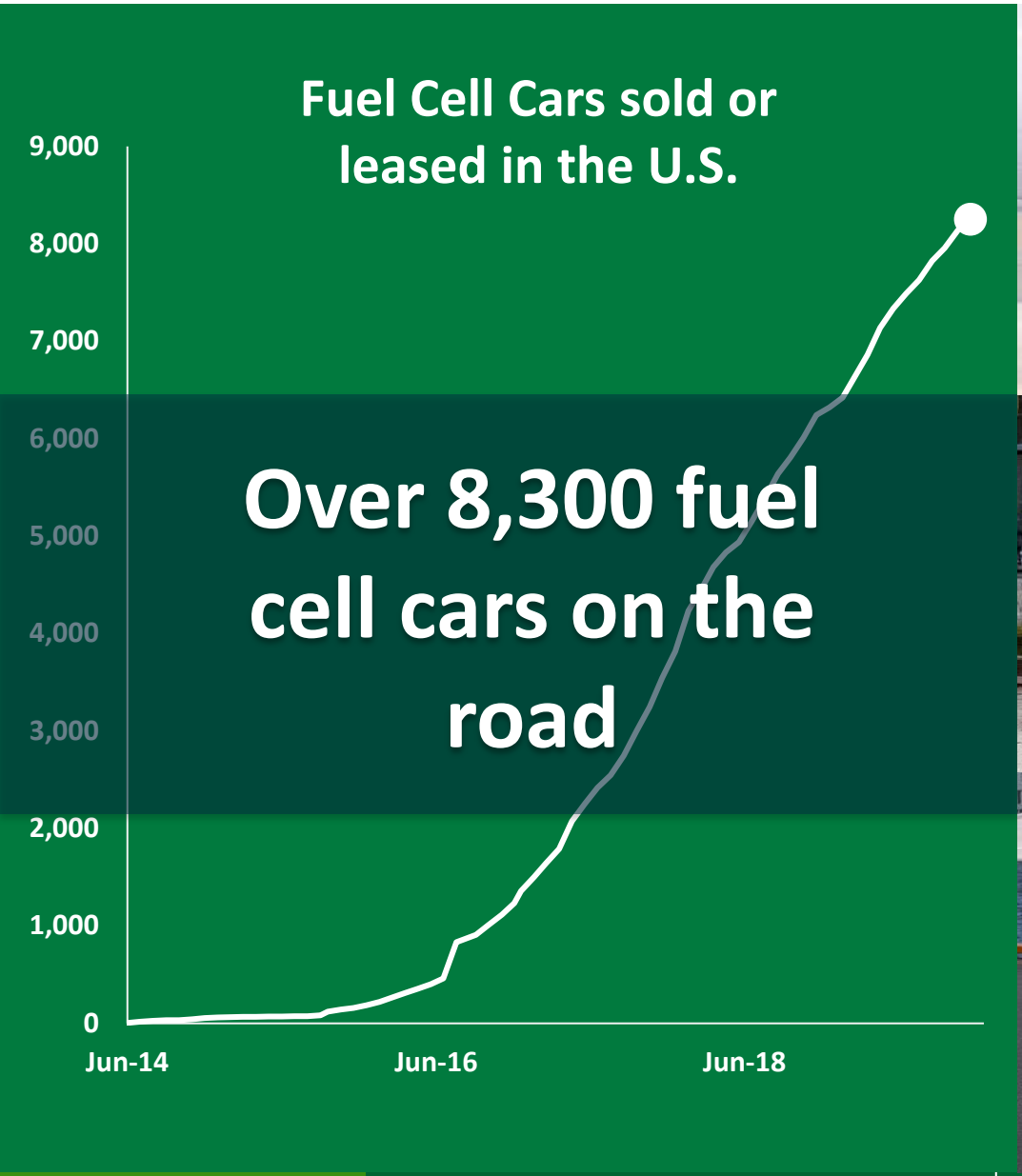
Source: DOE State of the States: Fuel Cells in 2016 Report

Material Handling Applications

More Than **30,000 Forklifts**

Over **22 Million Refuelings**

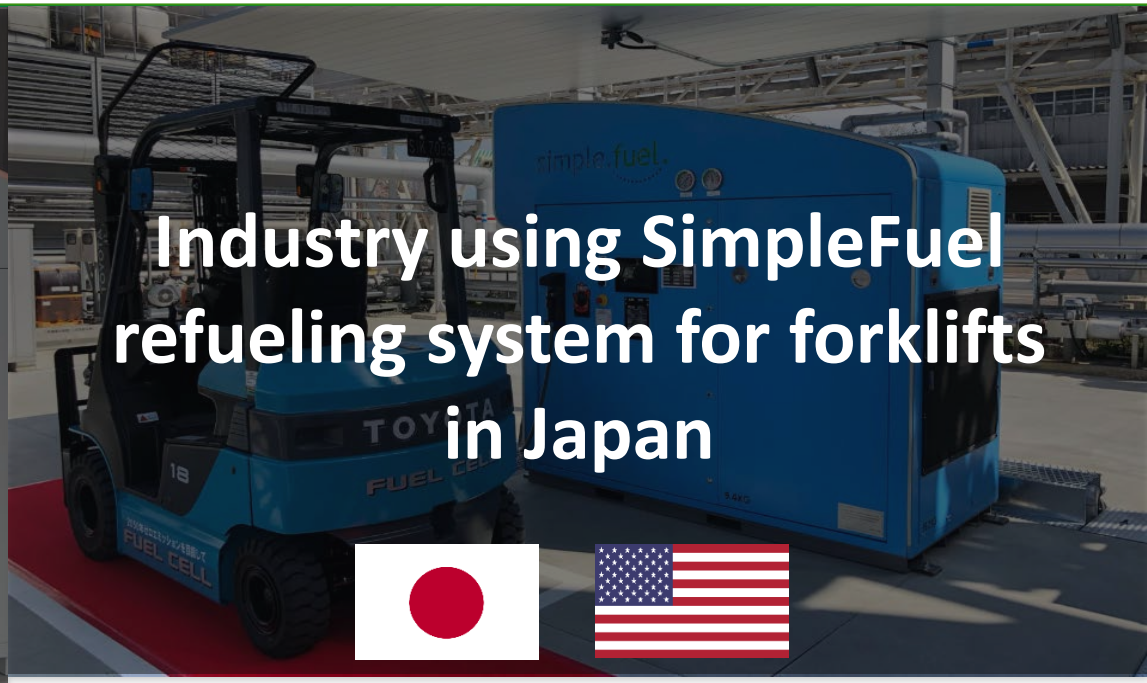
Hydrogen fuel cell cars on the road in select U.S. regions



Hydrogen stations growing, driven at the state-level

Complementing retail stations: H2Refuel H-prize

DOE awards $1M H-Prize to SimpleFuel for winner of small-scale H_2 fueling system



Industry using SimpleFuel refueling system for forklifts in Japan

simple.fuel.™

Ivys Energy Solutions (MA)
McPhya Energy (MA)
PDC Machines (PA)

Email:
connect@ivysinc.com

More info:
www.teamsimplefuel.com

H2refuel
U.S. Department of Energy

Bus and long-range, heavy duty applications emerging

UPS unveils first extended range fuel cell electric delivery vehicle

The Nikola Badger, a fuel cell truck with a 966 km range

ProGen-powered Fedex operates more than 10,000 miles on-road

1st Hydrogen ferry under construction in U.S.

More interest emerging in trucks and heavy-duty vehicles – State and regional emissions drivers

Industry Plans For Hydrogen Fuel Cell Trucks And Supporting Infrastructure Underway

Photo Credit: Toyota

Photo Credit: Nikola

ZH2: U.S. Army And GM Collaboration on Truck for Military Applications


Photo Credit: General Motors

R&D Needs and Program Overview

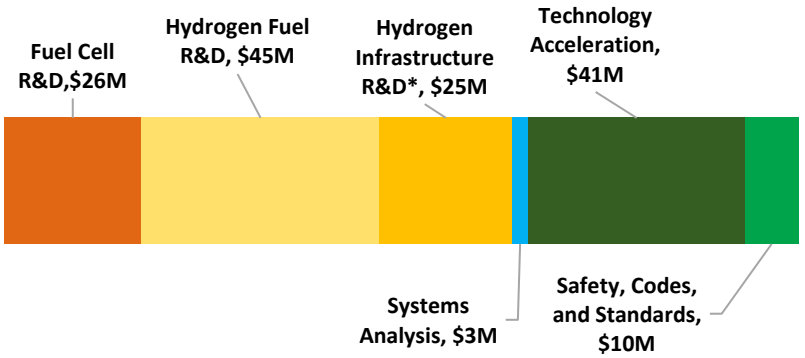
Budget

Fuel Cell Technologies Office (FCTO) within Energy Efficiency and Renewable Energy (EERE)

	FY 2018	FY 2019	FY 2020
Fuel Cell R&D	32,000	30,000	26,000
Hydrogen Fuel R&D	54,000	39,000	45,000
Hydrogen Infrastructure R&D*	-	21,000	25,000
Technology Acceleration	19,000	21,000	41,000
Safety, Codes, and Standards	7,000	7,000	10,000
Systems Analysis	3,000	2,000	3,000
Total	**$115,000**	**$120,000**	**$150,000**

*Will be moved under Hydrogen Fuel R&D in FY 2021

FCTO – Hydrogen and Fuel Cells Breakdown FY 2020



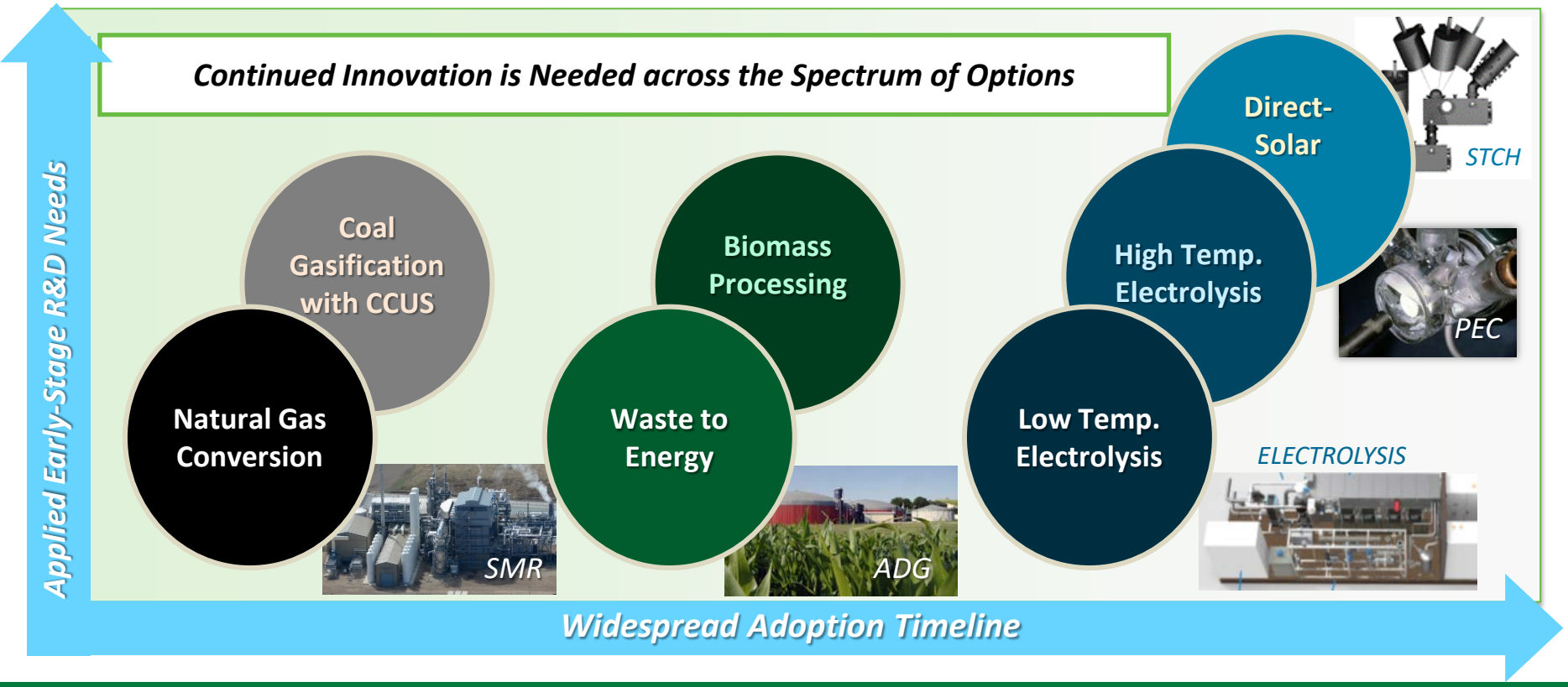
*Will be moved under Hydrogen Fuel R&D in FY 2021

DOE Hydrogen and Fuel Cells Appropriations

DOE Office	Funding (in thousands)
EERE (FCTO)	$150,000
Fossil Energy (SOFC)	$30,000
Nuclear Energy	$11,000*

* For coordination between NE and EERE FCTO on nuclear to hydrogen Office of Science, Basic Energy Sciences Funding is for FY18 ~ $19 million for projects relevant to H2 and fuel cells (e.g. catalysis, etc.); FY 20 TBD For coordinated project with EERE
ARPA-E- Funding based on specific program selected each year; FY20 TBD

H_2 Production Pathways of Interest



Low-cost hydrogen production from diverse domestic feedstocks & energy resources—enhancing long-term resiliency & opening regional market opportunities

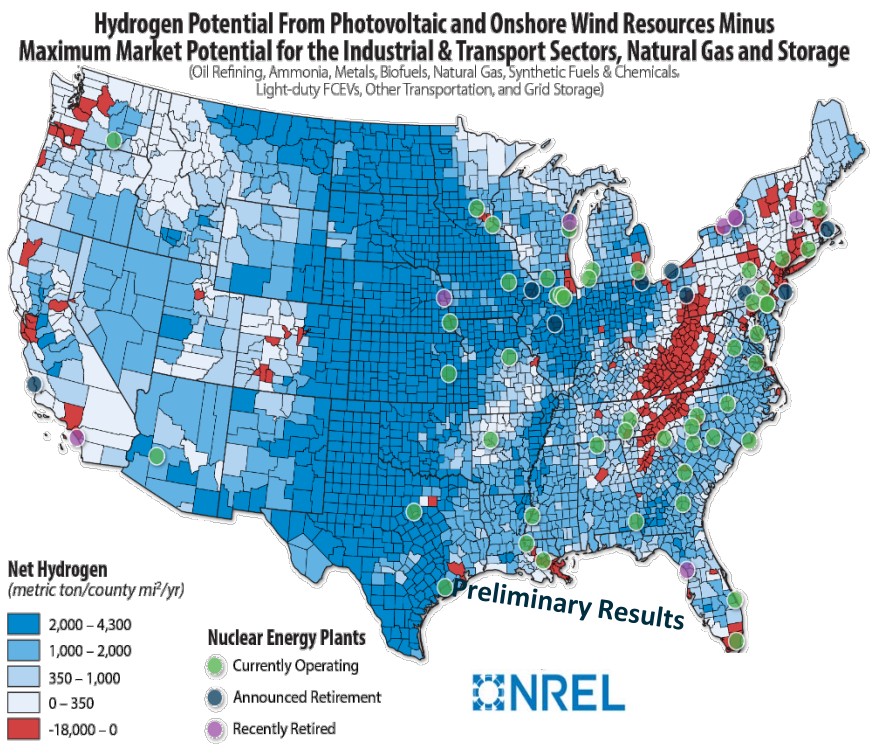
Examples of Activities to Enable H2@Scale

Assessing resource availability.
Most regions have sufficient resources.

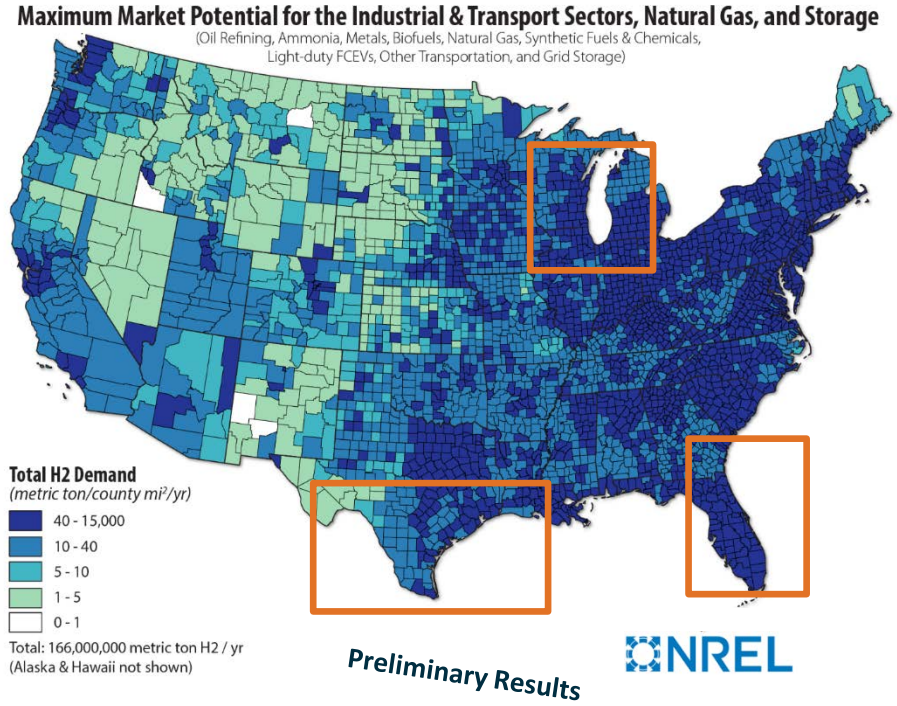
4 new H2@scale demonstration projects in Texas, Florida and Midwest.

Includes 1 project by Office of Nuclear Energy

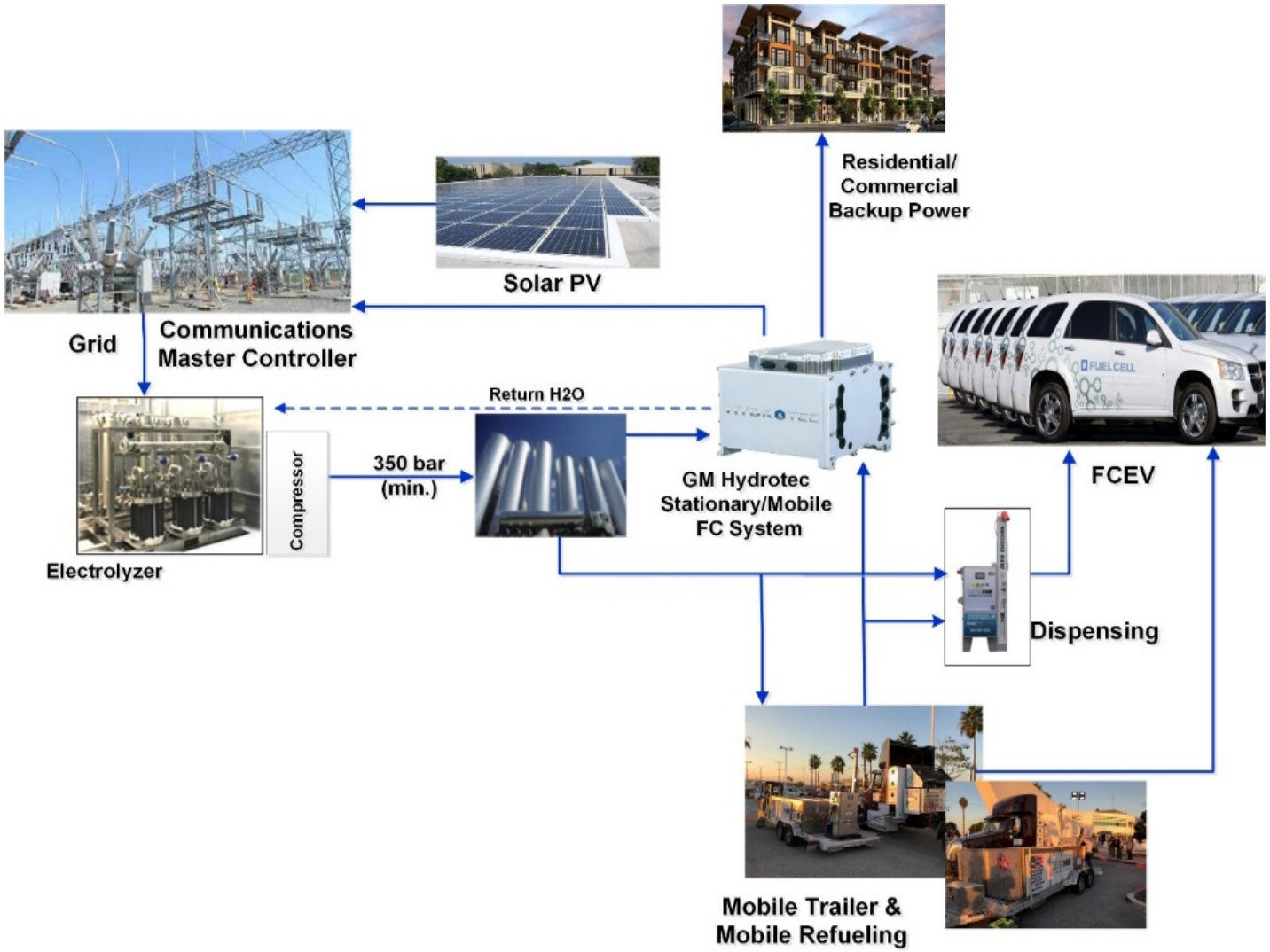
Hydrogen Availability



Hydrogen Demand Potential



Example of H2@Scale Project: Integrated Hydrogen Production and Consumption for Improved Utility Operations – Orlando, FL



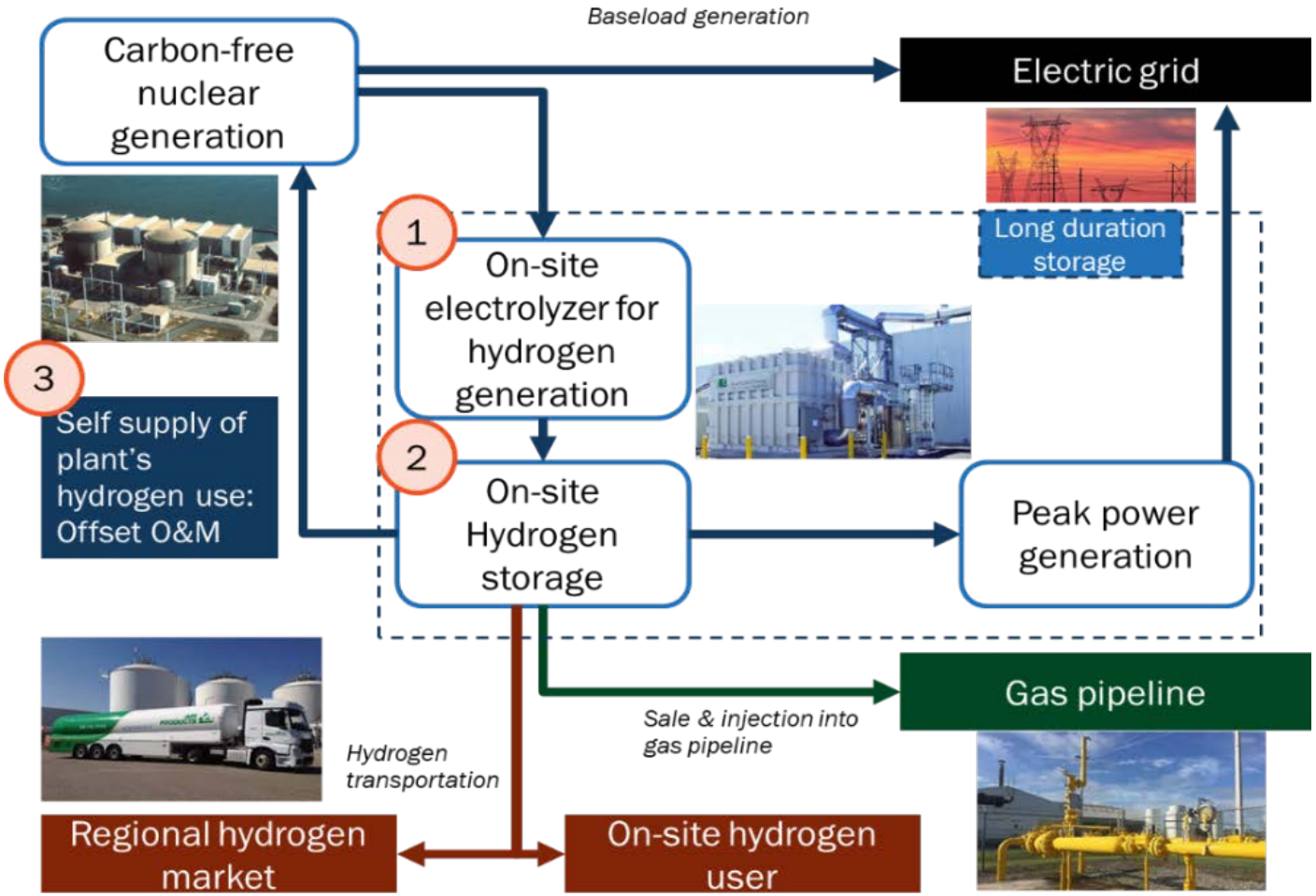
Partners
Giner ELX Inc.
Orlando Utilities Commission
General Motors
OneH2
UCF-FSEC

Duration
36 Months

Total Budget
~$8.5m

Note: Based on original submission. To be updated based on project finalization

Example of H2@Scale Project: Electrolyzer Operation at Nuclear Plant and In-House Hydrogen Supply



Partners

Exelon & Nel Hydrogen

INL

NREL

ANL

Duration

36 months

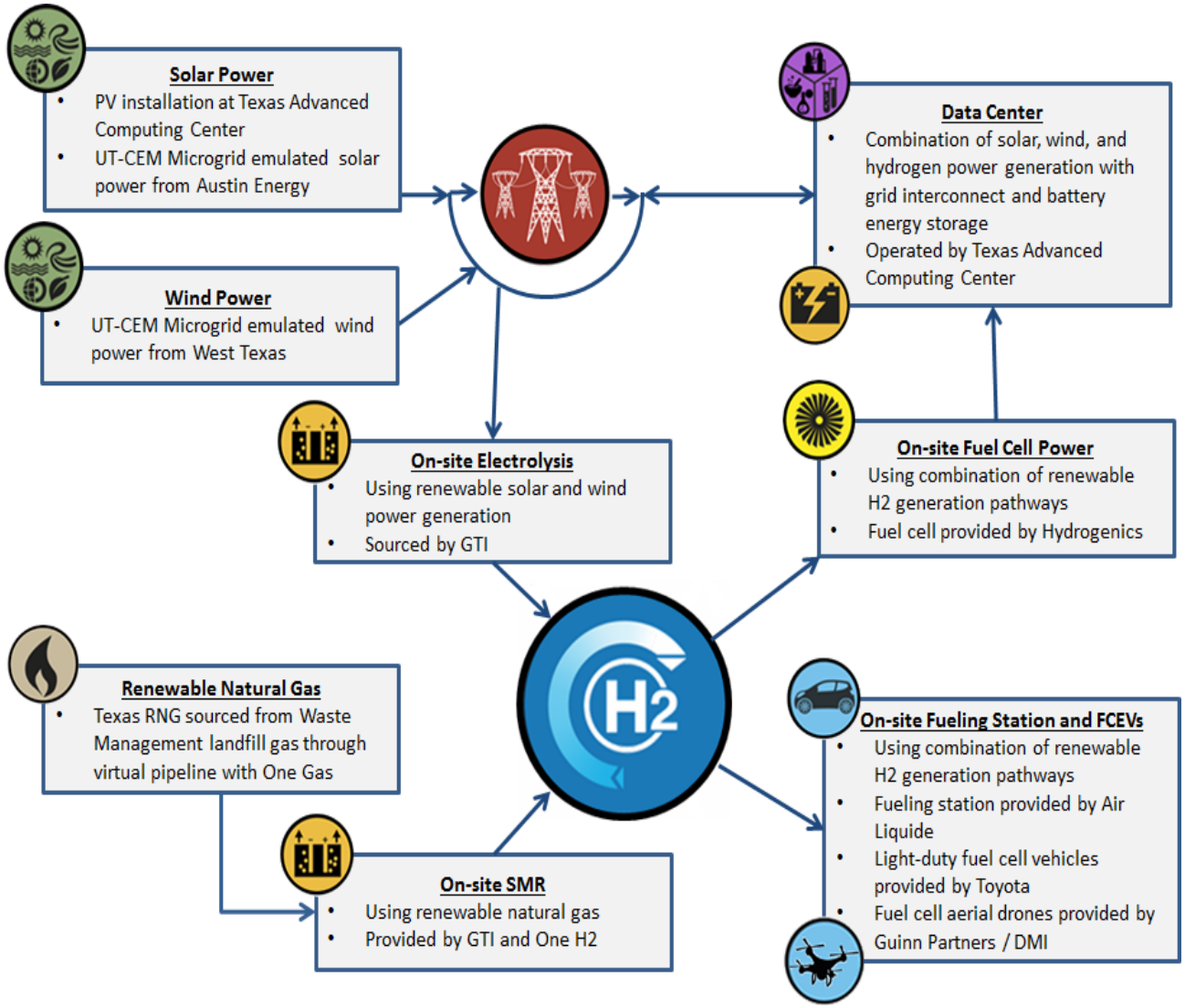
Total budget

$7.2M

Note: Based on original submission. To be updated based on project finalization

Example of H2@Scale Project: Demonstration and Framework for H2@Scale in Texas and Beyond

Integration Concepts Being Considered



Partners

Frontier Energy
University of Texas
GTI
Toyota
Air Liquide
Waste Management
OneH2
Hydrogenics

Duration

36 Months

Total budget

$12.7M

Note: Based on original submission. To be updated based on project finalization

Opportunities Identified in H2@Ports, H2@Rail, H2@Datacenters Workshops

H2@Datacenters

- **Collaboration between DOE, industry, end user**

- **RD&D & techno-economic assessment needs**

- Prime or backup power for critical loads of data centers
- Scenario development to enable cost effective fuel cells and hydrogen storage
- Potential additional revenue streams

H2@Ports

- **Collaboration between DOE, DOT - Maritime Administration, FCH JU, European Commission, global industry, end users and ports, states**

- **RD&D & techno-economic assessment needs**

- Power system options and TCO
- Cluster approach to increase scale
- Regulations and standards

H2@Rail

- **Collaboration between DOE, DOT - Federal Railroad Administration, global industry, end users, states**

- RD&D & techno-economic assessment needs

- Prime power system development
- Rail system operations and TCO
- Regulations, safety, codes, standards

TCO: Total cost of ownership

Workshop details available at: www.energy.gov/eere/fuelcells/workshop-and-meeting-proceedings

Targets to Guide Long Term R&D for Heavy-Duty Vehicles

Fuel Cell Truck Targets Developed To Enable Comparable Total Cost Of Ownership With Diesel Trucks

hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf

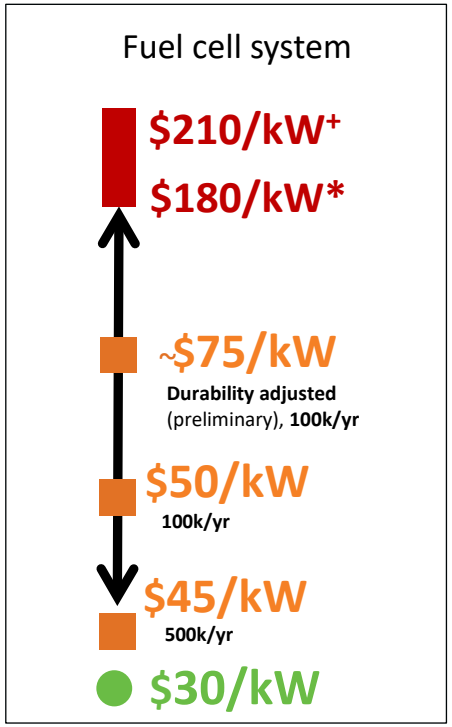
Table 1. Technical System Targets: Class 8 Long-Haul Tractor-Trailers

Characteristic	Units	Targets for Class 8 Tractor-Trailers	
		Interim (2030)	Ultimate[9]
Fuel Cell System Lifetime[1,2]	hours	**25,000**	**30,000**
Fuel Cell System Cost[1,3,4]	$/kW	**80**	**60**
Fuel Cell Efficiency (peak)	%	**68**	**72**
Hydrogen Fill Rate	kg H_2/min	**8**	**10**
Storage System Cycle Life[5]	cycles	**5,000**	**5,000**
Pressurized Storage System Cycle Life[6]	cycles	**11,000**	**11,000**
Hydrogen Storage System Cost[4,7,8]	$/kWh ($/kg H_2 stored)	**9 (300)**	**8 (266)**

Developed through industry workshop, input and analysis on long term stretch goals to guide R&D community

R&D focus is on Affordability and Performance: DOE Targets Guide R&D

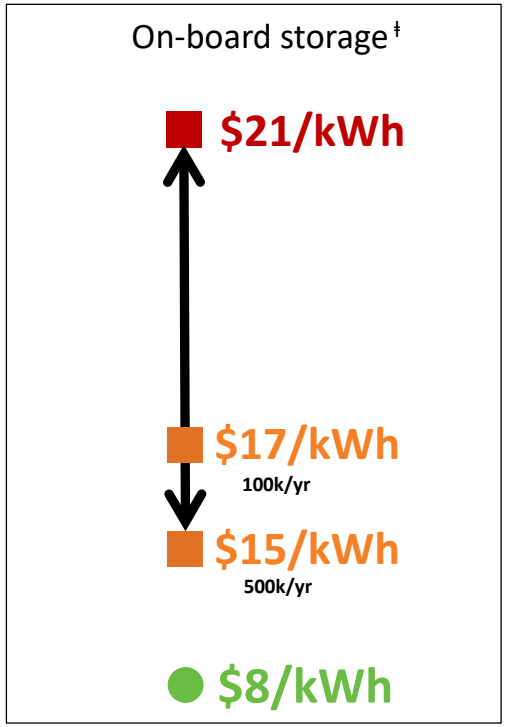
Fuel Cell R&D



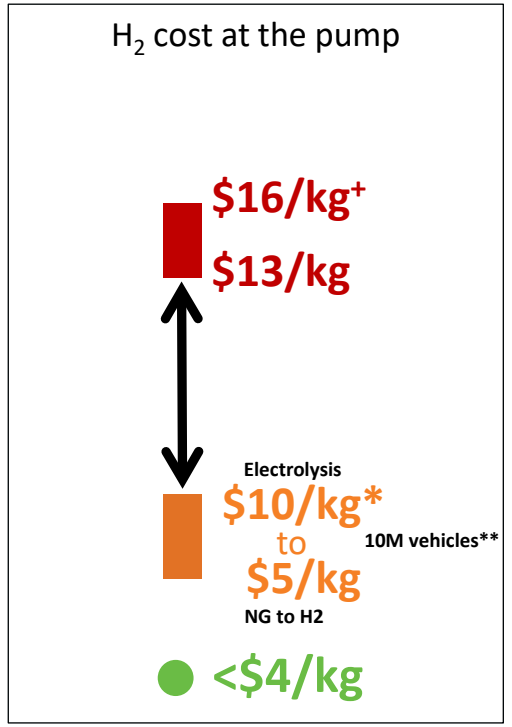
†Based on commercially available FCEVs

*Based on state of the art technology

Hydrogen R&D



ǂ Storage costs based on preliminary 2019 storage cost record



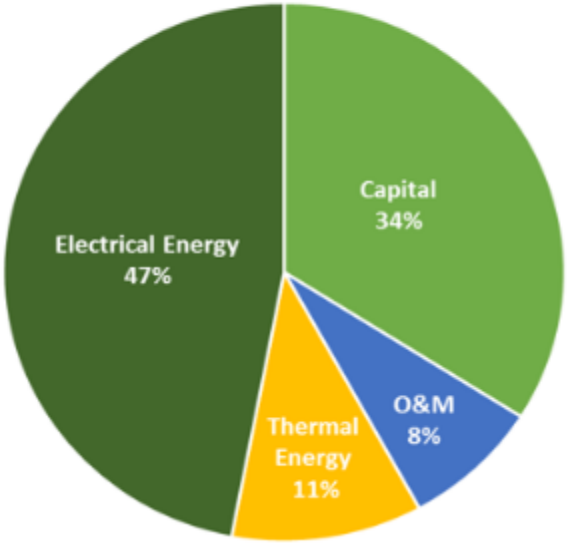
†For range: H2 production from natural gas (NG), delivered dispensed at today's (2018) stations (~180kg/d)

*For range: Assumes high volume manufacturing in 1) H2 production costs ranging from $2/kg (NG) to $5/kg (electrolysis manufactured at 700 MW/year), and 2) Delivery and dispensing costs ranging from $3/kg (advanced tube trailers) to $5/kg (liquid tanker or advanced pipeline technologies).

** Range assumes >10,000 stations at 1,000 kg/day capacity, to serve 10 million vehicles

Hydrogen R&D Areas – Examples

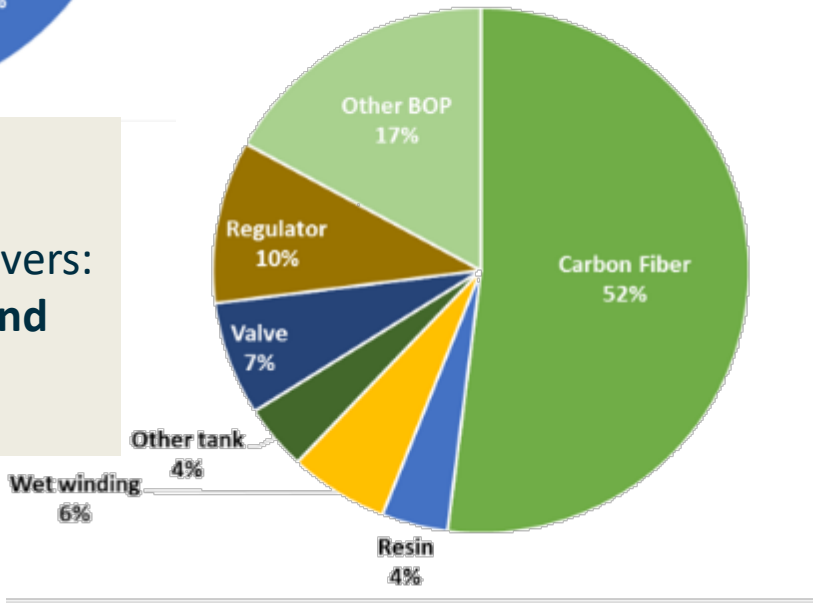
Hydrogen Production Cost
(High Temperature Electrolysis)



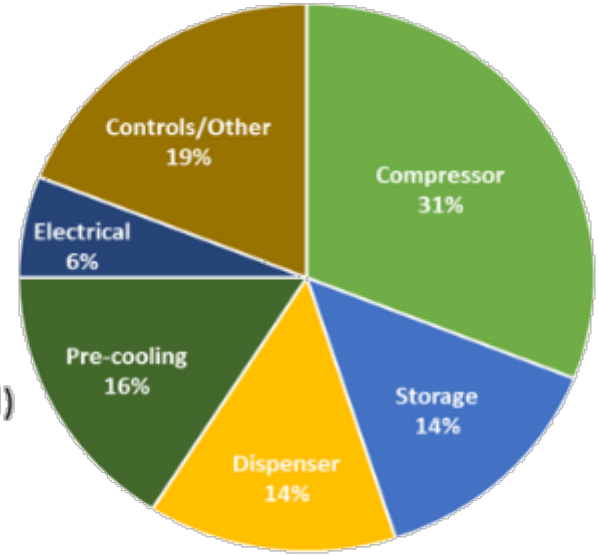
H_2 Production (Electrolysis) Cost Drivers:
Electrical energy and capital costs

H_2 Onboard Storage Cost Drivers:
Carbon Fiber Precursors and Processing

Hydrogen Storage Cost
(Onboard 700 Bar Hydrogen Storage Vessel)



Hydrogen Infrastructure Cost
(700 Bar Hydrogen Station)

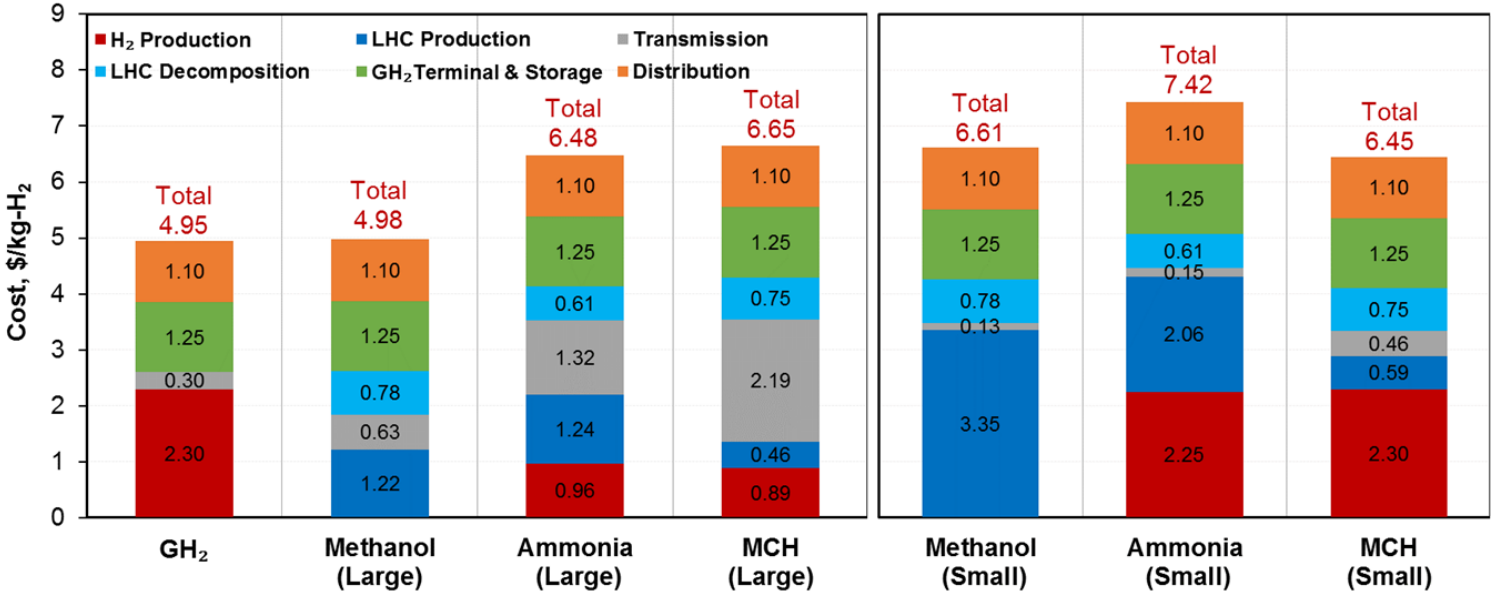


H_2 Infrastructure Cost Drivers:
Compressors and Storage

Note: Updates to be published May, 2020

Example of Recent Hydrogen Carriers Analysis

- **Preliminary analysis shows cost of transporting H_2 in carriers ranges between ~$5/kg and $7.50/kg**
- **At large volumes, methanol is competitive with compressed H_2 even when transported 3,000 km from gulf coast**

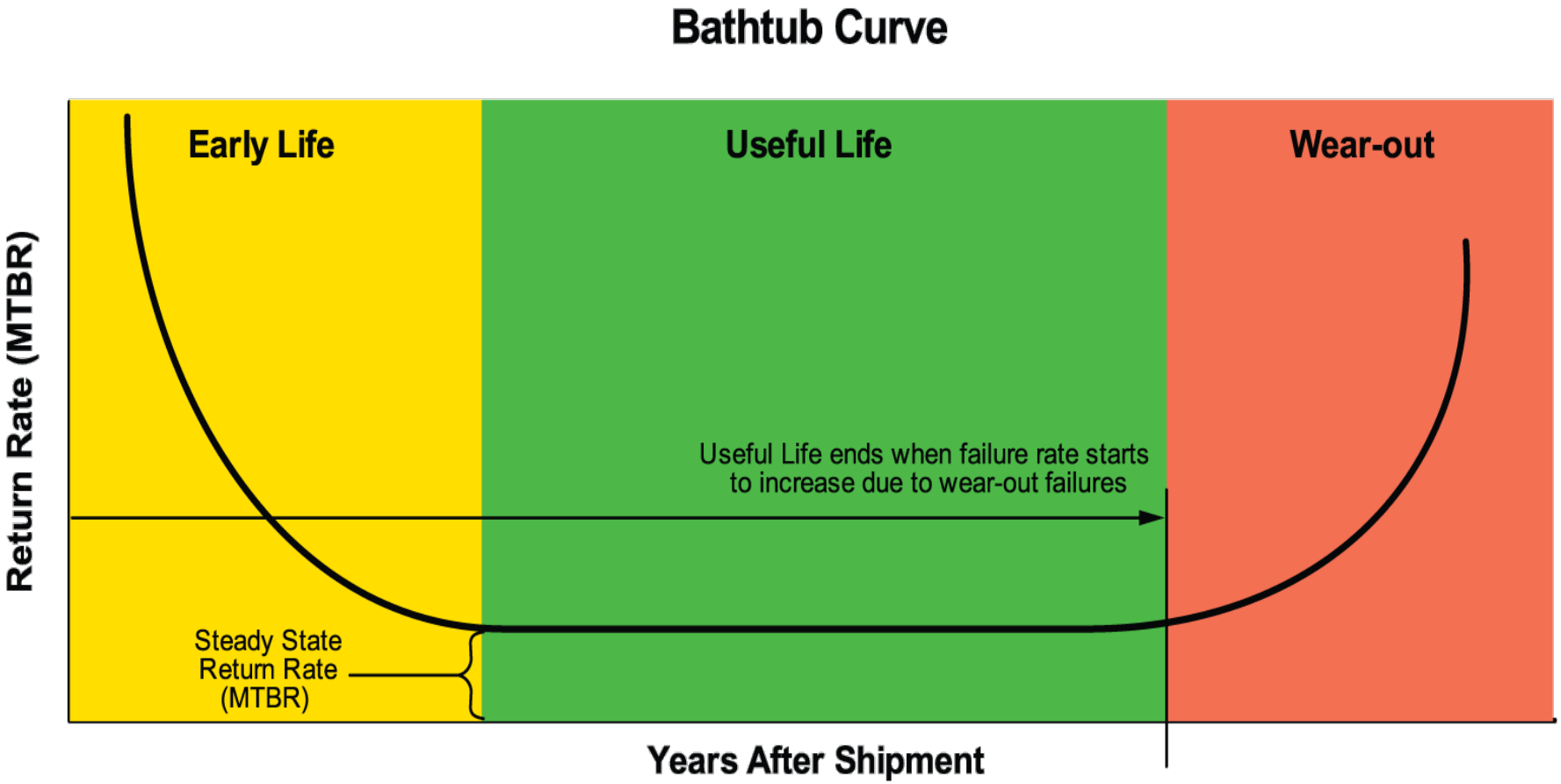


Analysis planned between ANL and Chiyoda

Source: Argonne National Laboratory

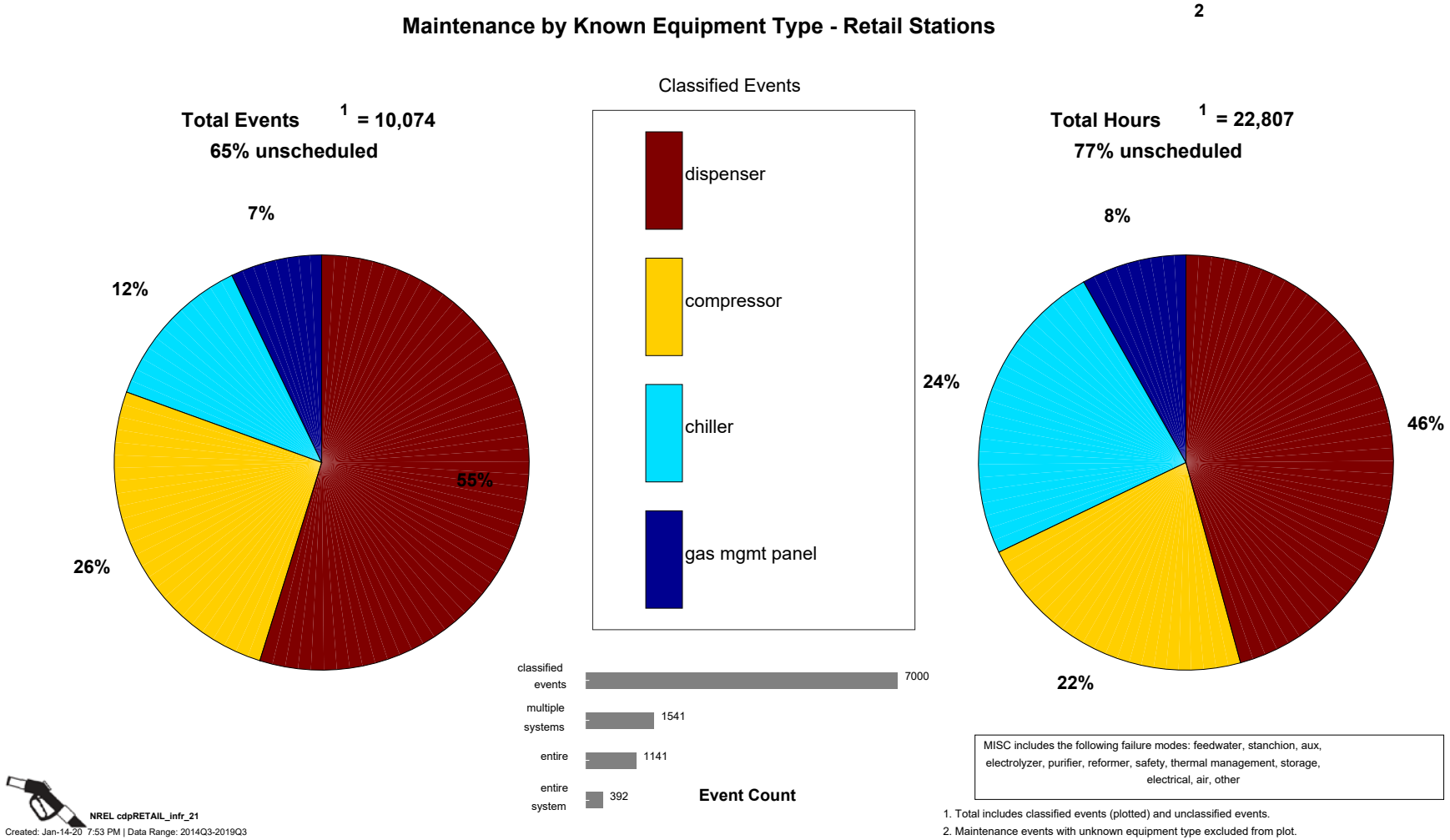

Real world data collection, sharing and analysis are key tools to enable collective progress addressing technical issues

Example from Reliability Engineering



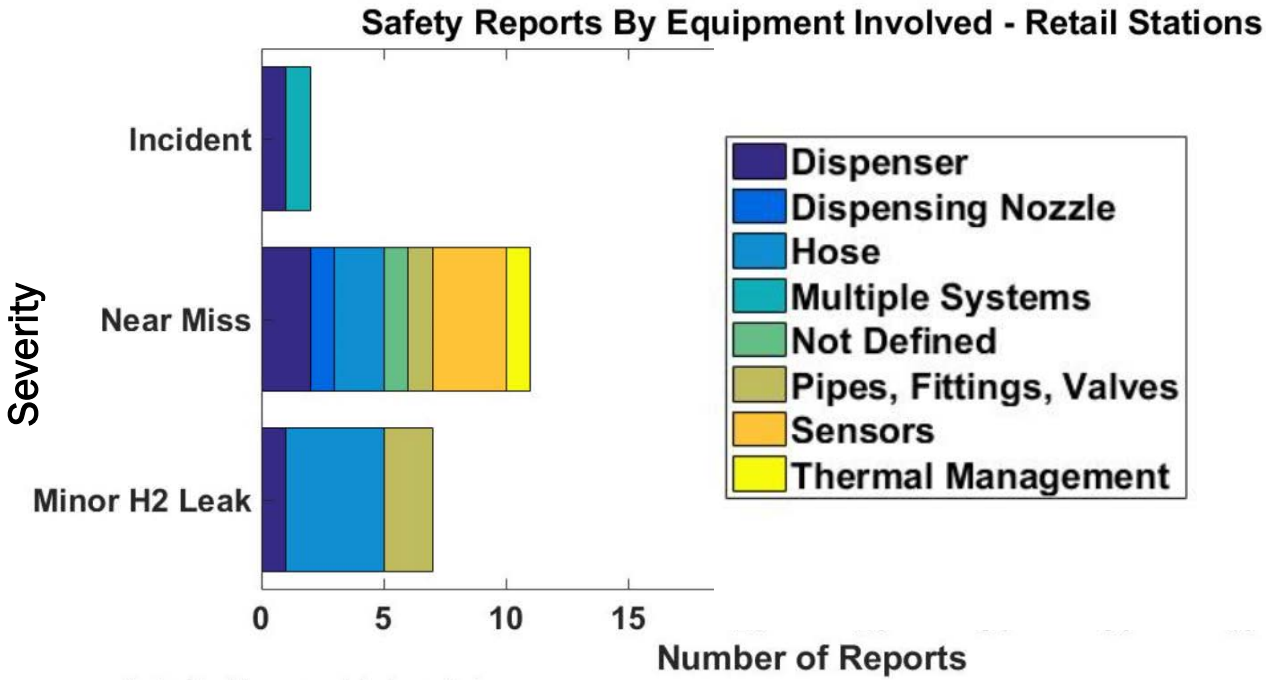
Hydrogen Infrastructure Maintenance by Equipment Type

National Fuel Cell Technical Evaluation Center (NFCTEC) at DOE's National Renewable Energy Laboratory (NREL) collects data to inform future work



1. Total includes classified events (plotted) and unclassified events.
2. Maintenance events with unknown equipment type excluded from plot.

Safety Incident Reports by Type



An Incident is an event that results in:
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites
- release of any volatile, hydrogen containing compound (including the hydrocarbons used as common fuels)

A Near Miss is:
- an event that under slightly different circumstances could have become an incident
- any hydrogen release sufficient to sustain a flame if ignited

A Minor H2 Leak is:
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite

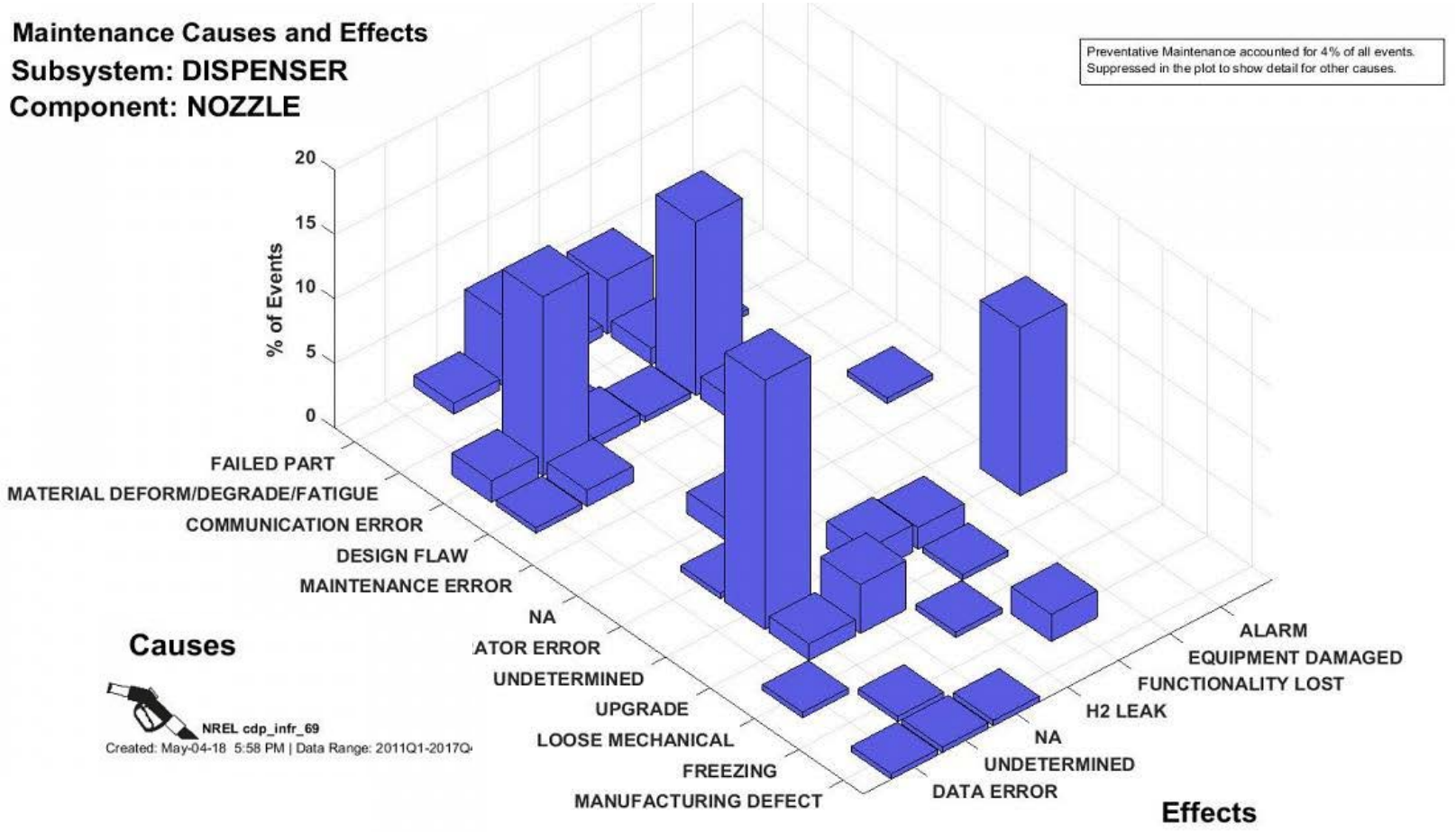
NREL cdpRETAIL_infr_32
Created: Mar-18-19 12:42 PM | Data Range: 2014Q3-2018Q4

Contact:

techval@nrel.gov
or
fuelcells@ee.doe.gov

Cause and Effect Analysis of Hydrogen Infrastructure Incidents

Example of Cause and Effect Analysis



Example of insight on hydrogen components safety

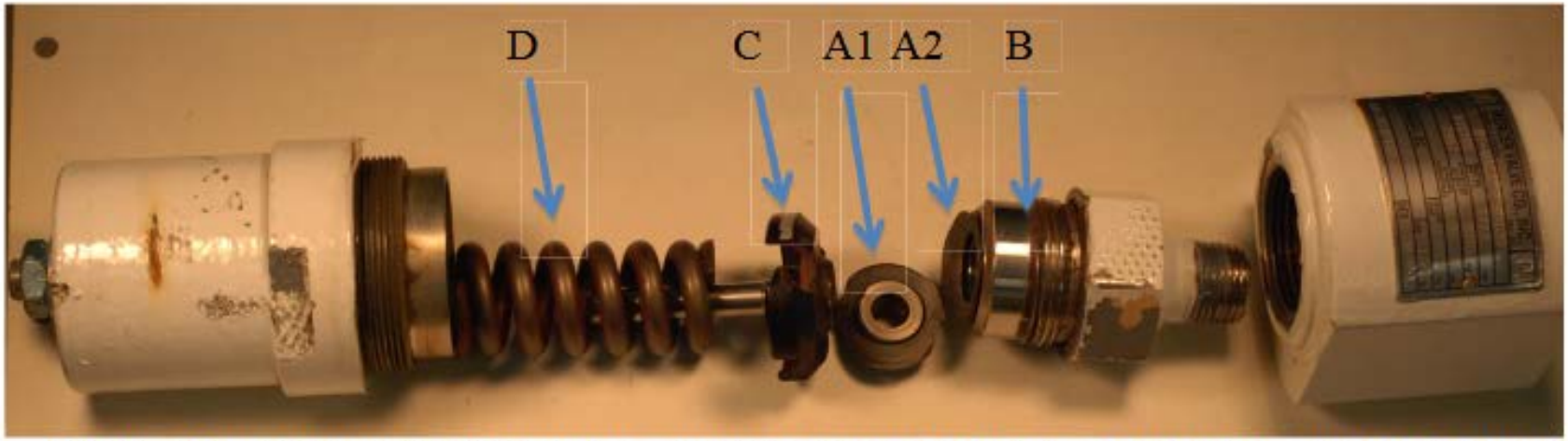


Figure A2. pressure relief valve components: failed nozzle subassembly (A1 and A2); inlet base (B); disk subassembly (C); set spring (D).

Pressure relief valve failure caused hydrogen release- led to safety concerns and evacuation

Type 440C Stainless Not Suitable For This Application

Example of insight on hydrogen component reliability

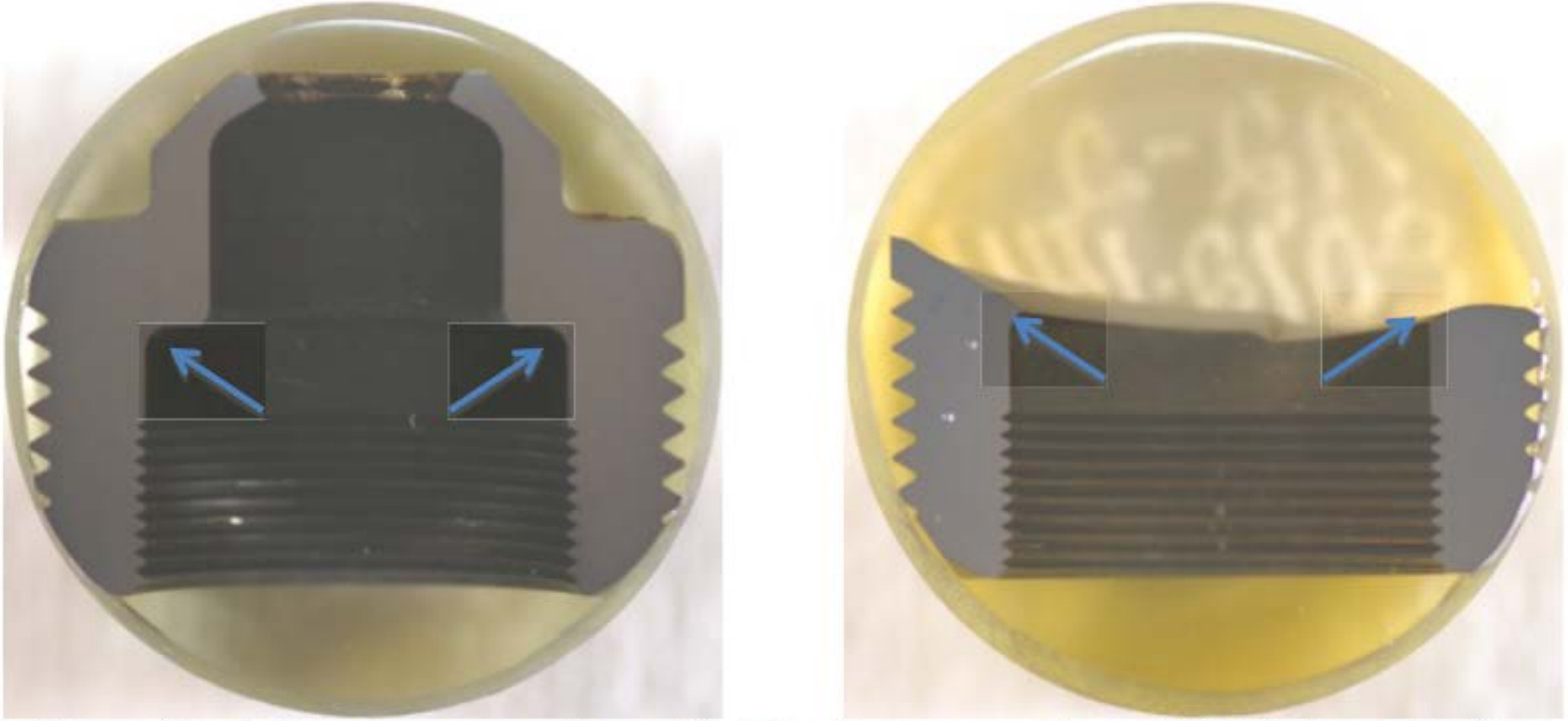


Figure A5. Polished cross sections of (a) functioning nozzle and (b) failed nozzle. The arrows indicate the internal corner associated with failure of the nozzle.

Type 440C Stainless Not Suitable For This Application

Source: prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2012/128642.pdf

Example of Collaboration: Global Center for H_2 Safety (CHS)

IPHE Steering Committee action: Increase awareness of safety partnership. Promotes safe operation, handling and use of hydrogen across all applications.

IPHE Hydrogen Council

AIChE Pacific Northwest National Laboratory

Includes over 40 partners from industry, government and academia

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

HYDROGEN Safety Panel

HYDROGEN Emergency Response Training Resources

Access to >110 countries, 60,000 members

Fact Sheet Translated into Japanese

CENTER FOR 水素安全センター Hydrogen SAFETY
Connecting a Global Community

水素は、石油、風力、太陽光、その他のエネルギー資源から作られている。水素はエネルギーキャリアーとして注目されている。

化学工業 石油精製 電子工業 医薬品業界

世界中では毎年7,000万トンの水素が産業用途として生産されている。

輸送分野の水素利用:

汚染物質、炭素排出量、騒音の削減手段として、トラックや船舶にゼロエミッションの燃料電池活用への関心が急速に高まっている。

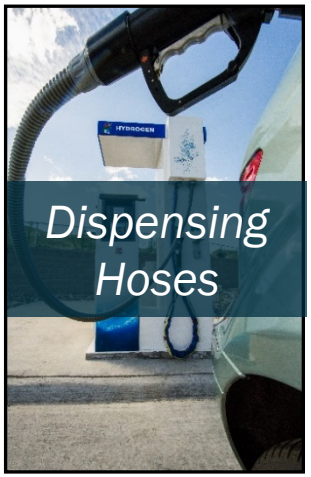
60 輌 燃料電池電車

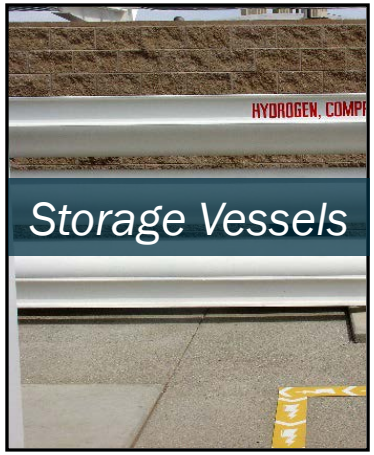
www.aiche.org/CHS

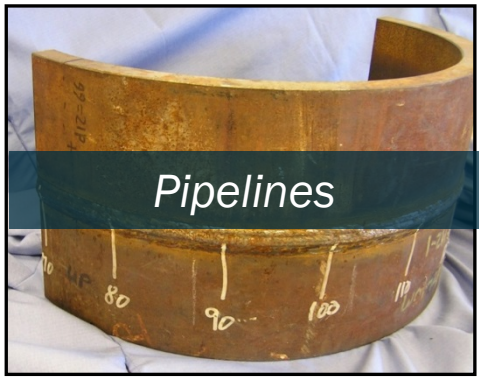
Cross-cutting Materials Compatibility R&D

H-Mat SM Hydrogen Materials Compatibility Consortium

H-Mat Consortium launched in FY18 to conduct R&D on hydrogen effects on polymers and metals







Focus of current activities include:

1) **Reduce expansion of seals in hydrogen by 50%**
2) **Enhance life of vessels by 50% through improved understanding of crack nucleation.**
3) **Enhance fracture toughness of high-strength (>950 MPa) steels by 50%.**

Sandia National Laboratories | Pacific Northwest National Laboratory | Oak Ridge National Laboratory | Savannah River National Laboratory (Operated by Savannah River Nuclear Solutions) | Argonne National Laboratory

For more information
energy.gov/eere/fuelcells/h-mat-hydrogen-materials-consortium
h-matinfo@pnnl.gov


Collaboration Is Key

Global government partnership to accelerate progress on hydrogen and fuel cells

The International Partnership for Hydrogen and Fuel Cells in the Economy

Enabling the global adoption of hydrogen and fuel cells in the economy

Elected Chair and Vice-Chair, 2018

Working Groups: Education & Outreach
Regulations, Codes, Standards & Safety

Top Priorities	SHARE INFORMATION	INFORM FUTURE GOVERNMENT RD&D	FOSTER COLLABORATION

Mission Innovation Hydrogen Challenge 2017

Clean Energy Ministerial New Hydrogen Initiative Launched 2019

Find IPHE on Facebook, Twitter and LinkedIn
Follow IPHE **@The_IPHE**

www.iphe.net

Formed 2003
19 Countries and EC

Hydrogen Energy Ministerial (HEM)

International Energy Agency (IEA)

Information available and IPHE actions underway

Regulations, Codes, Standards and Safety (RCSS)

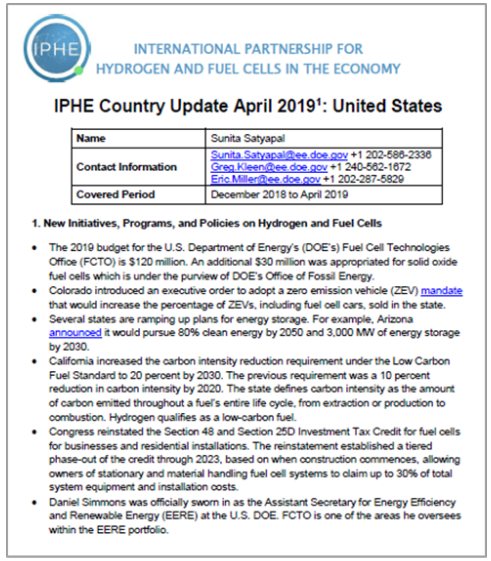
Fosters RCS harmonization across countries

Shares safety information, best practices, lessons learned

Education and Outreach (E&O)

- **Creates unbiased factual** materials for each country
- **Increases stakeholder engagement** through workshops, policy forum events, education events
- **Shares information** on status, gaps, analysis, policies, opportunities, and more

Examples of IPHE Member Deliverables - Country Updates



INTERNATIONAL PARTNERSHIP FOR HYDROGEN AND FUEL CELLS IN THE ECONOMY

IPHE Country Update April 2019[1]: United States

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Covered Period	December 2018 to April 2019

1. New Initiatives, Programs, and Policies on Hydrogen and Fuel Cells

- The 2019 budget for the U.S. Department of Energy's (DOE's) Fuel Cell Technologies Office (FCTO) is $120 million. An additional $30 million was appropriated for solid oxide fuel cells which is under the purview of DOE's Office of Fossil Energy.
- Colorado introduced an executive order to adopt a zero emission vehicle (ZEV) mandate that would increase the percentage of ZEVs, including fuel cell cars, sold in the state.
- Several states are ramping up plans for energy storage. For example, Arizona announced it would pursue 80% clean energy by 2050 and 3,000 MW of energy storage by 2030.
- California increased the carbon intensity reduction requirement under the Low Carbon Fuel Standard to 20 percent by 2030. The previous requirement was a 10 percent reduction in carbon intensity by 2020. The state defines carbon intensity as the amount of carbon emitted throughout a fuel's entire life cycle, from extraction or production to combustion. Hydrogen qualifies as a low-carbon fuel.
- Congress reinstated the Section 48 and Section 25D Investment Tax Credit for fuel cells for businesses and residential installations. The reinstatement established a tiered phase-out of the credit through 2023, based on when construction commences, allowing owners of stationary and material handling fuel cell systems to claim up to 30% of total system equipment and installation costs.
- Daniel Simmons was officially sworn in as the Assistant Secretary for Energy Efficiency and Renewable Energy (EERE) at the U.S. DOE. FCTO is one of the areas he oversees within the EERE portfolio.

Task Force on H_2 production methodology

Analysis to facilitate international H2 trade & guide 'certificate' of origin method formulation

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Save the Date – March 18: Hydrogen as main topic in upcoming Nuclear Innovation Clean Energy Future (NICE) webinar

NICE Future NUCLEAR INNOVATION: CLEAN ENERGY FUTURE
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

IPHE

HYDROGEN INITIATIVE
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

Opportunities for Hydrogen

Topic

In the lead up to the June 2020 Eleventh CEM meeting in Viña del Mar Chile, tune in to the webinar and hear how ministers and stakeholders plan to accelerate action to realize hydrogen's potential. Hear from experts from the United States, Canada, Japan and the IEA about new technologies in this arena that advance a clean and integrated systems approach.

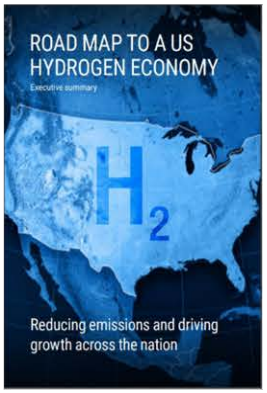
When

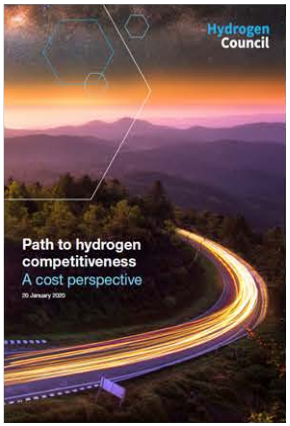
March 18, 2020, 8:00 am – 9:30 am EST

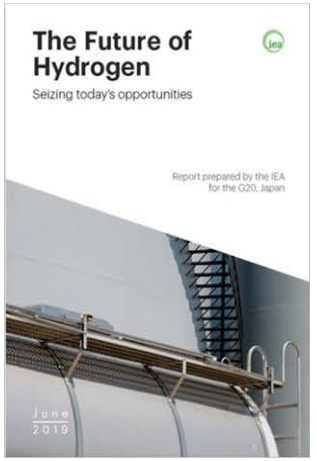
Where To Register

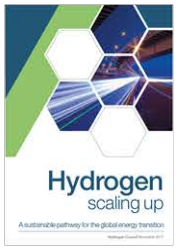
attendee.gotowebinar.com/register/8279771562413966605

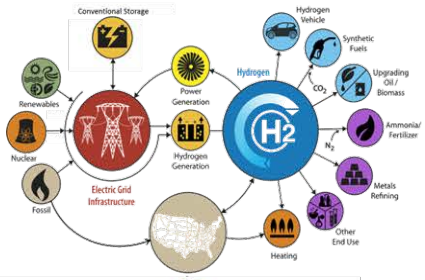
"Hydrogen – at Scale and Sector Coupling" – A Common Vision Across Multiple Regions in the World



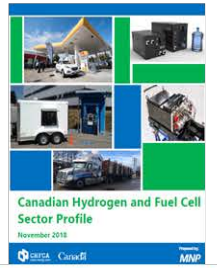






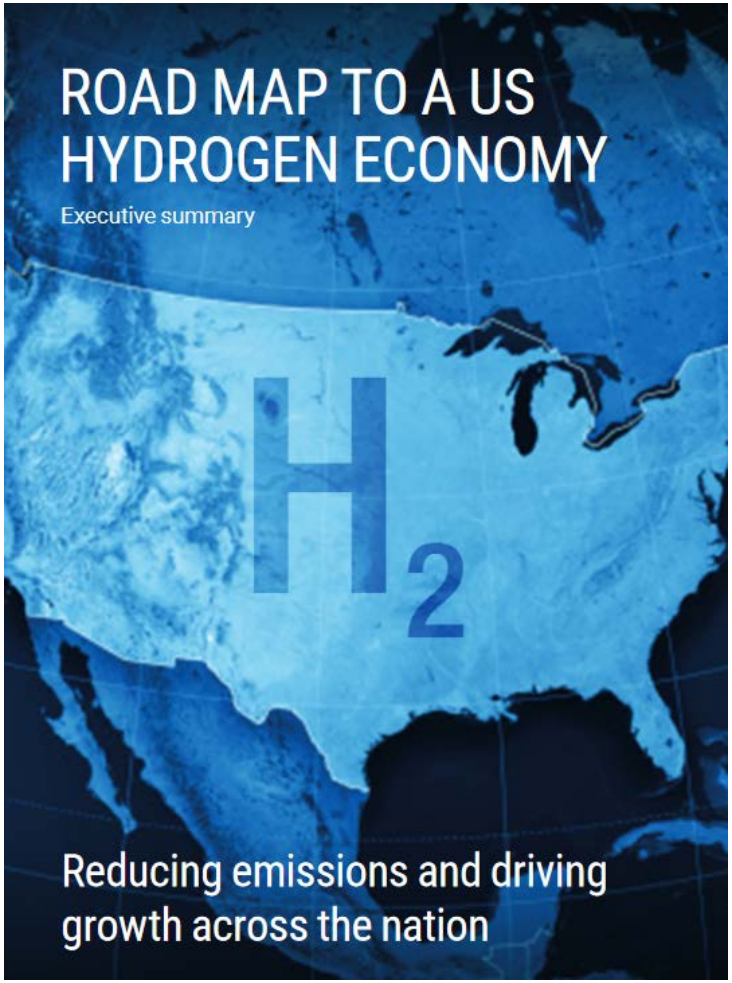


Global Action Agenda released at Hydrogen Energy Ministerial, Tokyo (9/25/2019)
Aspirational Targets: "10, 10, 10"
10M systems, 10K stations, 10 years



High priority areas include: Global harmonization of codes and standards and addressing gaps, safety

Industry-Led Hydrogen Roadmap To Inform Stakeholders on Hydrogen Potential Across Sectors in the US

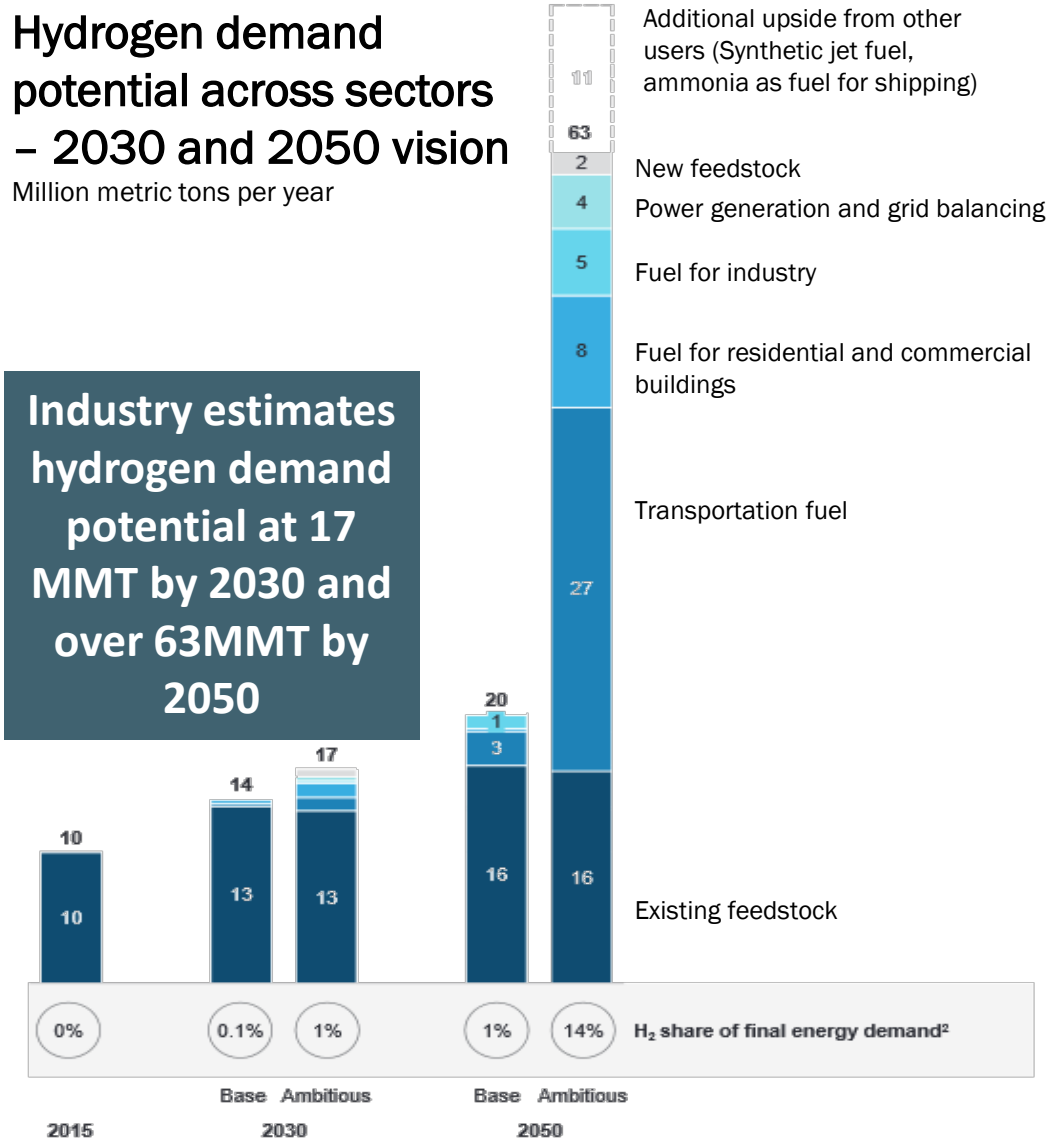


More info:
www.fchea.org/us-hydrogen-study

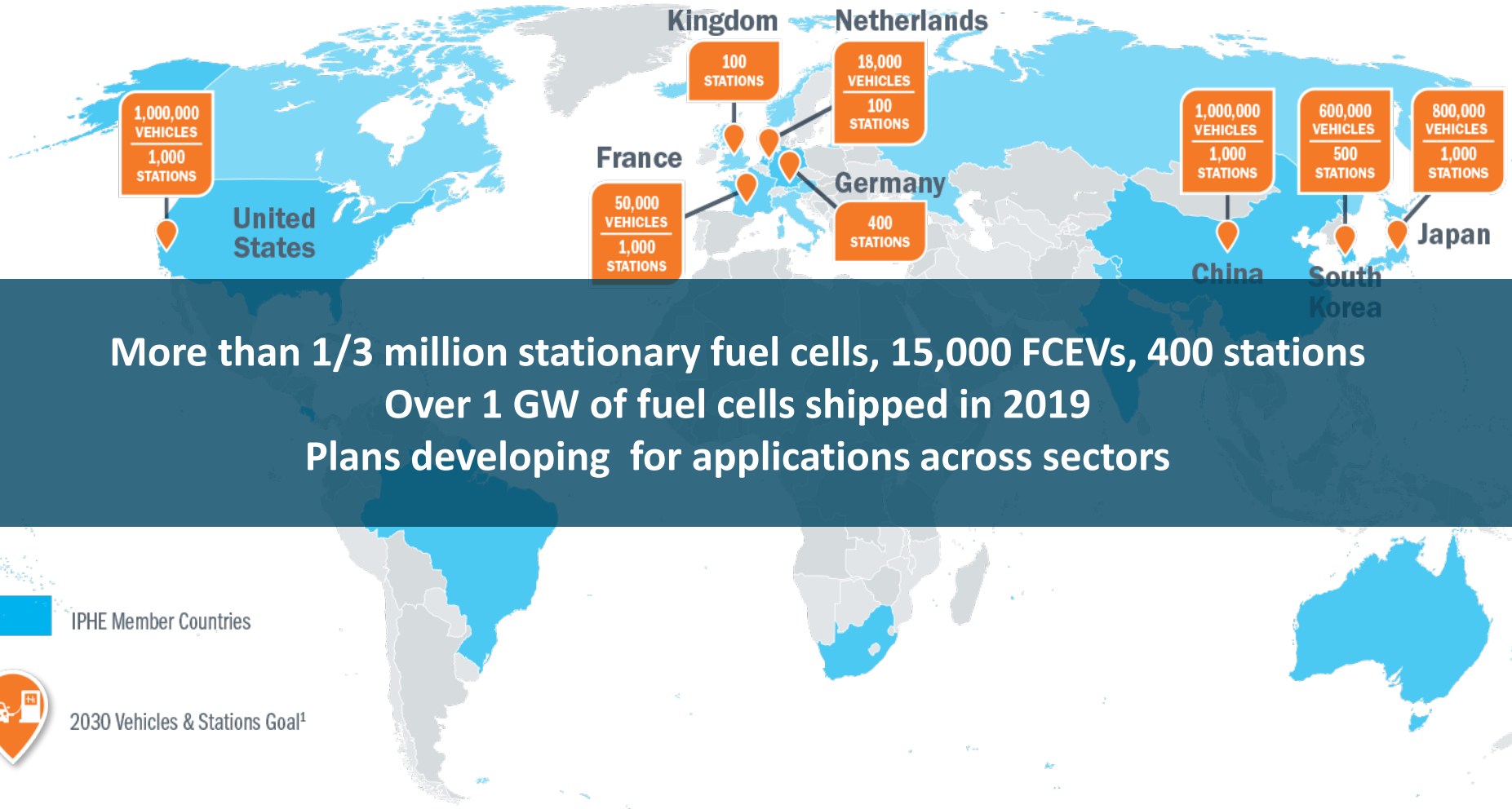
Hydrogen demand potential across sectors – 2030 and 2050 vision

Million metric tons per year

Industry estimates hydrogen demand potential at 17 MMT by 2030 and over 63MMT by 2050



Global Activities and Commitments are Strong



More than 1/3 million stationary fuel cells, 15,000 FCEVs, 400 stations
Over 1 GW of fuel cells shipped in 2019
Plans developing for applications across sectors

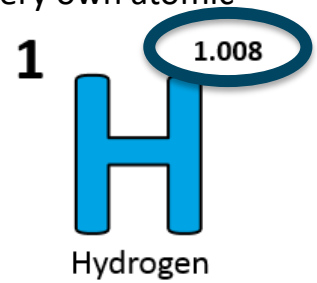
[1] IPHE Country Updates

Ways to increase awareness and outreach

Save the Date

May 19 – 21: 2020 Annual Merit Review and Peer Evaluation Meeting (AMR) for the DOE Hydrogen and Fuel Cells Program in Washington D.C.

Oct 8 - Hydrogen and Fuel Cells Day
(Held on its very own atomic-weight-day)



Resources

INCREASE YOUR H2IQ

Visit H2tools.org for hydrogen safety and lessons learned

Download the H2IQ resource for free:
energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Join monthly H2IQ hours to learn more about hydrogen and fuel cell topics
.energy.gov/eere/fuelcells/fuel-cell-technologies-office-webinars

Sign up to receive hydrogen and fuel cell updates
www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

Learn more at: energy.gov/eere/fuelcells or **hydrogen.energy.gov**

Thank You

DOE Hydrogen and Fuel Cells Program

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www.energy.gov/fuelcells
www.hydrogen.energy.gov