U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

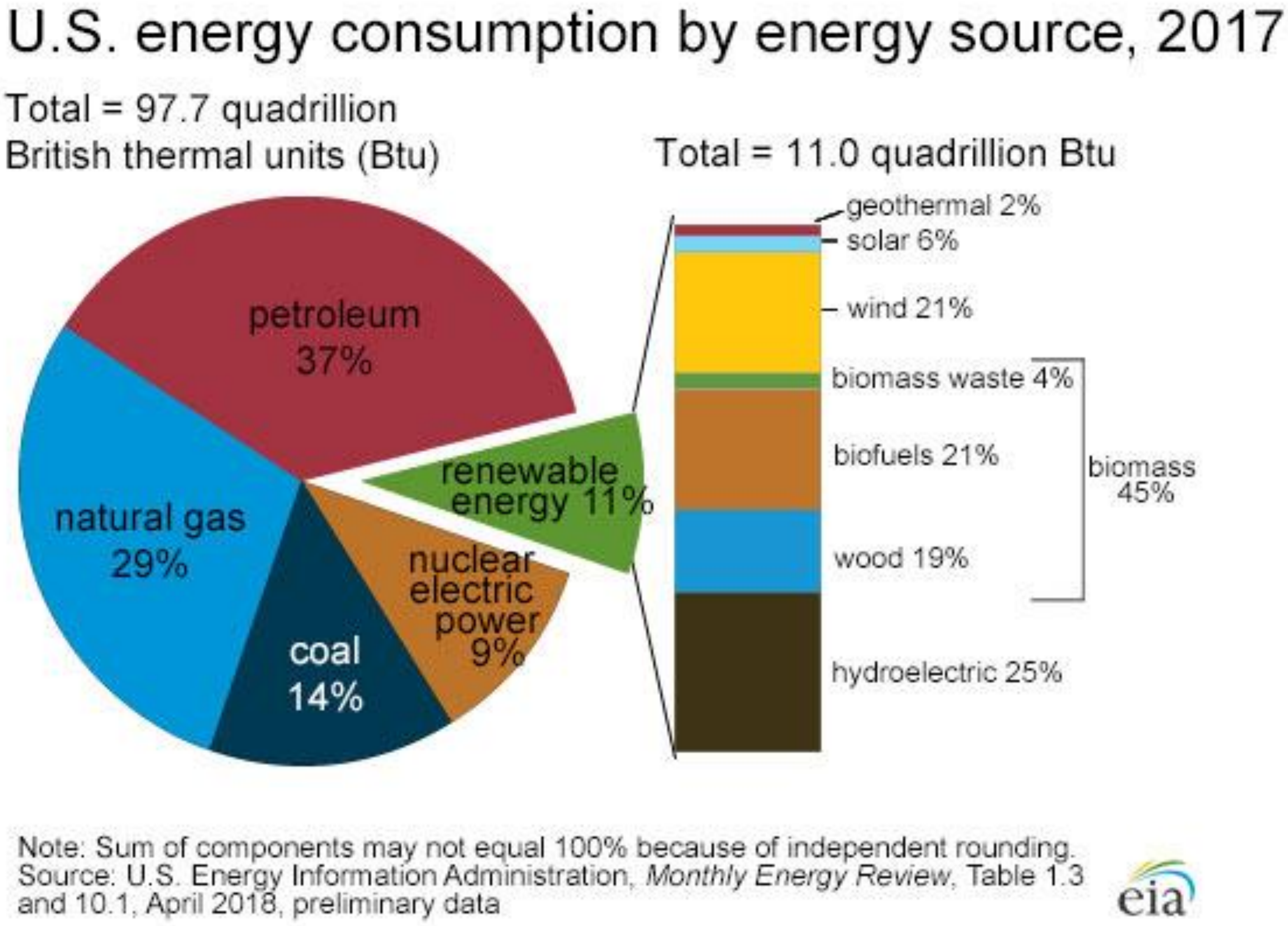
U.S. Department of Energy Hydrogen and Fuel Cell Overview

Dr. Sunita Satyapal, Director, U.S. Dept. of Energy Fuel Cell Technologies Office

2019 World Hydrogen Technologies Convention

June 3, 2019 – Tokyo, Japan

U.S. Energy Portfolio



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 2018, preliminary data

U.S. Emissions by Sector

SOURCE: United States Environment Protection Agency


Ashby Ave
NEXT EXIT
CARPOOL IS 3 OR MORE PERSONS PER VEHICLE

Transportation Sector

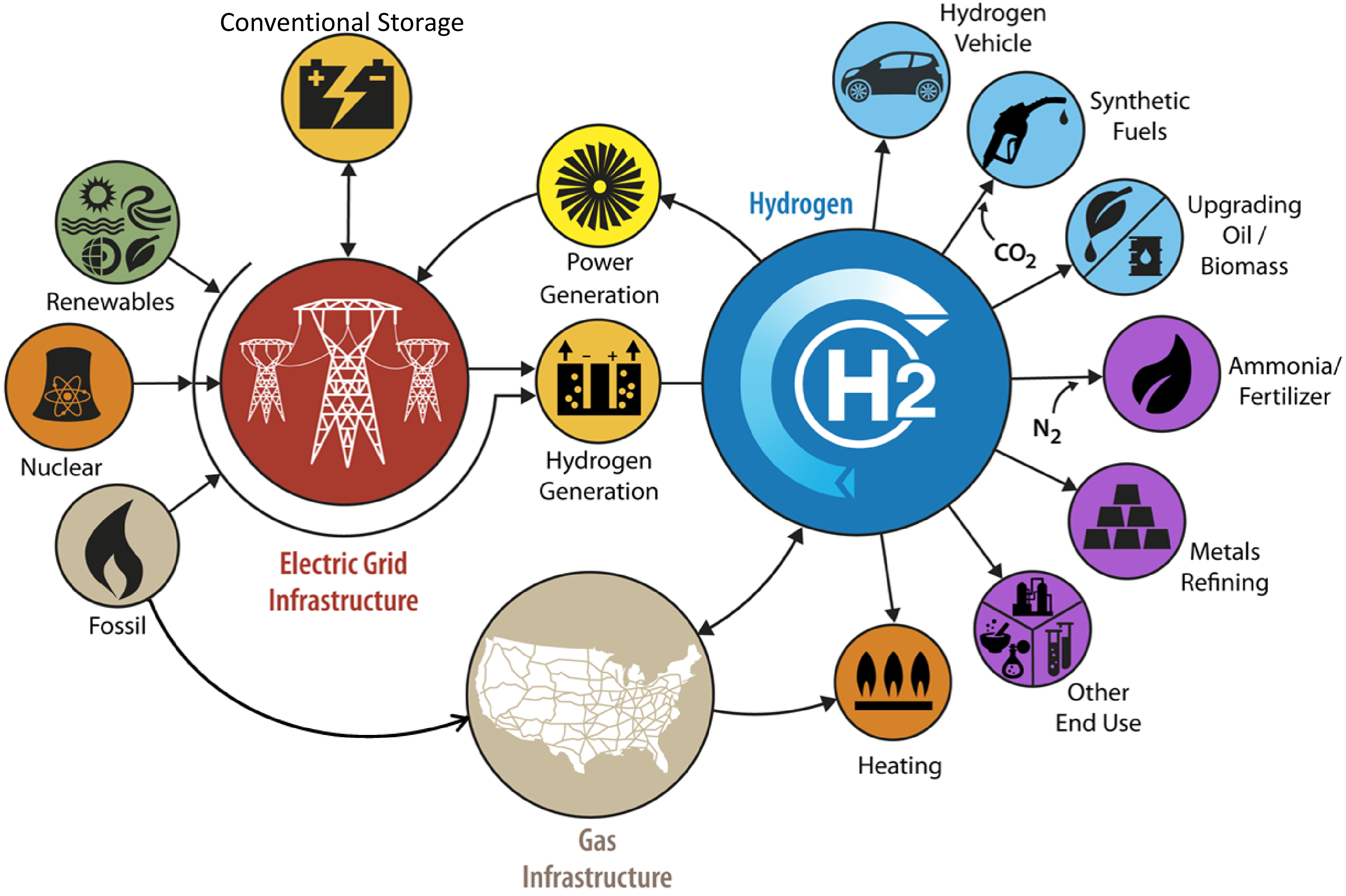
90% dependent on petroleum

85% of use is from on-road vehicles

2nd largest expense after housing

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

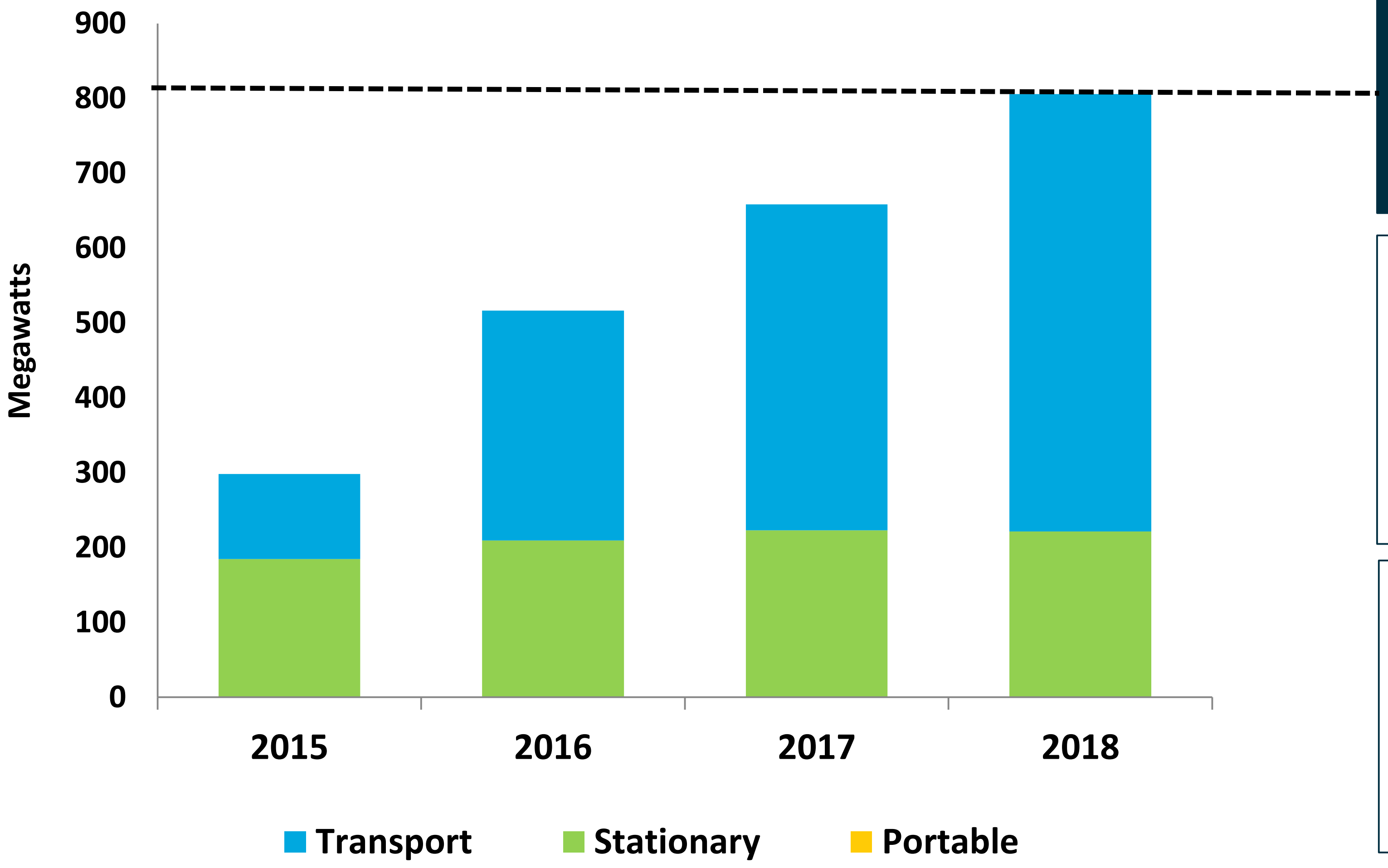
H_2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



Progress

Global Fuel Cell Shipments - Growth by Application

Global Fuel Cell Power Shipped (MW)



800 MW
fuel cell power
shipped worldwide

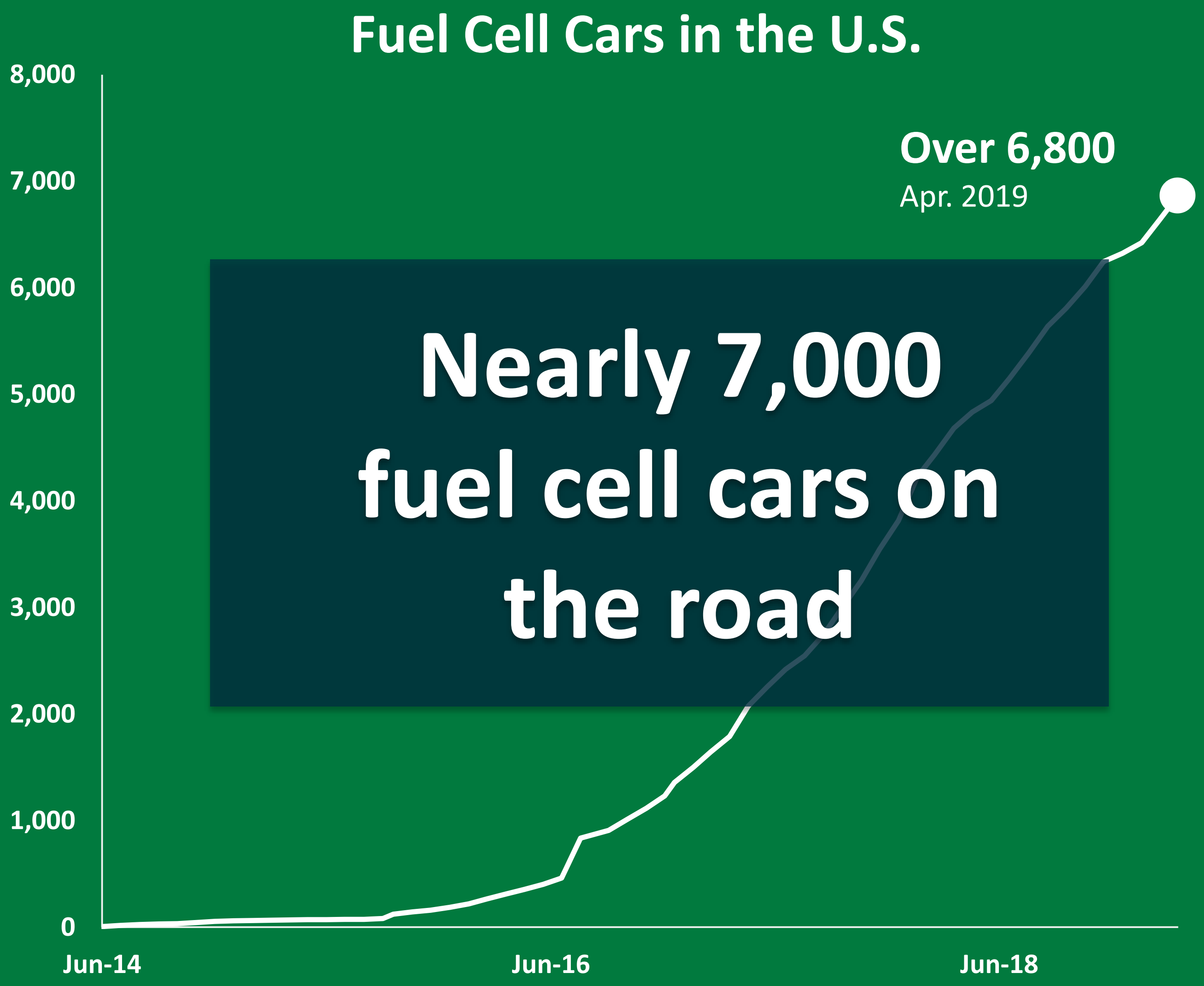
68,500
fuel cell units
shipped worldwide

Approximately
$2.3 Billion
fuel cell revenue*

* Revenue from publicly available

Source: DOE and E4Tech

Fuel Cell Passenger Vehicles Status


Fuel Cell Cars in the U.S.

Over 6,800
Apr. 2019

Nearly 7,000 fuel cell cars on the road

Examples of DOE-Industry Projects in the U.S.

Photo Credit: UPS

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

Completed word’s first fuel cell tow tractor project at Memphis airport

World’s first fuel cell for maritime ports in Hawaii

Interest in Hydrogen and Fuel Cells for Medium and Heavy Duty

Industry plans for hydrogen fuel cell trucks and supporting infrastructure underway

Photo Credit: Toyota

Photo Credit: Nikola

ZH2: U.S. Army and GM collaboration
First of its kind

Photo Credit: General Motors

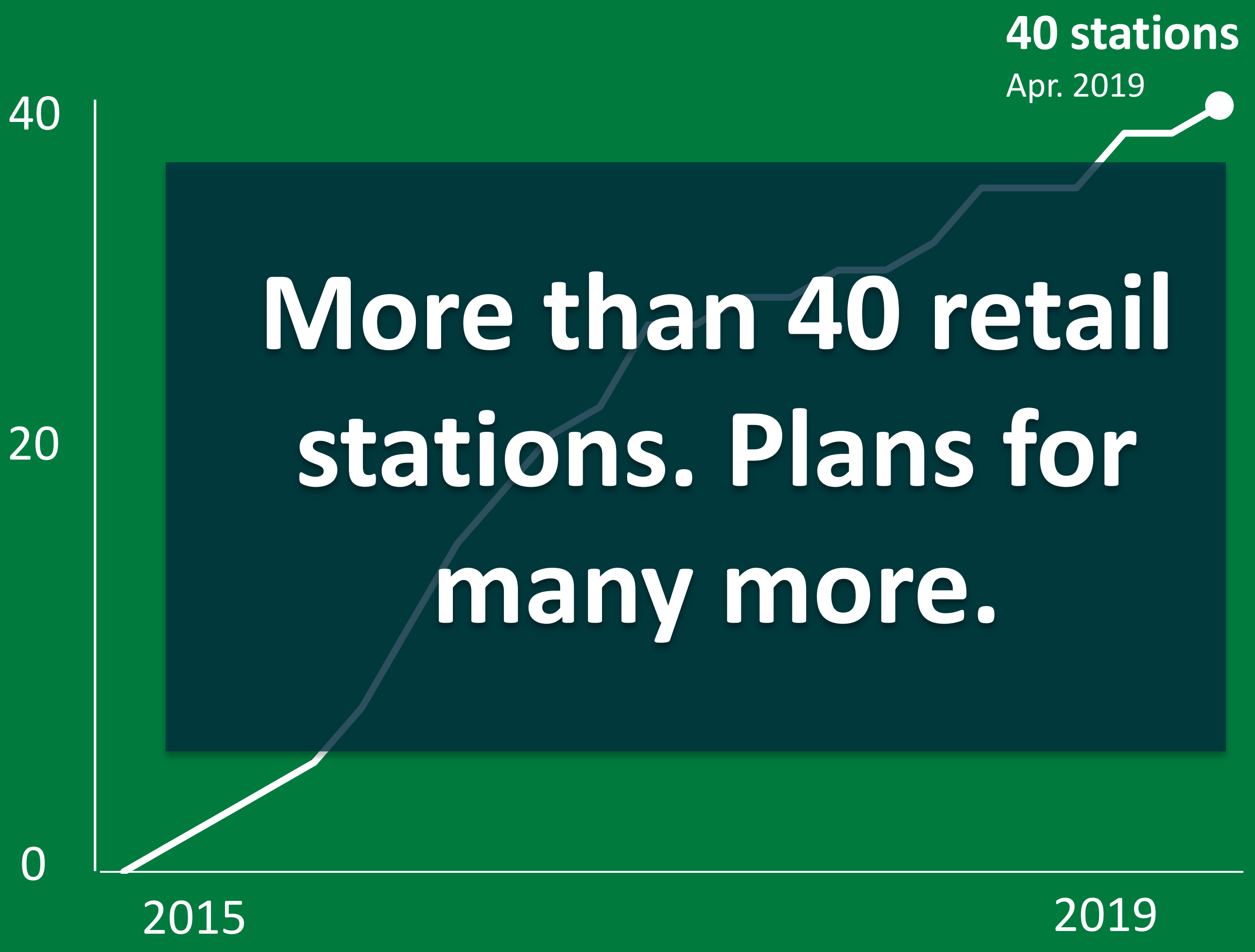
Material handling Applications

More than **25,000 forklifts**

Over **19 million refuelings**

Hydrogen Infrastructure Status

Retail Hydrogen Stations in the U.S.



More than 40 retail stations. Plans for many more.

Complementing Retail Stations: H_2Refuel H-Prize

DOE awards $1M H-Prize to Simple Fuel for winner of small-scale H_2 fueling design

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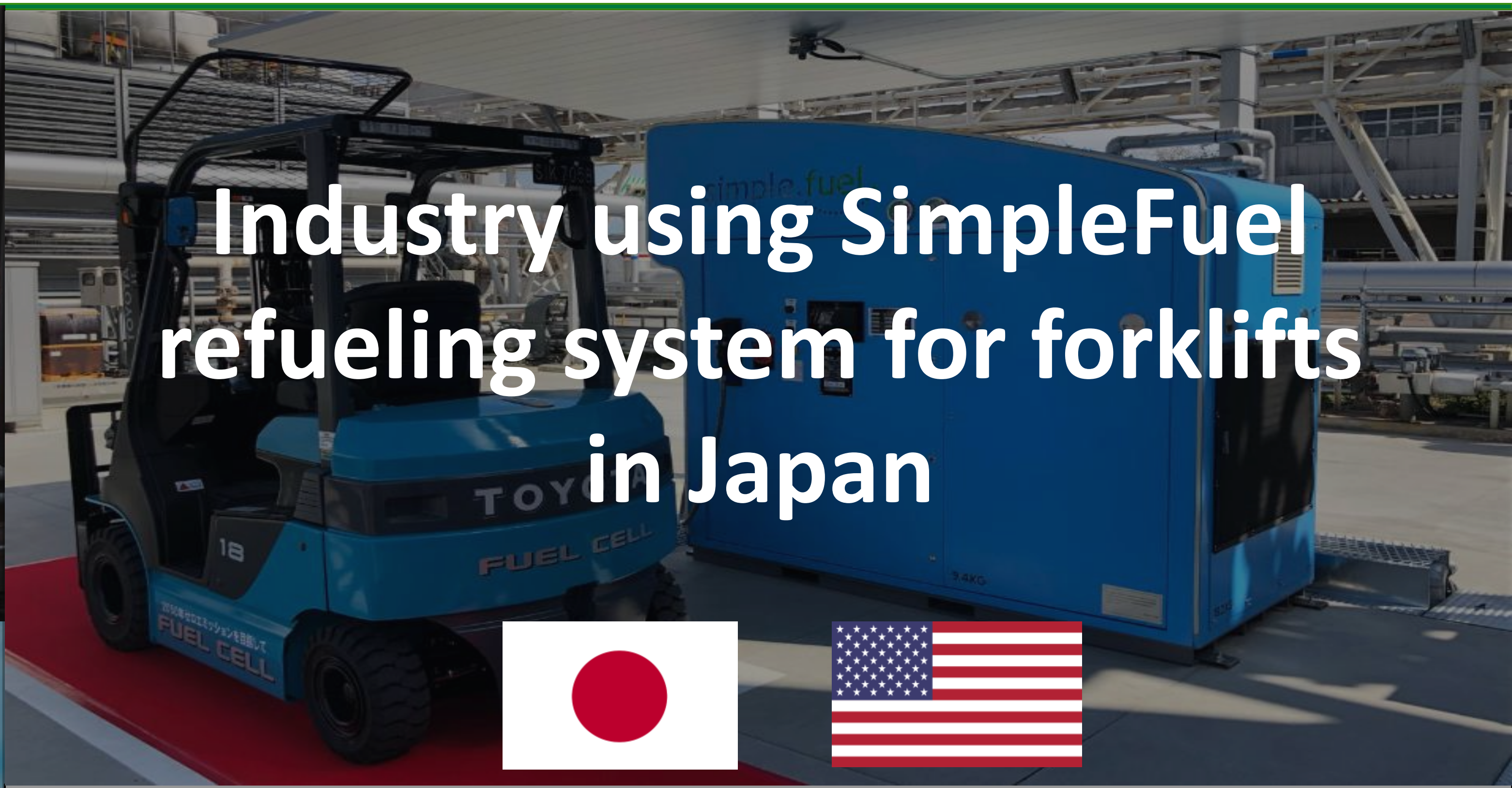


Industry using SimpleFuel refueling system for forklifts in Japan

simple.fuel.™

Email:
connect@ivysinc.com

More info:
www.teamsimplefuel.com

H2refuel
U.S. Department of Energy

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

U.S. Snapshot of Hydrogen and Fuel Cells Applications

Examples of Applications

>240MW
Backup Power

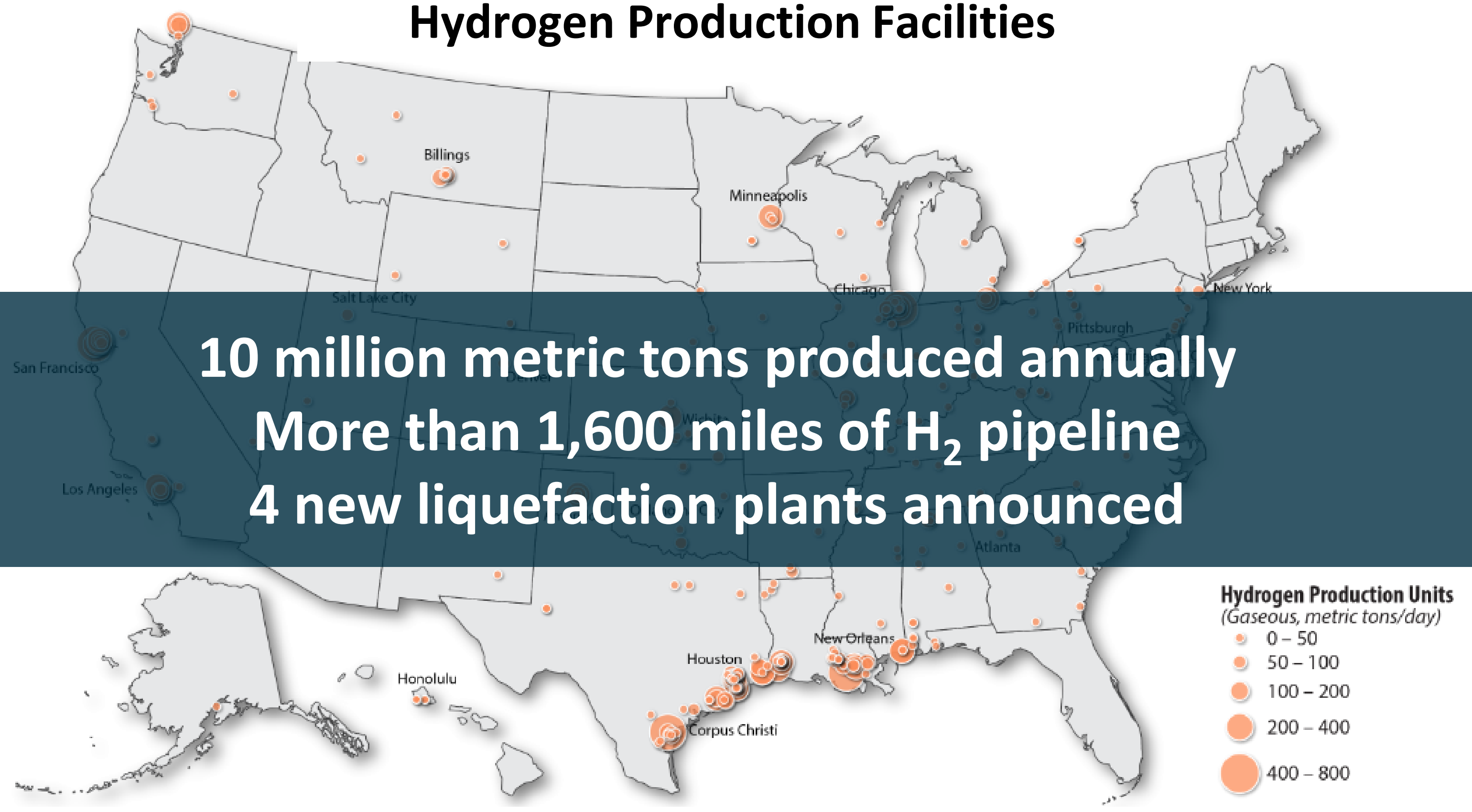
>25,000
Forklifts

>30
Fuel Cell Buses

>40
H_2 Retail Stations

~7,000
Fuel Cell Cars

Hydrogen Production Facilities



10 million metric tons produced annually
More than 1,600 miles of H_2 pipeline
4 new liquefaction plants announced

Hydrogen Stations: Examples of Plans Across States

California
1,000 stations by 2030

Northeast
12 – 20 stations planned

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

Assessing large scale applications to increase regional hydrogen demand

Source: DOT-FRA (top) & SNL (bottom)

H_2@Rail and H_2@Ports Initiatives

- U.S. DOE in collaboration with:
  - Dept. of Transportation (DOT)-Federal Railroad Administration
  - DOT-Maritime Administration

Data Centers and Energy Storage Applications

Challenges and R&D Needs

U.S. Department of Energy Focus Areas

Early R&D Focus

Applied research, development and innovation in hydrogen and fuel cell technologies leading to:

- Energy security
- Energy resiliency
- Strong domestic economy

Early R&D Areas

Fuel Cells	**Hydrogen Fuel**	**Infrastructure R&D**
• Cost, durability • Components - catalysts, electrodes, etc. • Increase focus beyond LDVs	• Cost of production across pathways • Cost and capacity of storage, including bulk/ energy storage	• Cost and reliability of infrastructure • Delivery components, supply chain • Safety

LDV: Light Duty Vehicle

New in FY19 Budget Request

National Lab-Based Consortia

HydroGEN Advanced Water Splitting Materials

HyMARC Hydrogen Materials Advanced Research Consortium

ElectroCat Electrocatalysis Consortium

FCPAD Fuel Cell Performance and Durability

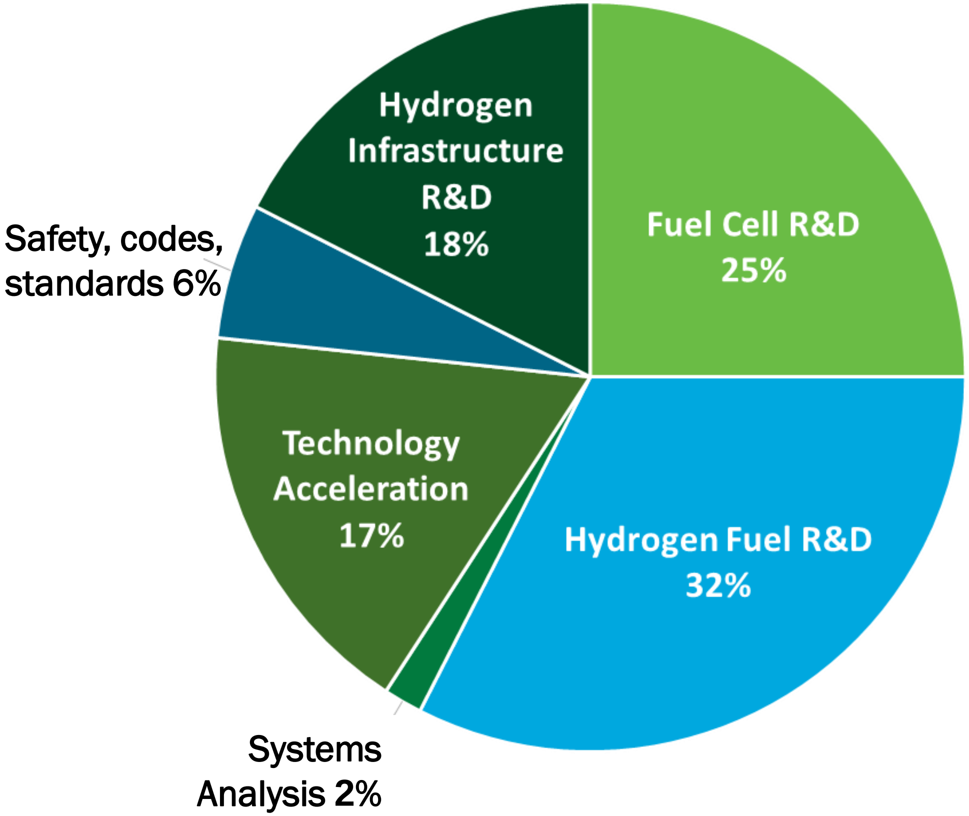
H-Mat Hydrogen Materials Compatibility Consortium

DOE Hydrogen and Fuel Cell Funding

EERE – Fuel Cell Technologies Office (FCTO)

Key Activity	FY 2017	FY 2018	FY 2019
	($ in thousands)		
Fuel Cell R&D	32,000	32,000	30,000
Hydrogen Fuel R&D	41,000	54,000	39,000
Hydrogen Infrastructure R&D	-	-	21,000
Systems Analysis	3,000	3,000	2,000
Technology Acceleration	18,000	19,000	21,000
Safety, Codes and Standards	7,000	7,000	7,000
Total	**101,000**	**115,000**	**120,000**

EERE: Office of Energy Efficiency and Renewable Energy



Additional $30M for SOFC through DOE Office of Fossil Energy

Additional funding for basic science, SOFC, ARPA-E- roughly 40M, subject to yearly appropriations and projects

Focus is on Affordability: DOE Targets Guide R&D

Fuel Cell R&D

Fuel cell system

🟥 $210/kW[+]

$180/kW*

🟧 ~$75/kW

Durability adjusted

(preliminary)

🟧 $50/kW

100K/yr

🟧 $45/kW

500K/yr

● $30/kW

Hydrogen R&D

On-board storage[ǂ]

🟥 $21/kWh

🟧 $17/kWh

100K/yr

🟧 $15/kWh

500K/yr

● $8/kWh

H_2 cost at the pump

🟥 $16/kg[+]

$13/kg

🟧 $10/kg*

to

$5/kg**

● <$4/kg

● Ultimate Target

🟥 Low-Volume Estimate

🟧 High-Volume Projection

[†] Based on commercially available FCEVs

[*] Based on state of the art technology

[ǂ] Storage costs based on preliminary 2019 storage cost record.

[†] Range assumes current production from NG and delivery and dispensing

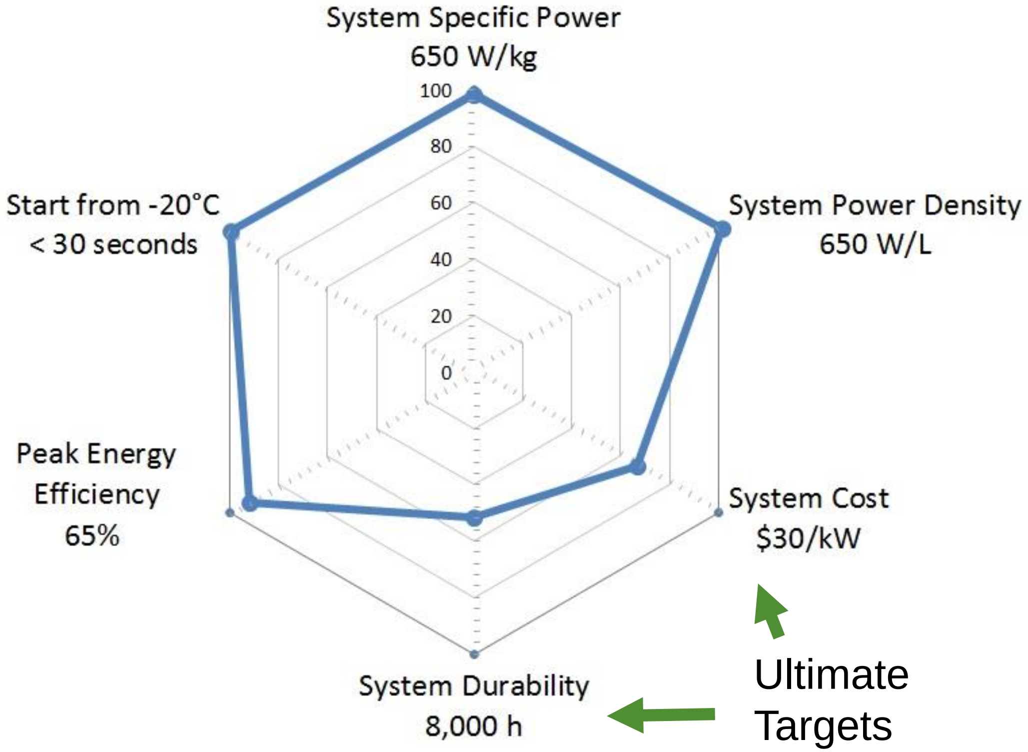
[*] Highest possible cost at high vol., assumes H2 from electrolysis at $5/gge and delivery via pipelines and liquid tankers at $5/gge

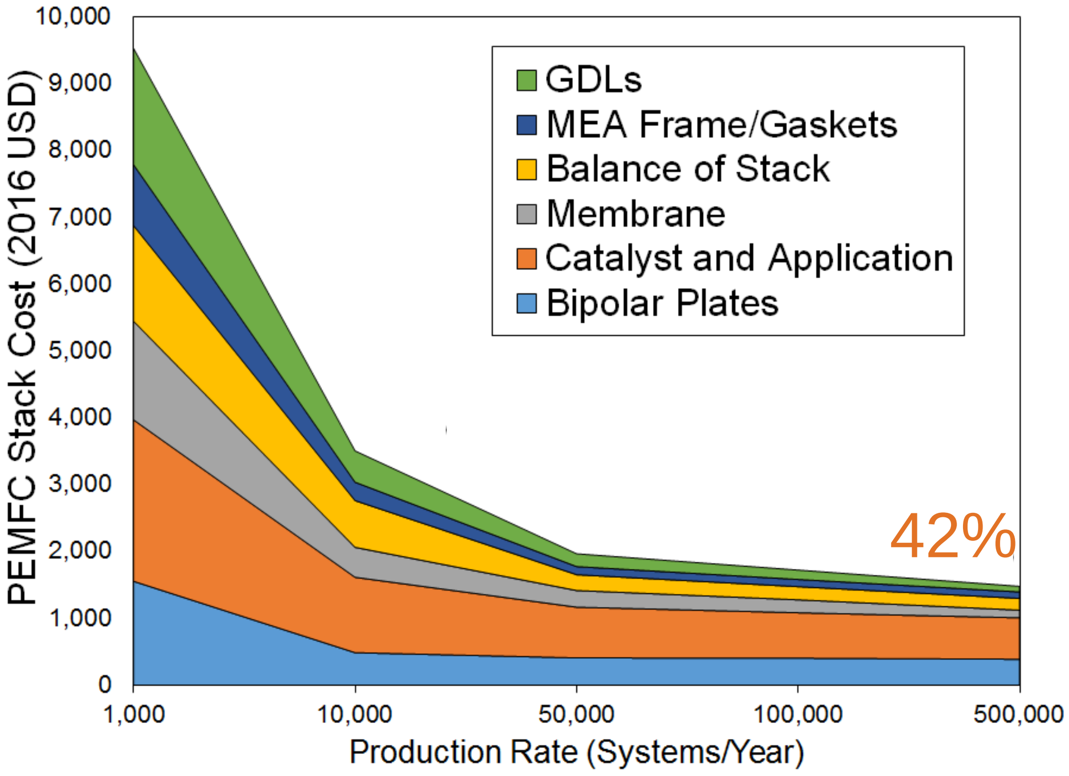
[**] Lowest possible cost at high vol., assumes H2 from SMR at $2/gge and delivery via tube trailer at $3/gge

Fuel Cell Status vs DOE Targets

Need to meet all targets simultaneously

Key cost contributors are stack components: Catalysts, membranes, bipolar plates, GDLs

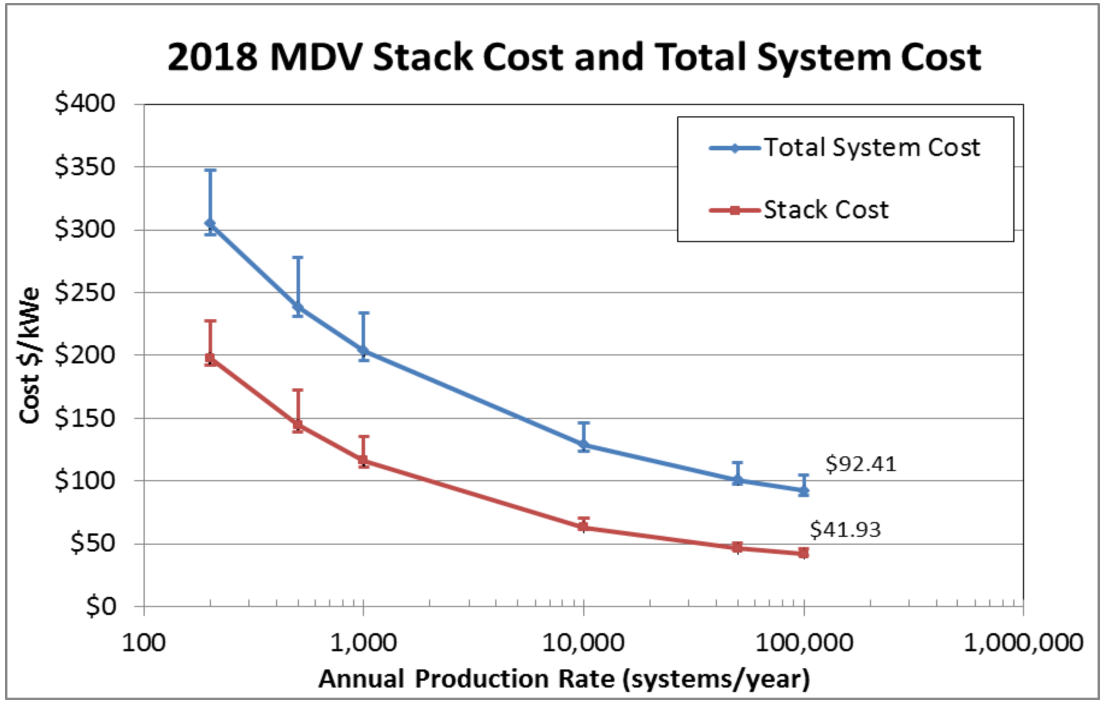




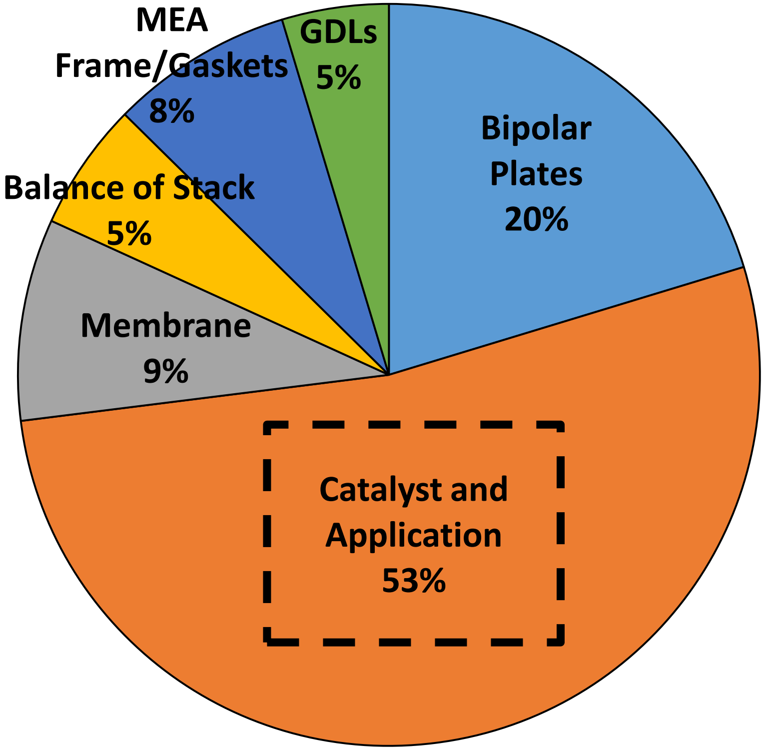
Catalyst is still the largest single component of PEMFC stack cost

Medium Duty Vehicle Cost Analysis Highlights R&D Needs

- Based on 2018 cost estimate for 160 kW_{net} system suitable for buses and medium-duty trucks
- High-volume manufacturing cost: $92/$kW_{net}$ (100,000 systems/year)



PEMFC stack cost breakdown



*Manufacturing volume: 100,000 systems/year

To be released: Heavy-duty fuel cell truck cost analysis

H_2 Fuel R&D - Cost Breakdown By Area

H_2 Production

(PEM Electrolysis)

High cost areas:
Electricity, capital costs

H_2 Infrastructure

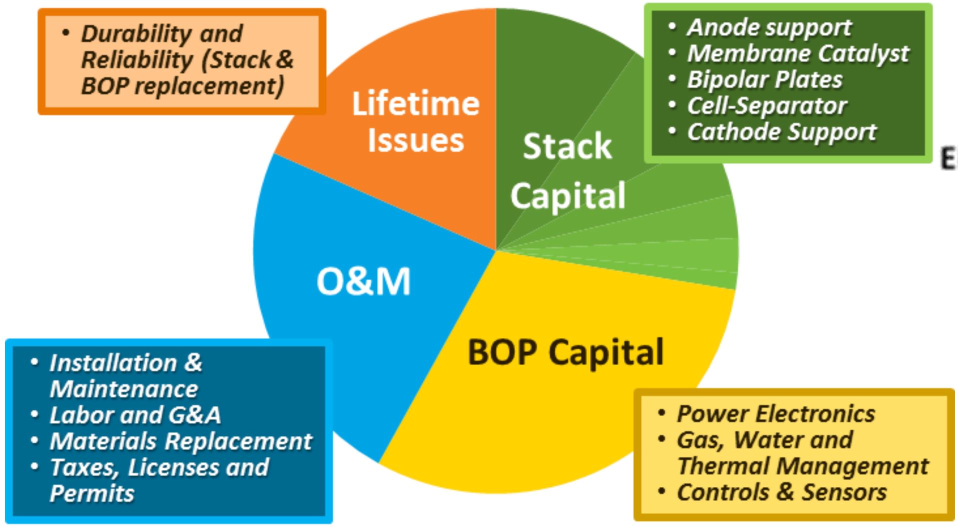
(700 bar station cost)

High cost areas:
Compressor, storage
and dispenser

H_2 Storage

(Onboard 700 bar storage vessel*)

High cost areas:
Carbon fiber

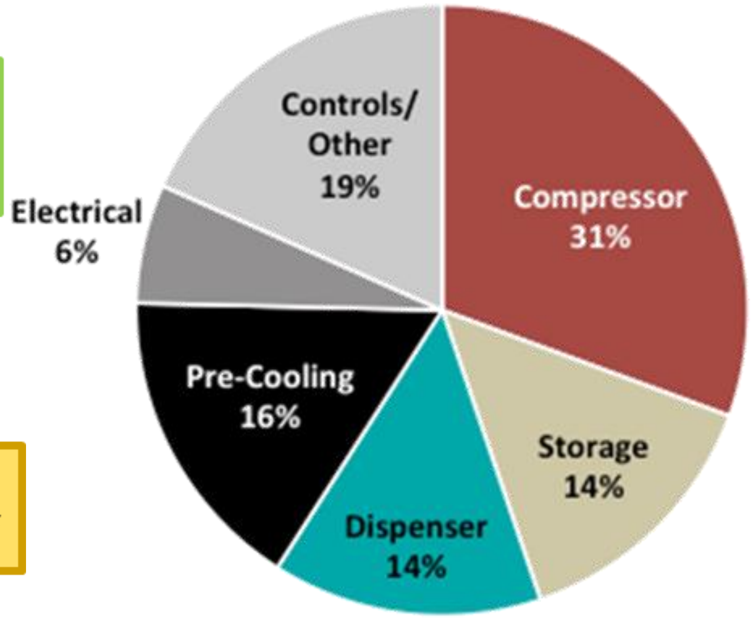


- *Durability and Reliability (Stack & BOP replacement)*

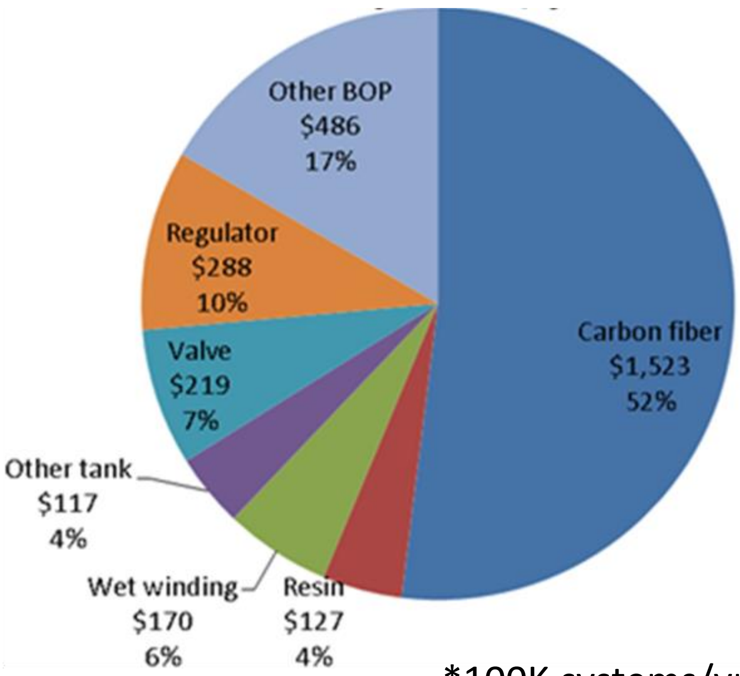
- *Anode support*
- *Membrane Catalyst*
- *Bipolar Plates*
- *Cell-Separator*
- *Cathode Support*

- *Installation & Maintenance*
- *Labor and G&A*
- *Materials Replacement*
- *Taxes, Licenses and Permits*

- *Power Electronics*
- *Gas, Water and Thermal Management*
- *Controls & Sensors*



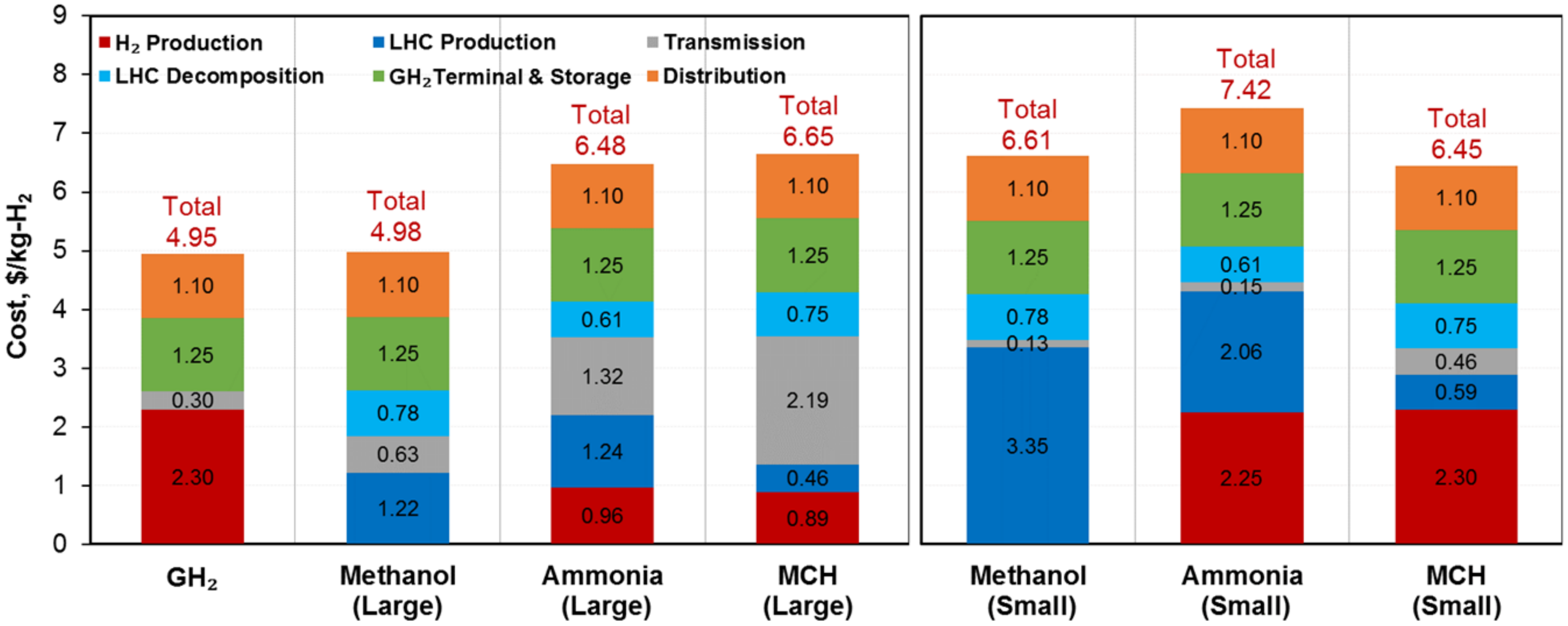
1,000 kg/day estimate



*100K systems/yr.

New H_2 Fuel R&D Area: Hydrogen Carriers

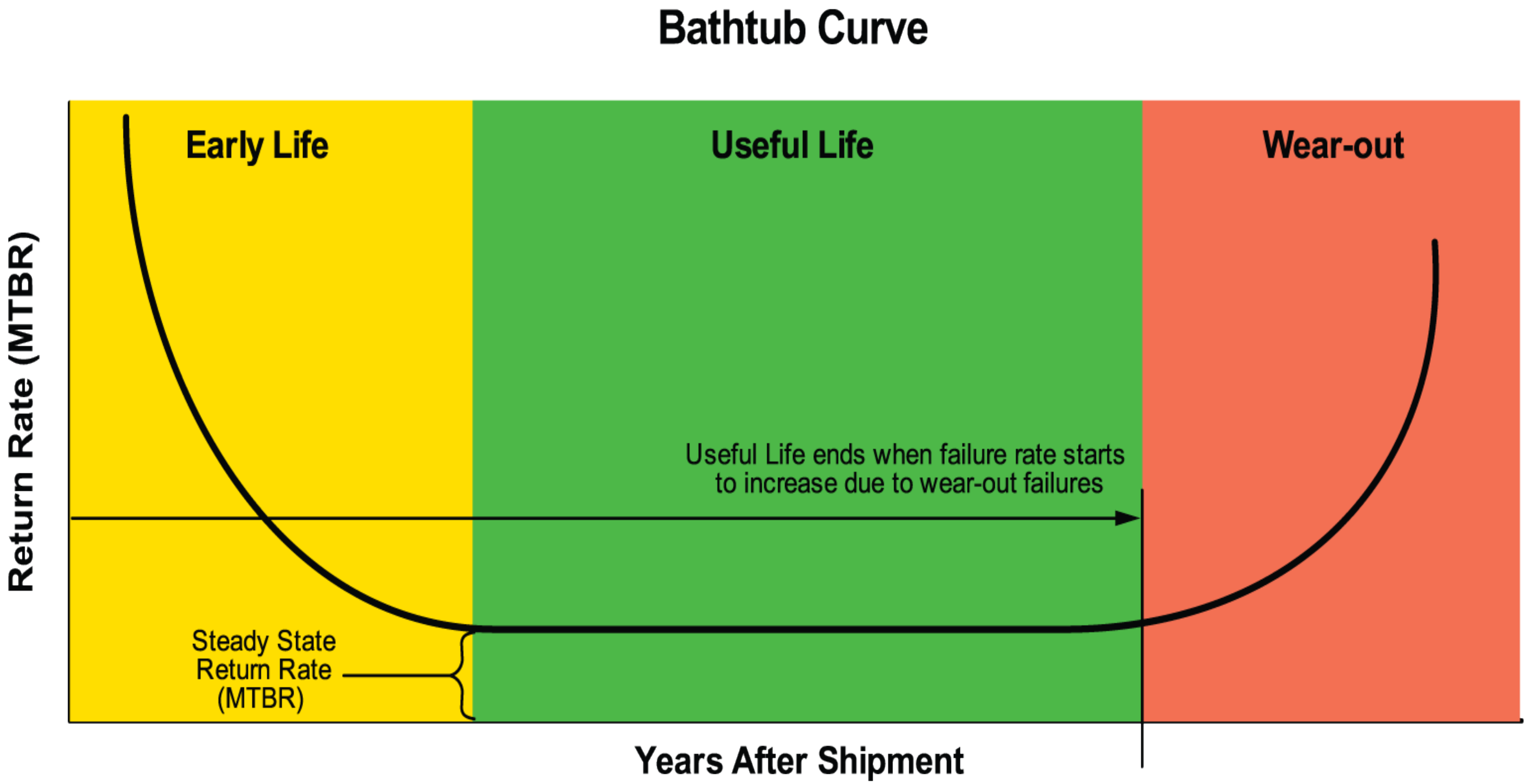
- **Preliminary analysis shows cost of transporting H_2 in carriers** ranges between **~$5/kg and $7.50/kg**
- At large volumes, **methanol is competitive with compressed H_2 even when transported 3,000 km from gulf coast**



Analysis planned between ANL and Chiyoda

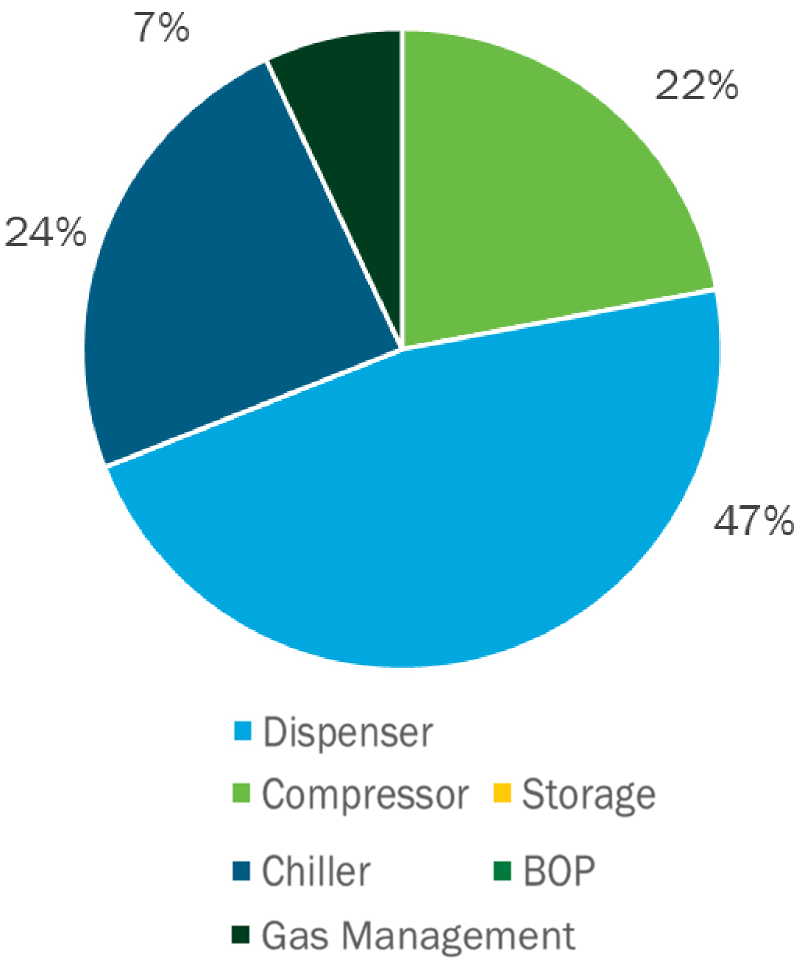
Source: Argonne National Laboratory

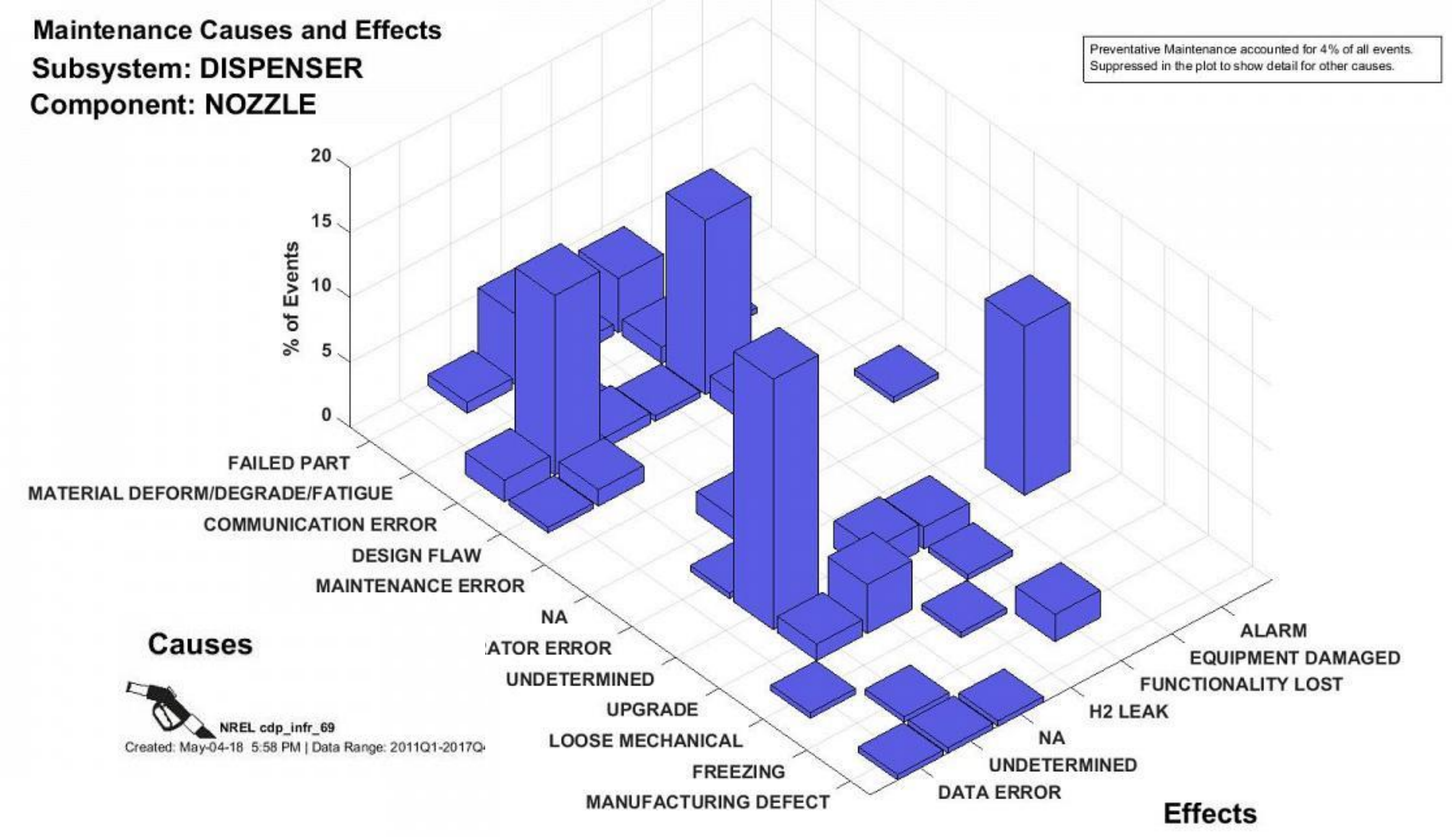
Example from Reliability Engineering



Examples of Real World Data and Analysis

Maintenance Hours at Fueling Stations





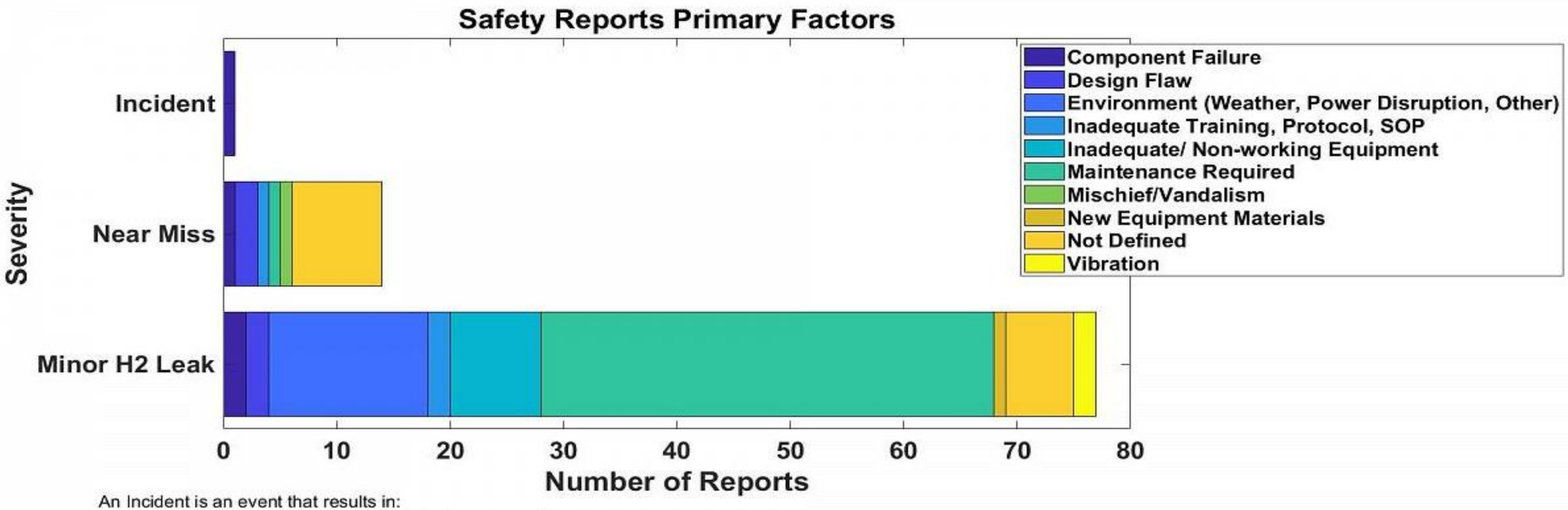
Maintenance Causes and Effects
Subsystem: DISPENSER
Component: NOZZLE

Preventative Maintenance accounted for 4% of all events. Suppressed in the plot to show detail for other causes.

NREL cdp_infr_69
Created: May-04-18 5:58 PM | Data Range: 2011Q1-2017Q

Composite Data Product 21, NREL
https://www.nrel.gov/hydrogen/hydrogen-infrastructure-analysis.html

Example of Real World Data Collection



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 cdp_infr_31
Created: May-15-18 5:38 PM | Data Range: 2008Q3-2017Q4

Real World Example

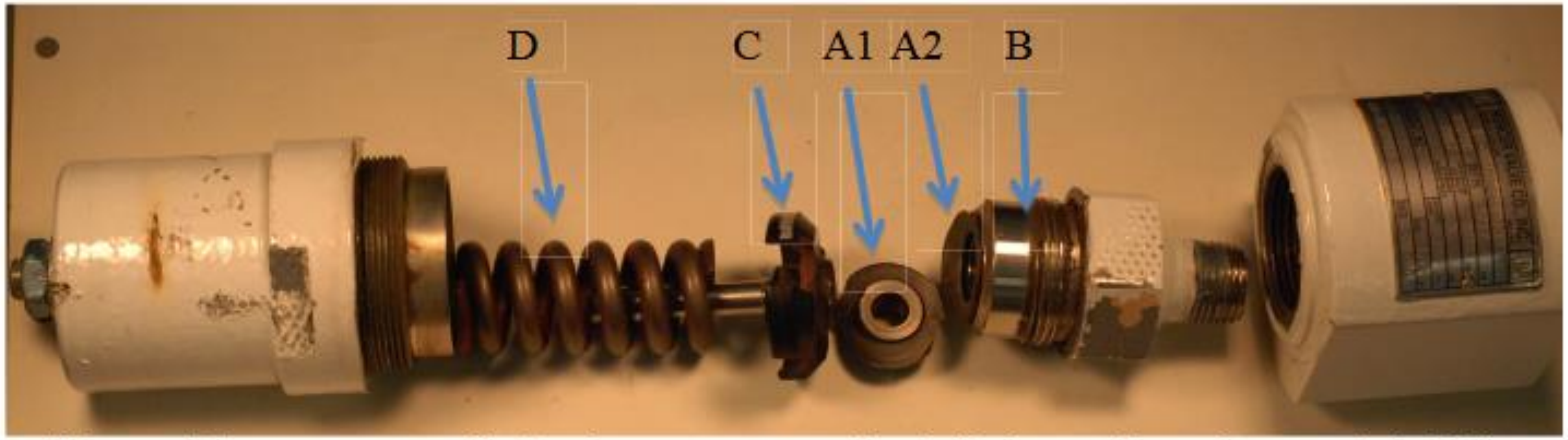


Figure A2. pressure relief valve components: failed nozzle subassembly (A1 and A2); inlet base (B); disk subassembly (C); set spring (D).

Pressure Relief Valve failure caused hydrogen release- led to safety concerns and evacuation

Type 440C stainless not suitable for this application

Real World Example

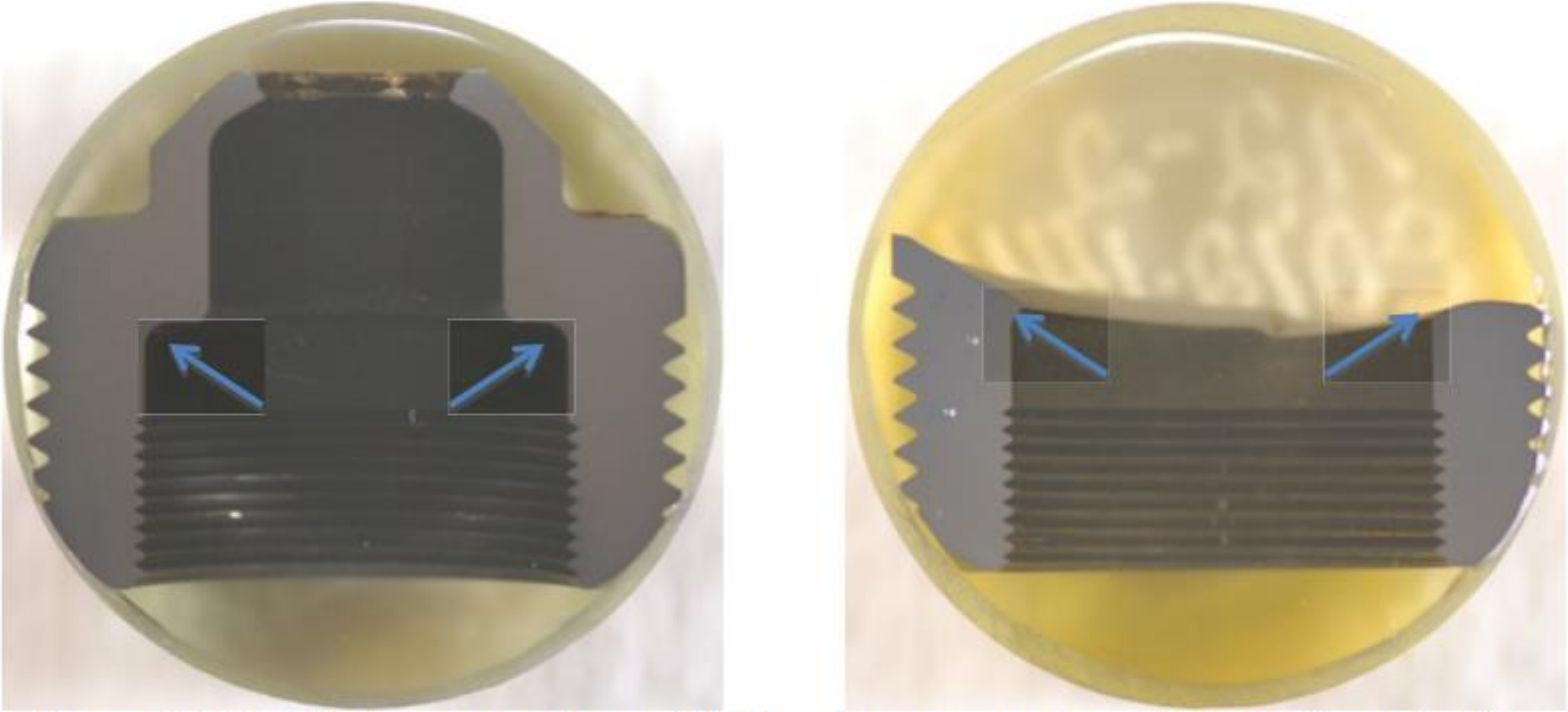


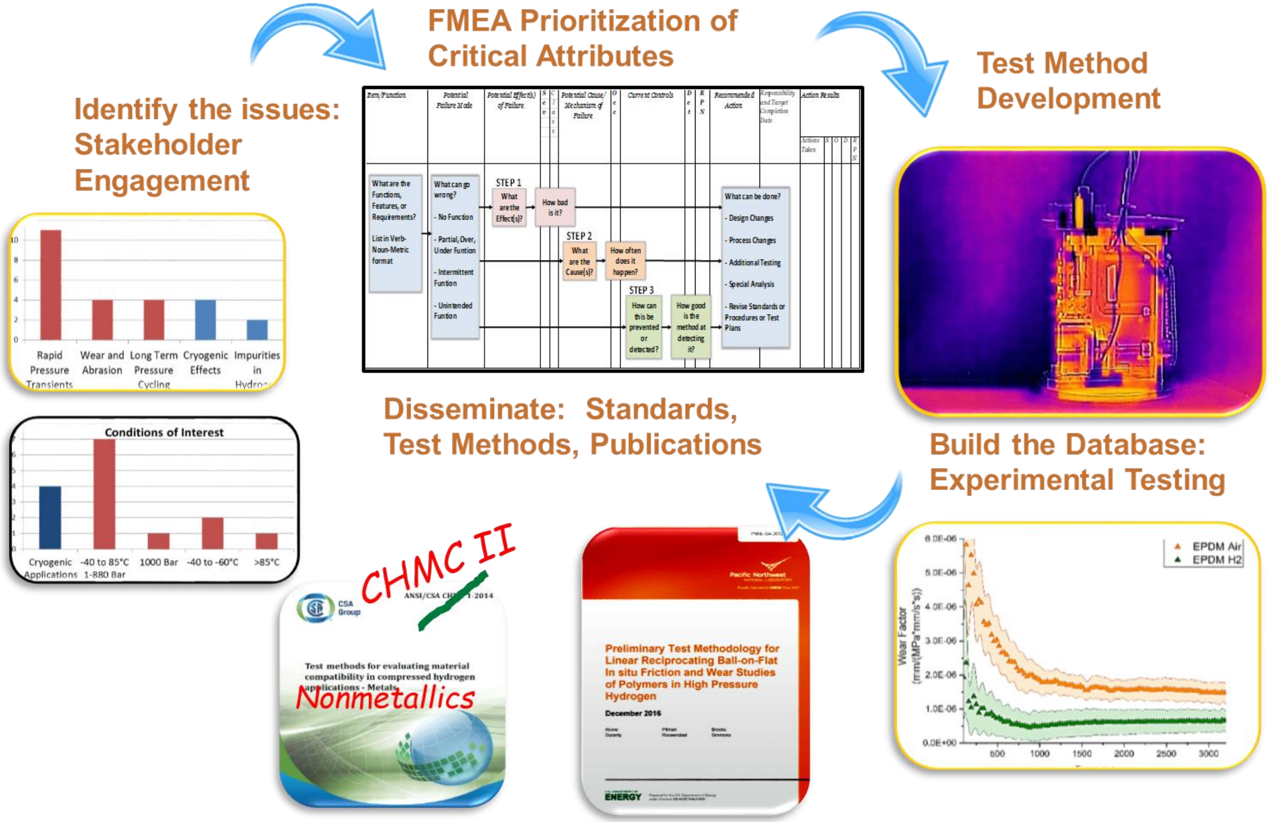
Figure A5. Polished cross sections of (a) functioning nozzle and (b) failed nozzle. The arrows indicate the internal corner associated with failure of the nozzle.

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

Recently Launched: H-Mat Consortium

H-Mat℠ | Hydrogen Materials Compatibility Consortium

Lead Labs: Pacific Northwest NATIONAL LABORATORY Sandia National Laboratories



Examples of Activities:

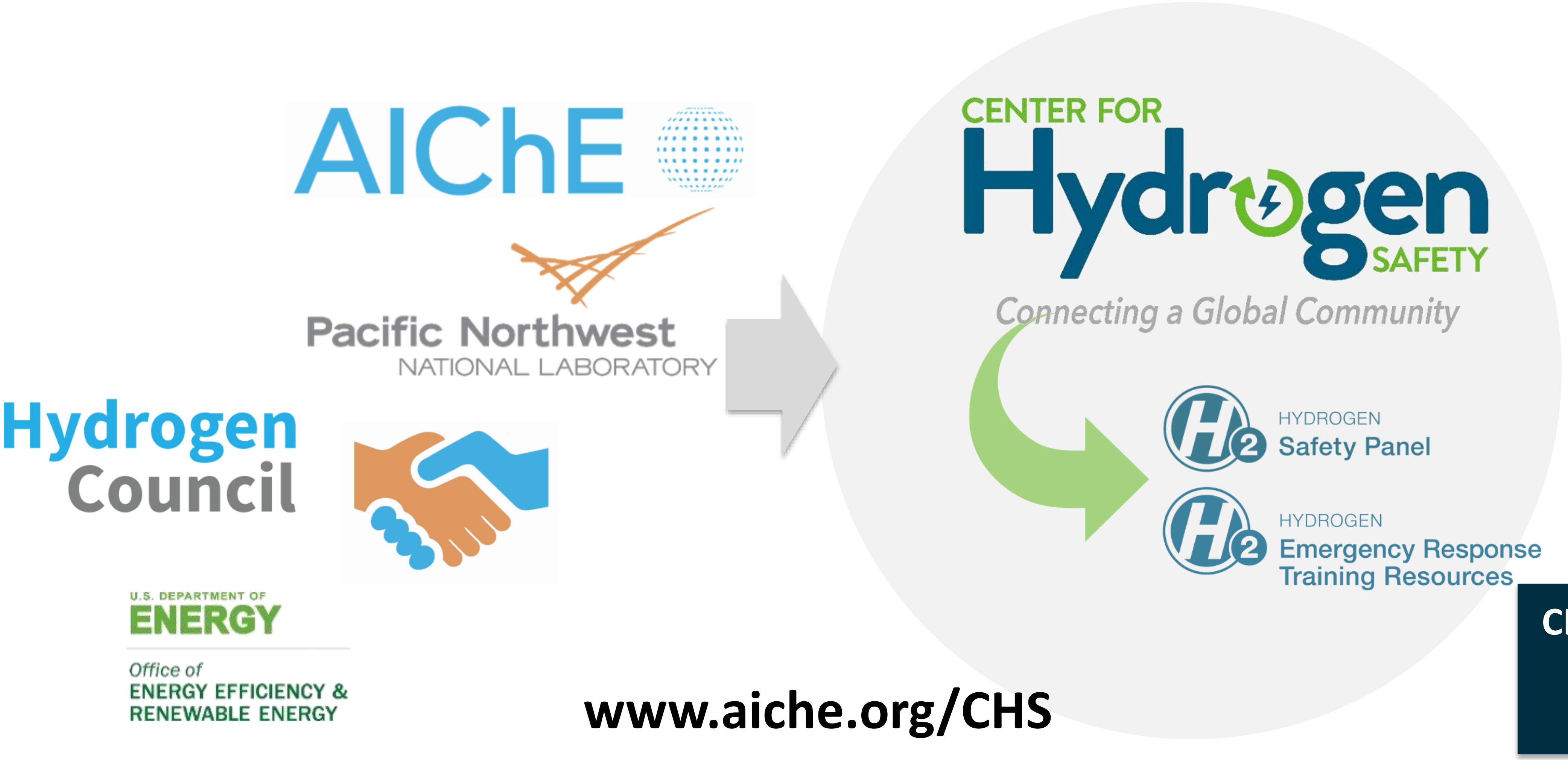
- **Determining degradation mechanisms based on hydrogen-materials interactions**
- **Providing science based strategies for materials design, multi-scale modeling, experimental validation**

New partners to be added including industry and universities

Collaboration is Key

New Global Safety Partnership: Center for H_2 Safety (CHS)

U.S. DOE Fuel Cell Technologies Office partners with CHS & global industry



www.aiche.org/CHS

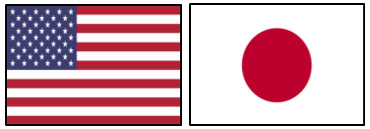
CHS Presentation:
June 4
12:10-12:30

Example of International Collaboration

The International Partnership for Hydrogen and Fuel Cells in the Economy

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

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



Elected Chair and Vice-chair

Top Priorities

- SHARE INFORMATION
- INFORM FUTURE GOVERNMENT RD&D
- FOSTER COLLABORATION

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Follow IPHE **@The_IPHE**

www.iphe.net

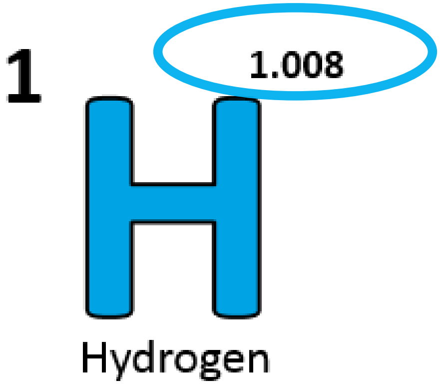
May 29, 2019
Canada launches Clean Energy Ministerial New Hydrogen Initiative

Formed 2003
Over 20 Countries

What can you do? Increase Awareness and Outreach

Celebrate National Hydrogen & Fuel Cell Day

October 8 or 10/8



Use Safety Information and Training Resources

H2tools.org

INCREASE YOUR H_2IQ

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

Save the Date

May 18-21, 2020
Annual Merit Review
Washington DC

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

Thank You

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