U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

DOE Hydrogen and Fuel Cell Technologies Office and Global Perspectives

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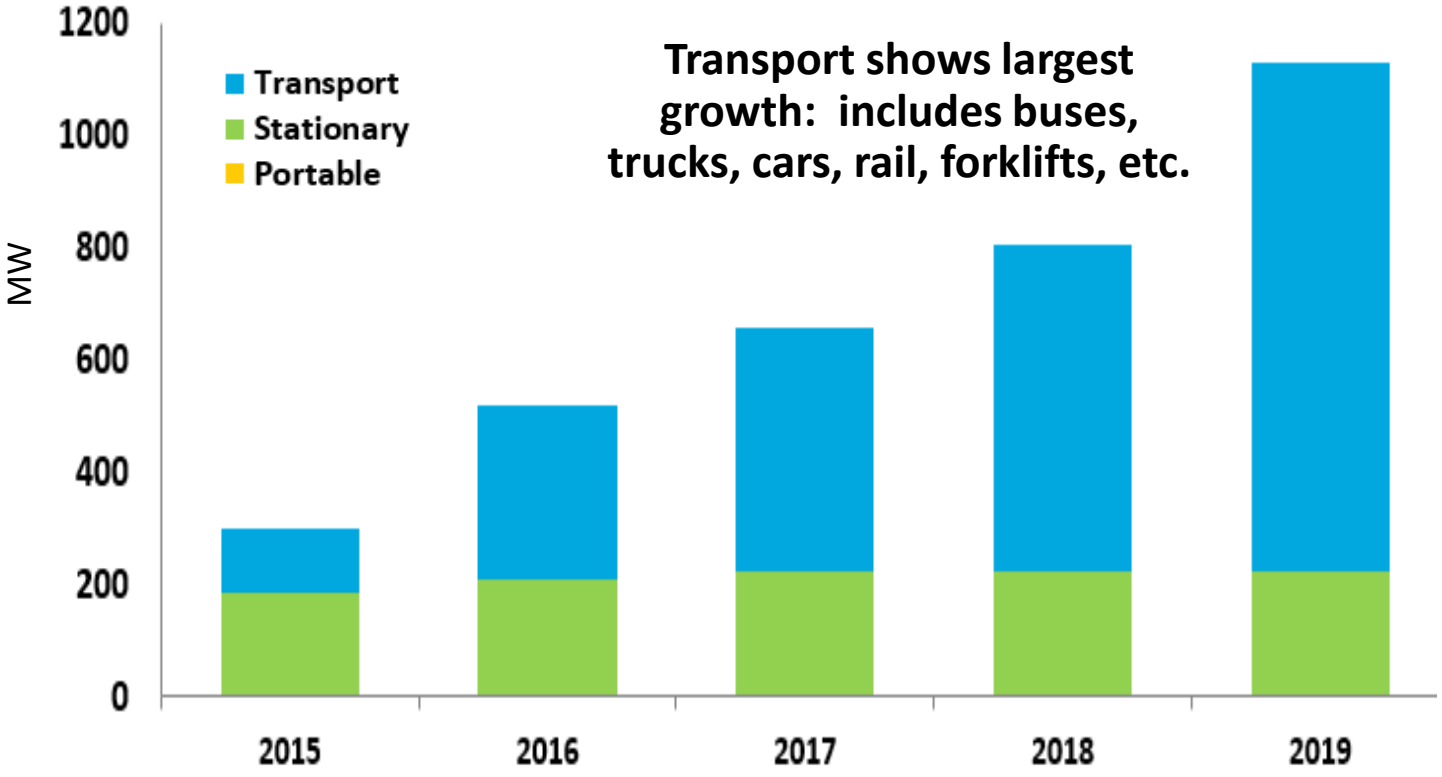
PIME Hydrogen Projects in Transport Workshop, Poland
December 11, 2020


Global
Perspectives

Hydrogen and Fuel Cell Technology Growth Worldwide

Global fuel fell shipments surpass 1 GW



Source: E4tech for DOE analysis project

25-fold increase in electrolyzers deployed in the last decade

<1MW in 2010 to >25 MW by the end of 2019

Global FCEVs doubled to >25,200

>12.3K sold in 2019 vs. 5.8K in 2018

470 H_2 fueling stations worldwide

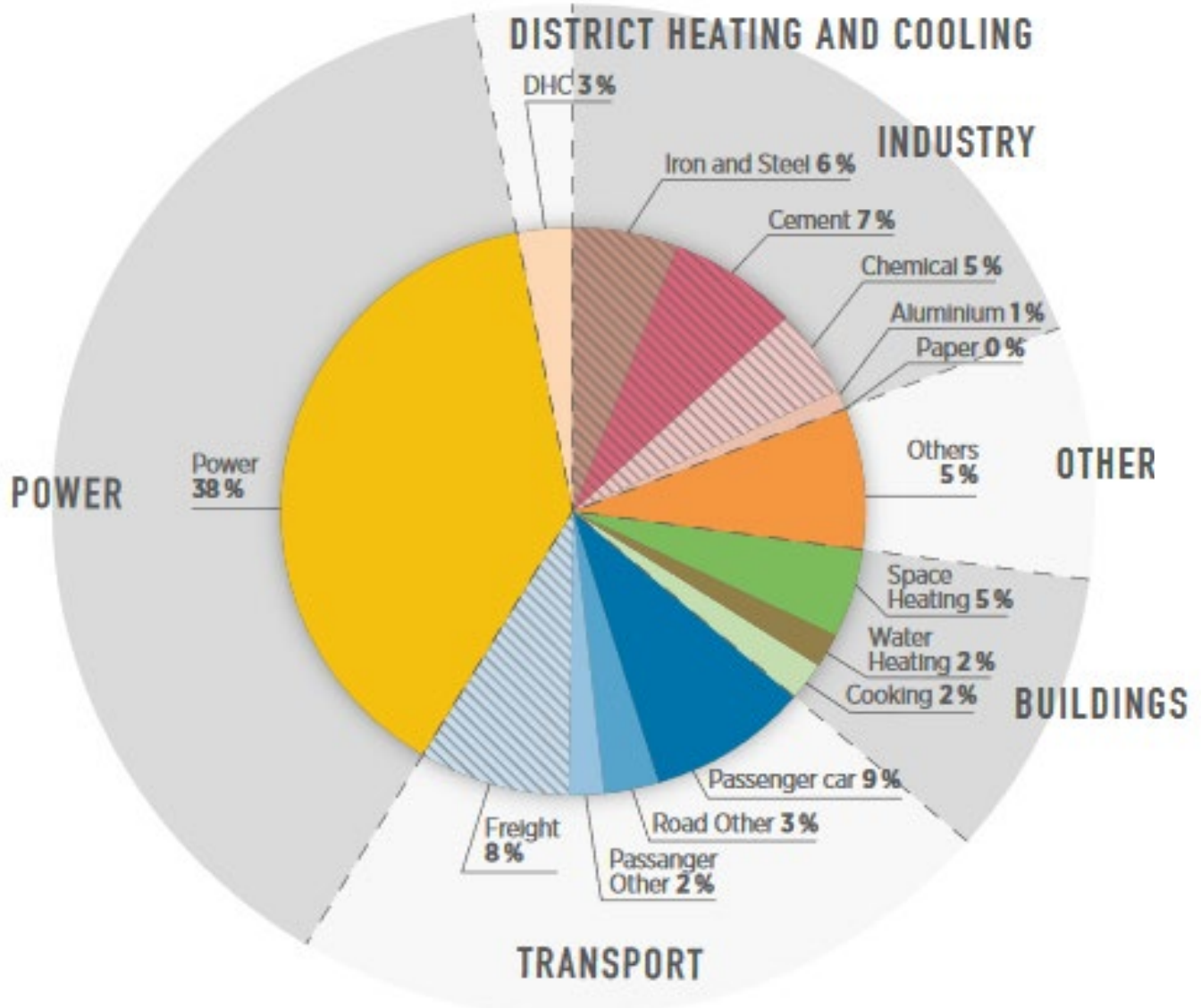
> 20% increase from 2018

Source: IEA (2020), *Hydrogen*, IEA, Paris, https://www.iea.org/reports/hydrogen

Global Drivers and Energy Related Carbon Emissions by Sector

Drivers include:

- Emissions reduction
- Energy security
- Economic growth
- Resiliency
- Energy efficiency
- Innovation potential
- Environmental benefits



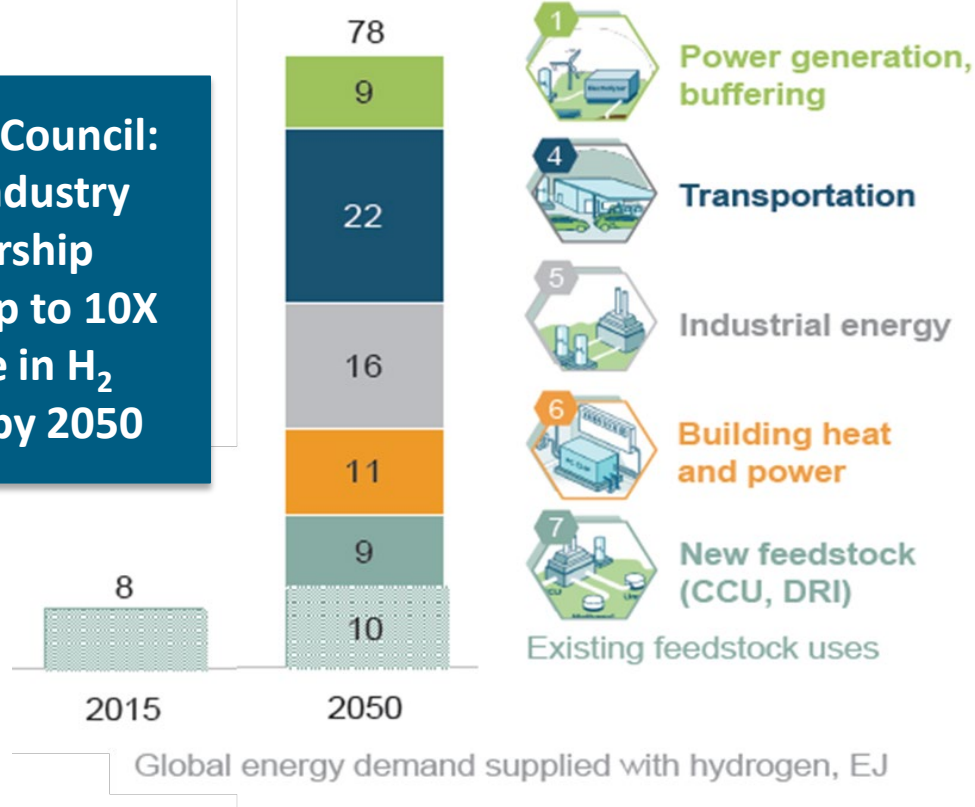
Sectors today with no economically scalable option for deep emission reductions

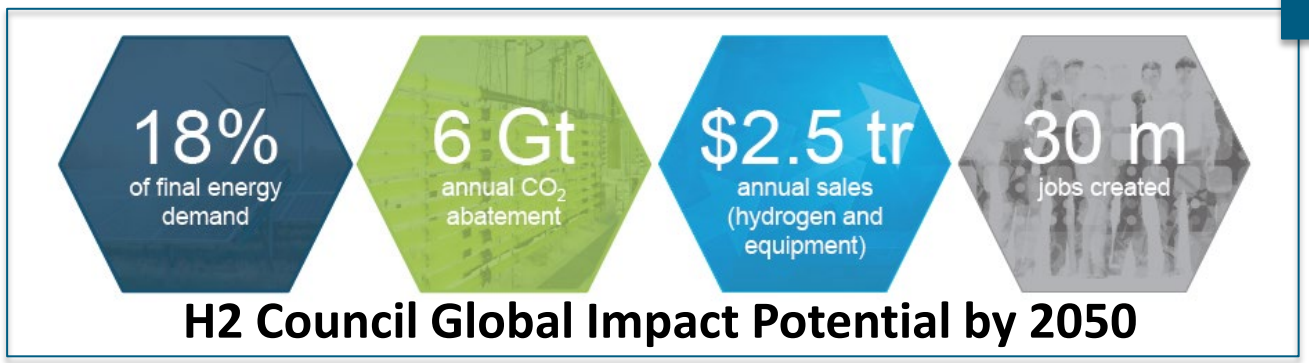
Source: IRENA, 2017a from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf

Roadmaps and Plans Developing Worldwide

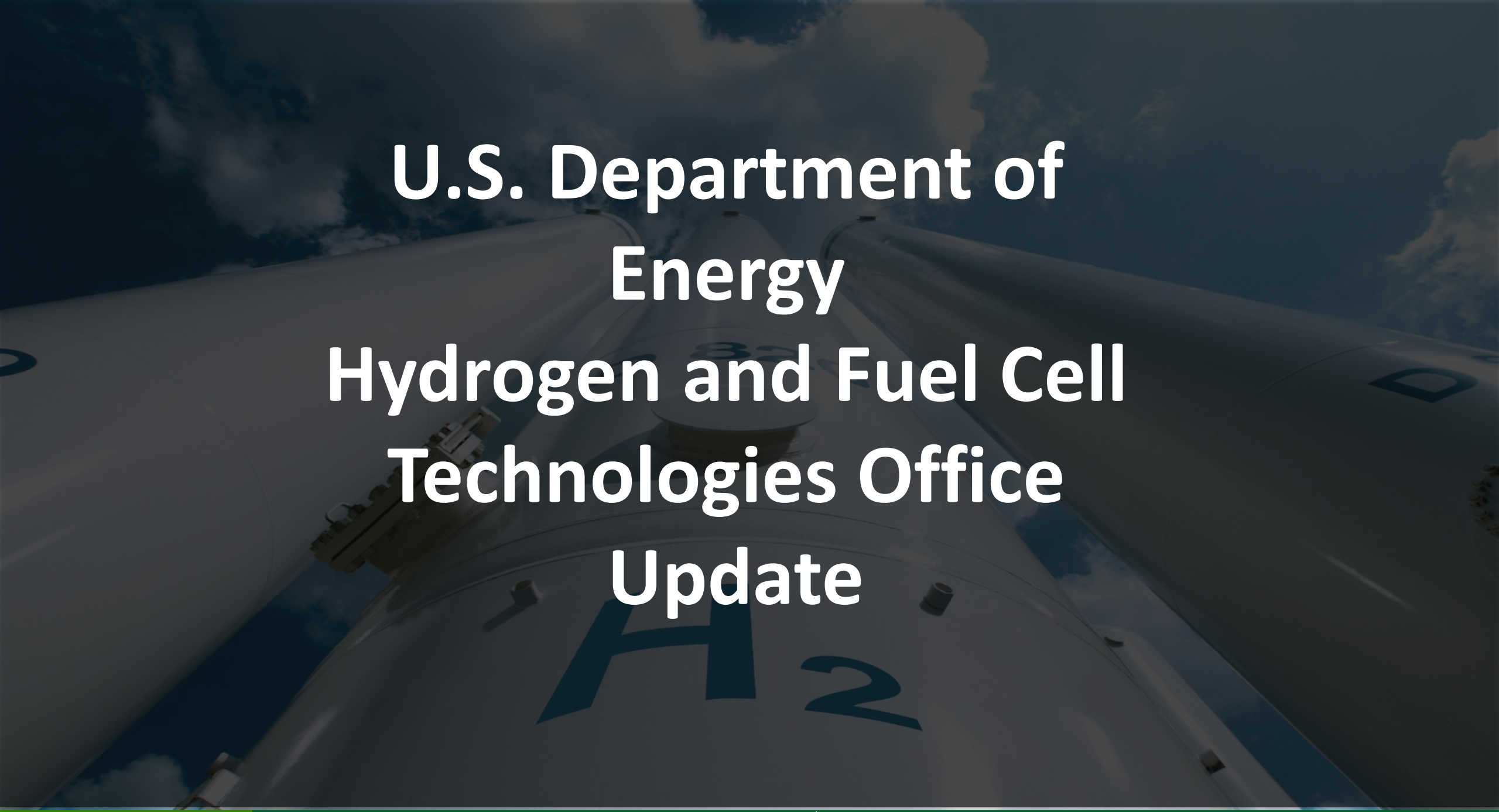
H2 Ministerial Global Action Agenda Goals:
"10, 10, 10"
10M systems, 10K stations, 10 years

Hydrogen Council: Global industry partnership projects up to 10X increase in H_2 demand by 2050



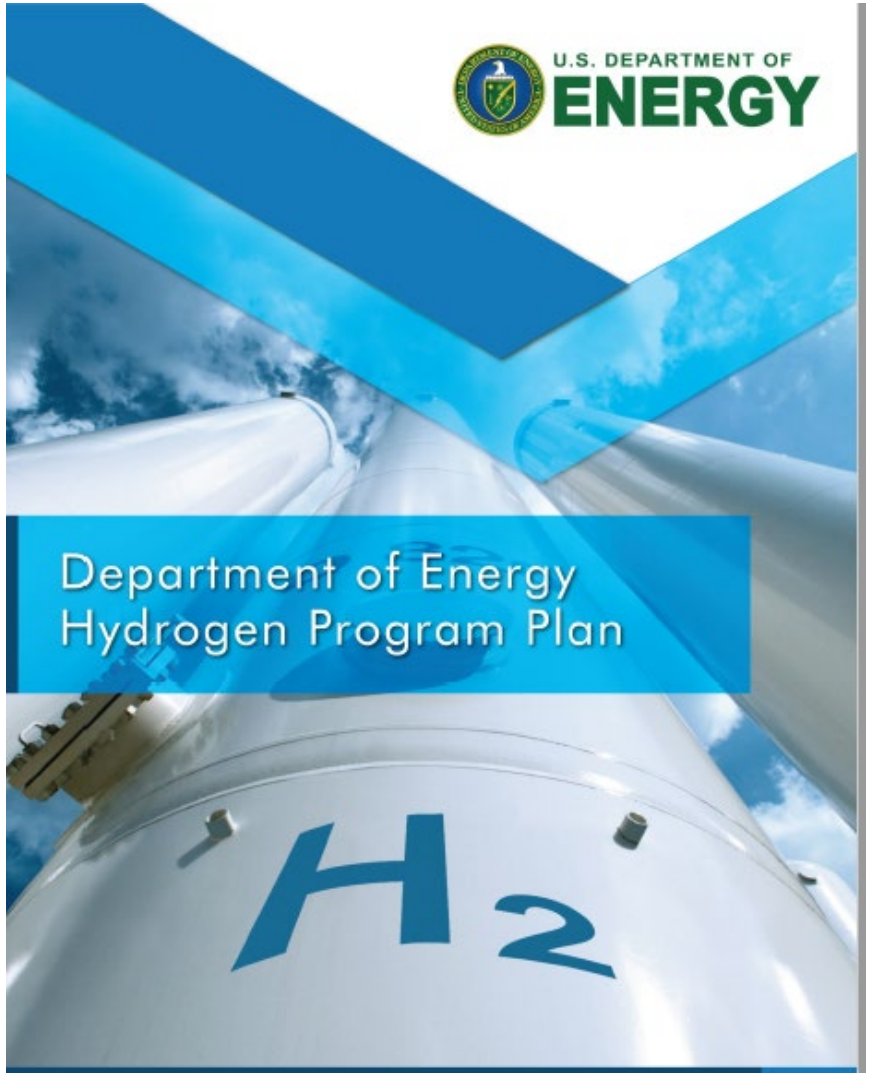


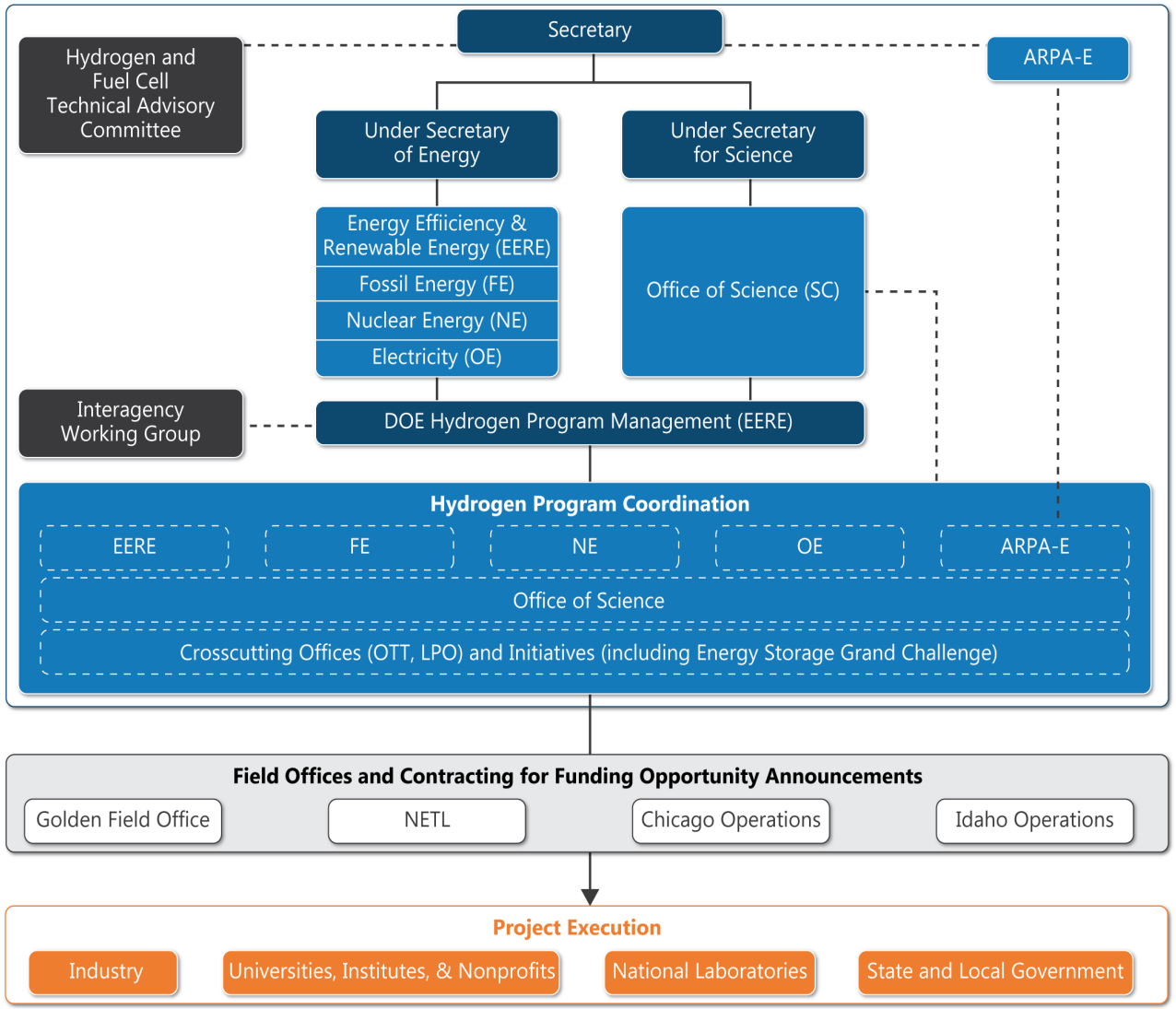
H2 Council Global Impact Potential by 2050



U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office Update

US DOE Hydrogen Program Plan





Released November 2020 - www.hydrogen.energy.gov

Hydrogen Program Vision and Key Targets

Vision

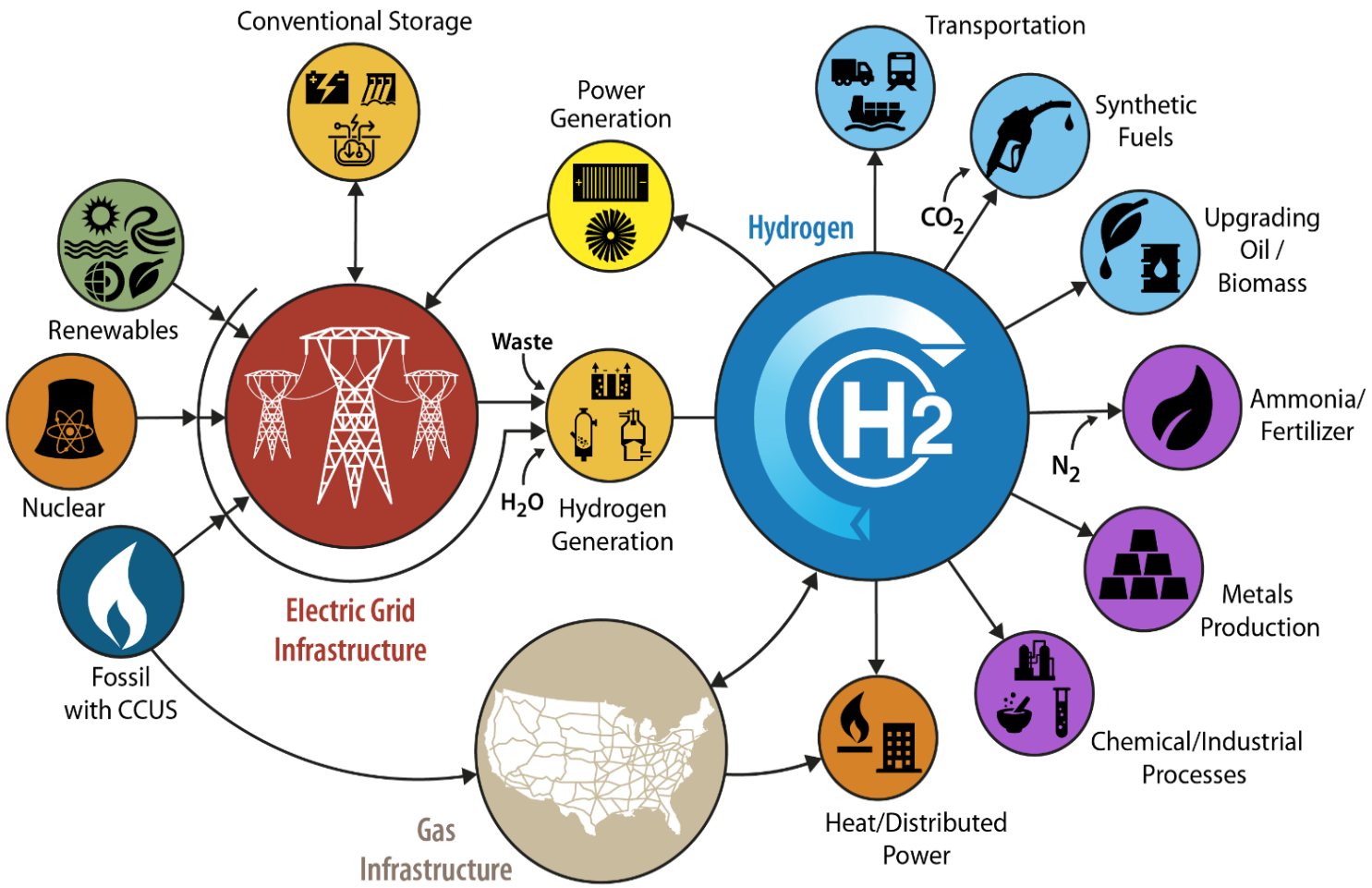
The Program's vision is a prosperous future for the nation, in which clean hydrogen energy technologies are affordable, widely available and reliable, and are an integral part of multiple sectors of the economy across the country.

Examples of Key DOE Hydrogen Program Targets

DOE targets are application-specific and developed with stakeholder input to enable competitiveness with incumbent and emerging technologies. These targets guide the R&D community and inform the Program's portfolio of activities. Examples include:

- $2/kg for hydrogen production and $2/kg for delivery and dispensing for transportation applications
- $1/kg hydrogen for industrial and stationary power generation applications
- Fuel cell system cost of $80/kW with 25,000-hour durability for long-haul heavy-duty trucks
- On-board vehicular hydrogen storage at $8/kWh, 2.2 kWh/kg, and 1.7kWh/l
- Electrolyzer capital cost of $300/kW, 80,000 hour durability, and 65% system efficiency
- Fuel cell system cost of $900/kW and 40,000 hour durability for fuel-flexible stationary high-temperature fuel cells

H2@Scale: Enabling affordable, reliable, clean, and secure energy



- Hydrogen can address specific applications across sectors that are hard to decarbonize
- Today: 10MMT H_2 in the U.S.
- Economic Potential: 2 to 4x more

Strategies

- Scale up technologies in key sectors
- Continue R&D to reduce cost and improve performance, reliability
- Address enablers: harmonization of codes, standards, safety, global supply chain, workforce development, sustainable markets

Source: U.S. DOE Hydrogen and Fuel Cell Technologies Office, https://www.energy.gov/eere/fuelcells/h2scale

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

Examples of Applications

>500MW
Stationary Power

>35,000
Forklifts

>60
Fuel Cell Buses

>45
H_2 Retail Stations

>8,800
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

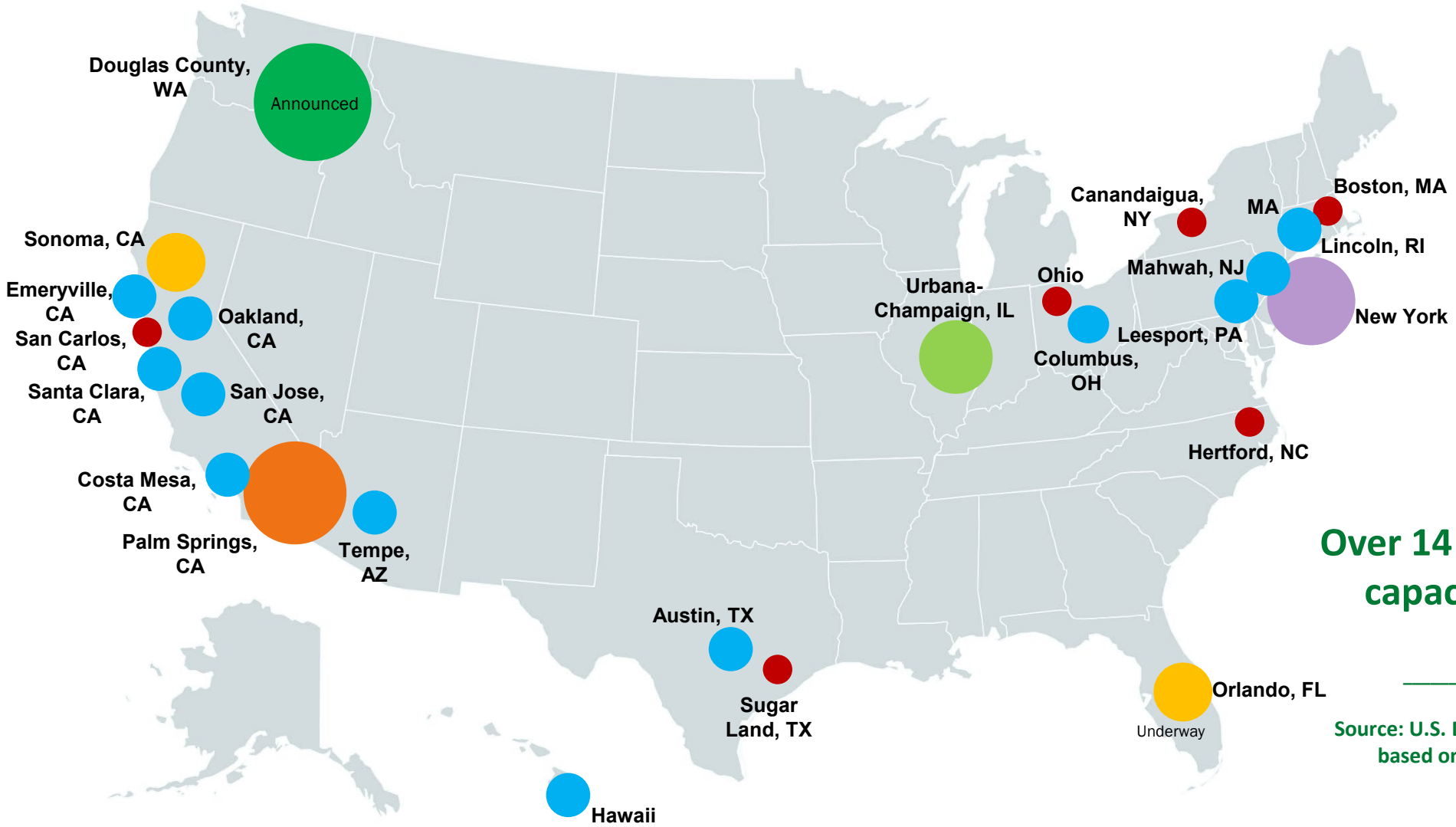
Hydrogen Stations: Examples of Plans Across States

California
200 Stations Planned
CAFCP Goal

Northeast
12 – 20
Stations Planned

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI
And Others

U.S. Hydrogen Electrolyzer Locations and Capacity (KW)



Electrolyzer Power Capacity
120 KW
180 KW
500 KW
1000 KW
1250 KW
2000 KW
5000 KW

Over 14 MW in PEM* electrolyzer capacity installed/underway across the U.S.

Source: U.S. DOE Hydrogen and Fuel Cell Technologies Office based on manufacturer input and publicly available information – October 2020

* Polymer electrolyte membrane

Fuel Cell Stationary Power for Multiple Applications

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

Fuel cells included for power to new World Trade Center in NYC

Fuel cell power for maritime ports demonstrated in Honolulu, Hawaii

Over 500 MW of fuel cell stationary power installed across more than 40 US states

Fuel Cell Forklifts for Material Handling Applications

More than **35,000 forklifts**

Over **20 million refuelings**

Heavy Duty Applications Emerging

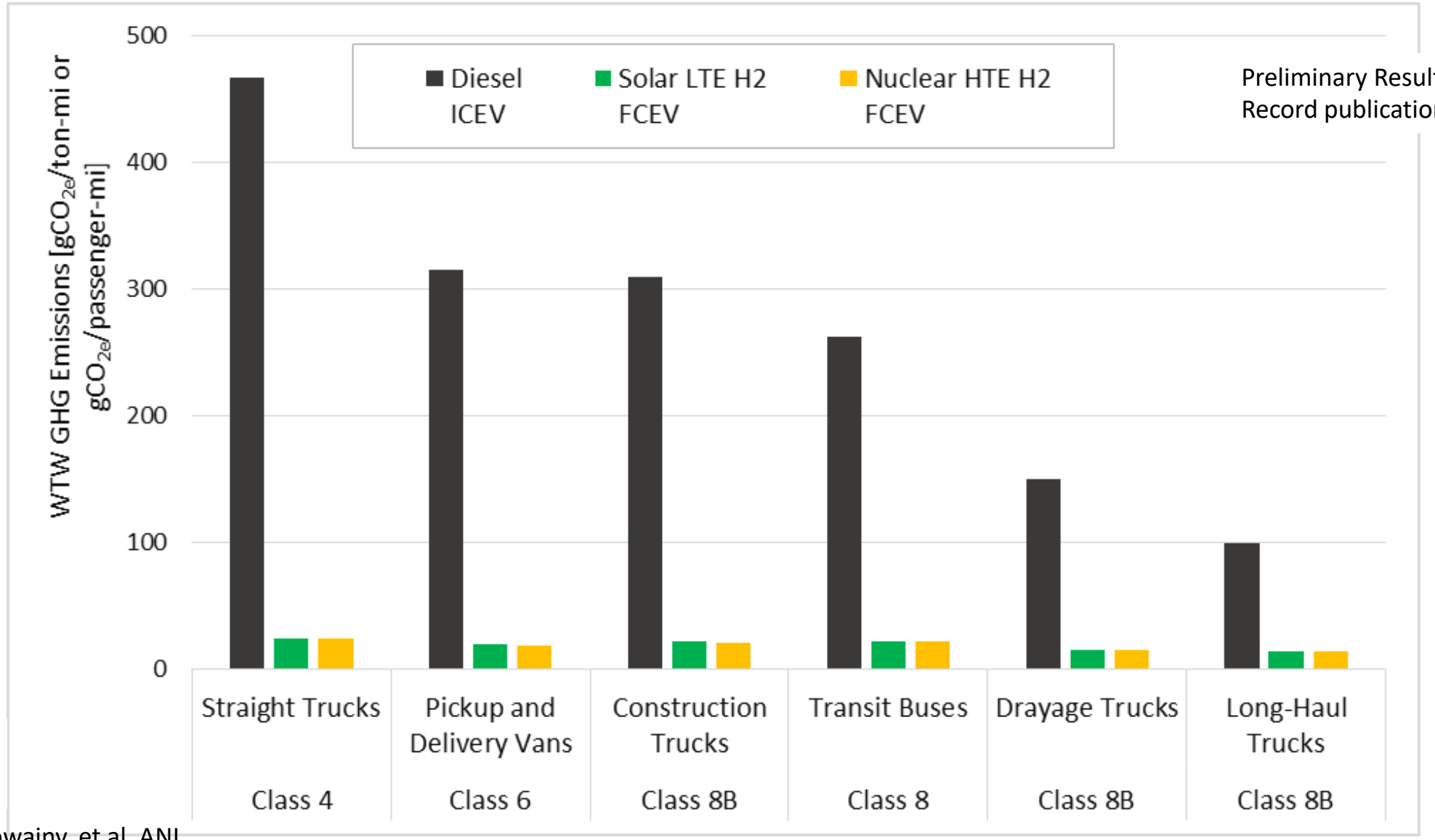
Several companies developing long haul Class 8 fuel cell trucks

Fuel cell buses in CA surpass 20M passengers

Fuel cell parcel truck demonstration projects by DOE + industry

Fuel cell delivery truck projects by DOE + industry

Benefits and Impacts Analyses Underway – Example



Preliminary Results
Record publication underway

Source: A. Elgowainy, et al, ANL

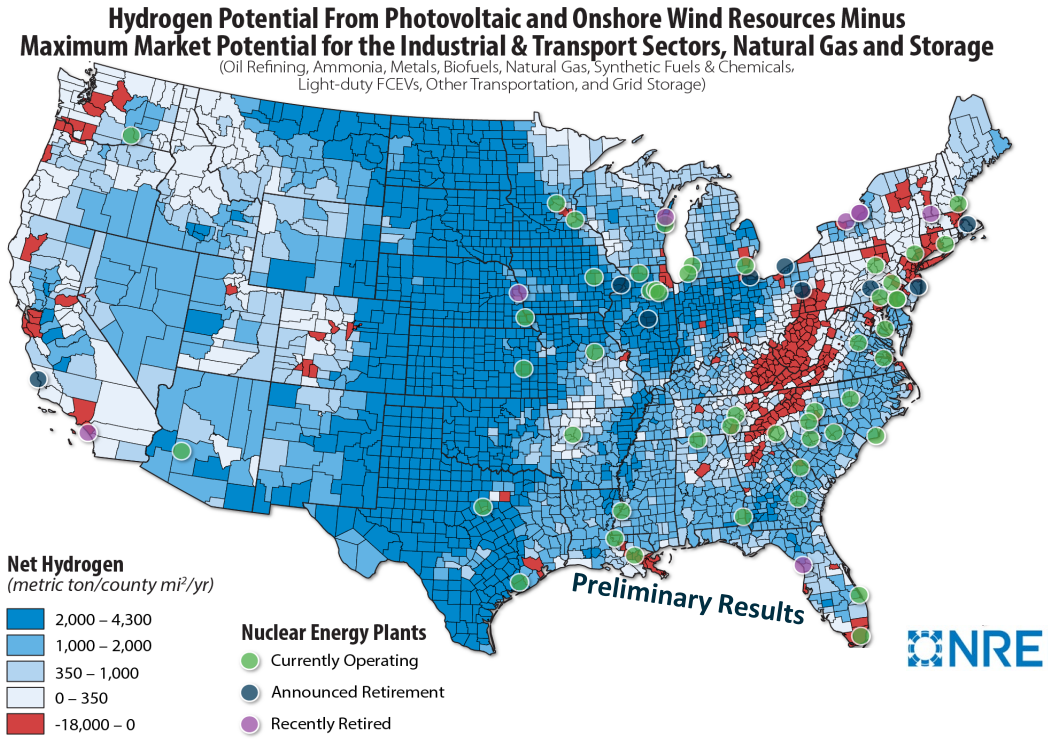
Examples of H2@Scale Analysis and Demonstration Projects

Assessing resource availability.
Most regions have sufficient resources.

New H2@Scale demonstration projects cover range of applications

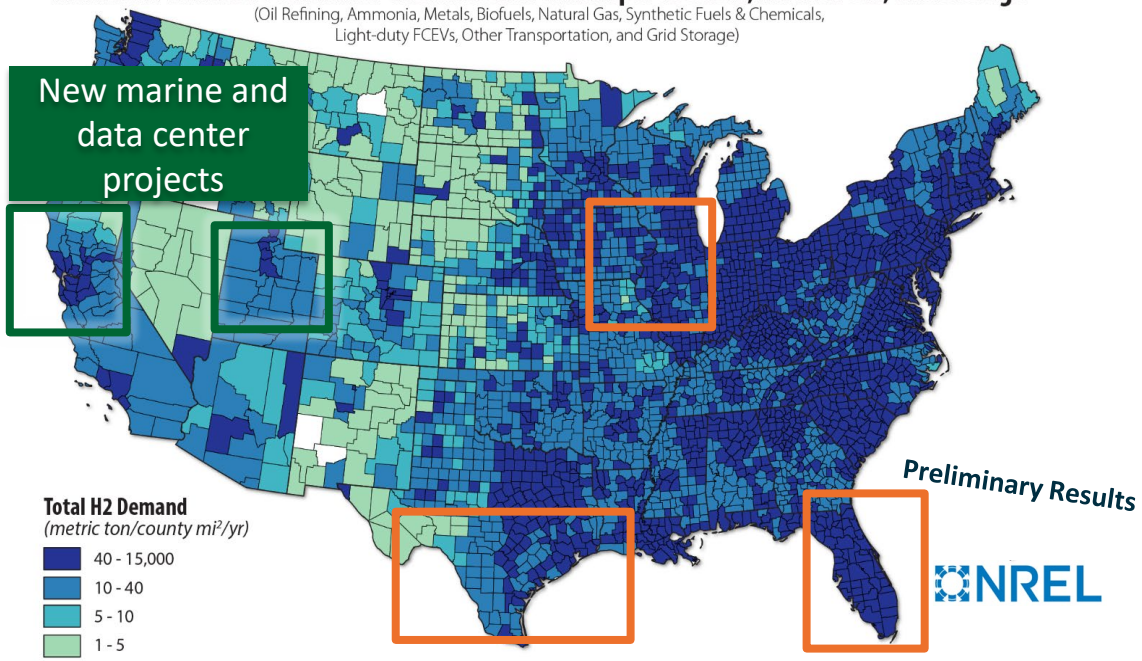
*Includes 1 project by Office of Nuclear Energy

Hydrogen Availability



Red: Only regions where projected industrial & transportation demand exceeds supply.

Hydrogen Demand Potential



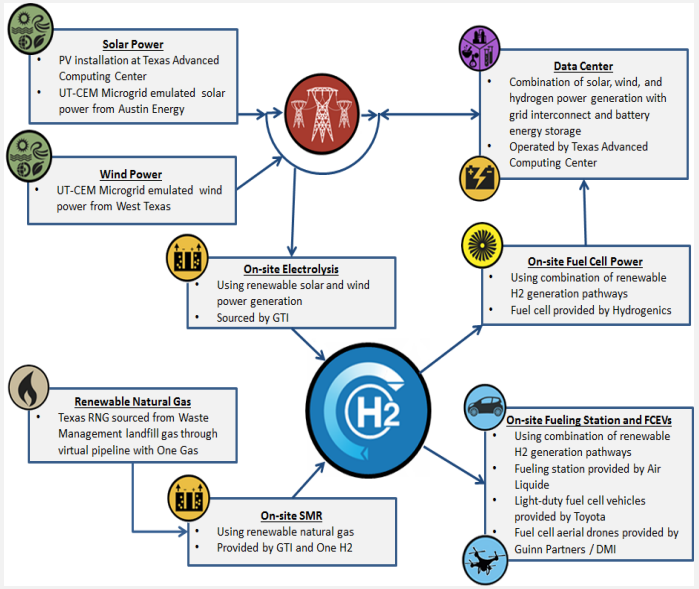
Example of H2@Scale Demonstration Projects

Demonstration of H2@Scale: Different regions, hydrogen sources and end uses

Texas

Total Budget
$10.8M

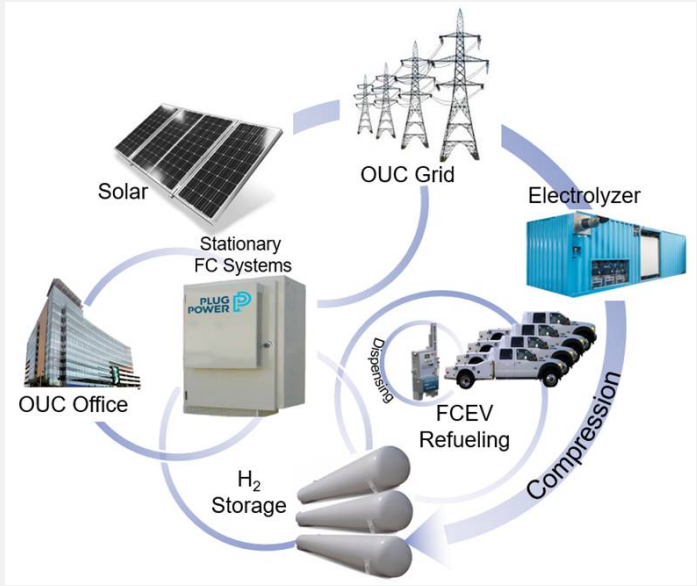
Wind, Solar, RNG/Waste



Florida

Total budget
$9.1M

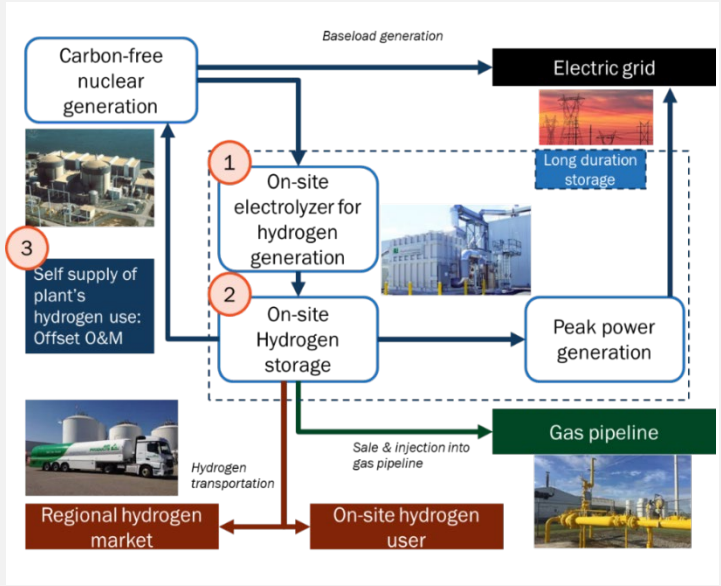
Solar-to-H_2 with End Uses



Site selection in process

Total Budget
$7.2M

Nuclear-to-H_2 for at-Plant Use



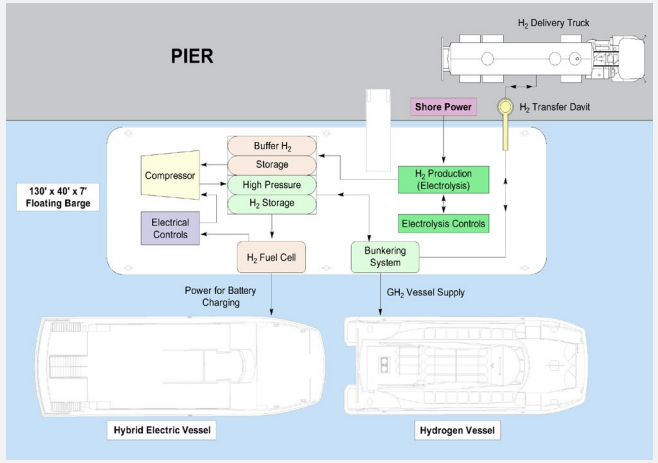
Examples of H2@Scale Demonstration Projects -2020

Demonstration of H2@Scale: Different regions, hydrogen sources and end uses

Marine Application

Total Budget $16M

Electrolyzer and fuel cell for marine application

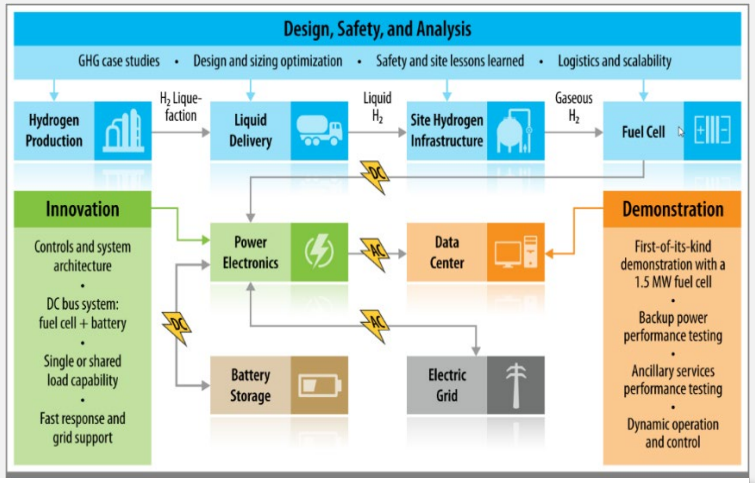


1st-of-its-kind maritime H_2 refueling on floating barge - up to 530 kg H_2 /day

H_2 for Data Center

Total Budget $13.7M

PEM fuel cell for data center power

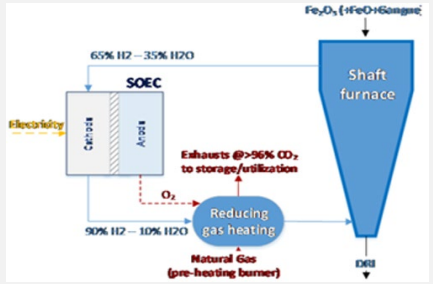


1.5MW fuel cell to meet data center requirements and future scale up

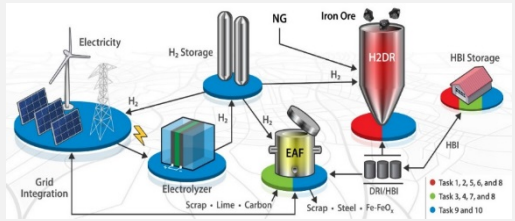
H_2 for Steel Production

Total Budgets $5.7M & $7.2M

DRI-process and grid-interactive steelmaking



Reduction of 30% in energy and 40% emissions vs conventional DRI processes



1 ton/wk iron prod.; scaled to 5,000 ton/day

R&D Efforts Underway

DOE Hydrogen and Fuel Cell Technologies Office Focus Areas

Mission

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

- Energy security
- Energy resiliency
- Strong domestic economy

Enabling H2@Scale U.S. Department of Energy

Key R&D Sub-Programs and Focus Areas

Fuel Cells

- Cost, durability, efficiency
- Components (catalysts, electrodes) & systems
- Focus on heavy duty applications (trucks, marine, data centers, rail, air, etc.)

Hydrogen

- Hydrogen production, infrastructure/delivery, storage (for transport and stationary storage)
- Cost, efficiency, reliability & availability.

Systems Development & Integration

- Hybrid, grid integrated systems, energy storage
- Safety, codes & standards
- Technology acceleration, workforce development

Data, Modeling, Analysis: Assess pathways, impacts; set targets, guide R&D

Key Goals by 2030

Reduce the cost of:

- Heavy duty fuel cells by 2X to $80/kW
- Electrolyzers by 3 to 5x to $300/kW
- Storage tanks by over 40% to $9/kWh
- H_2 delivery and dispensing by 4 to 5x to $2/kg
- H_2 production by 2 to 3x to $2/kg

Improve fuel cell durability 5x to 25,000 hours

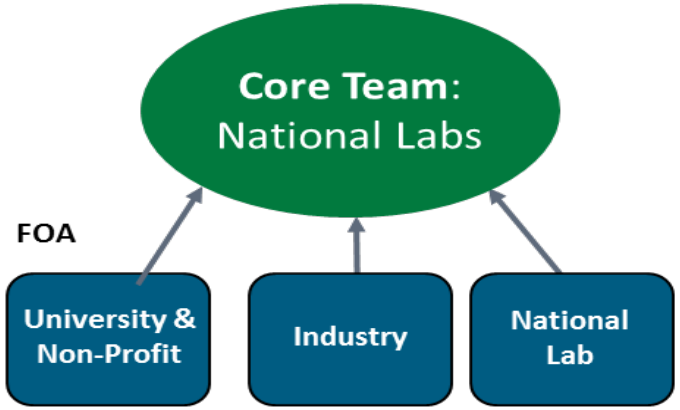
Double energy density for onboard storage to **1.7 kWh/L**

Budget: $150M in FY2020

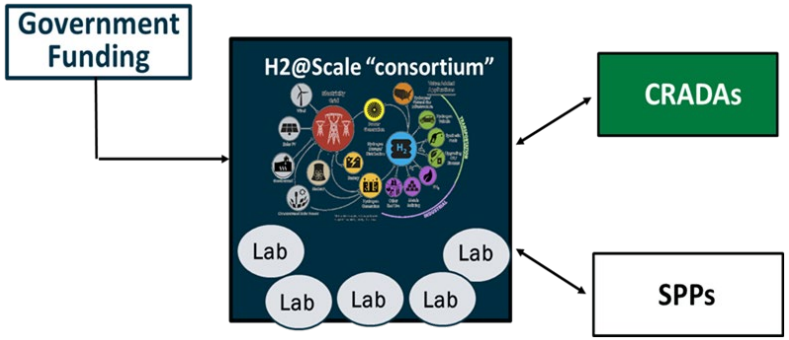
Key Programmatic Areas

<u>Includes early stage R&D</u>: Funding Opportunity Announcements (FOAs) for industry, universities and national labs, including consortia

<u>And includes later stage RD&D</u>: Leverages private sector for large-scale demonstrations and cost-shared RD&D. Demos in TX, FL, Midwest, CA and more



2 New Lab Consortia Just Announced: H2NEW and Million Mile Fuel Cell Truck Consortium



CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project ('Work for Others')

HydroGEN Advanced Water Splitting Materials

ElectroCat Electrocatalysis Consortium

HyMARC Hydrogen Materials Advanced Research Consortium

H-Mat Hydrogen Materials Compatibility Consortium

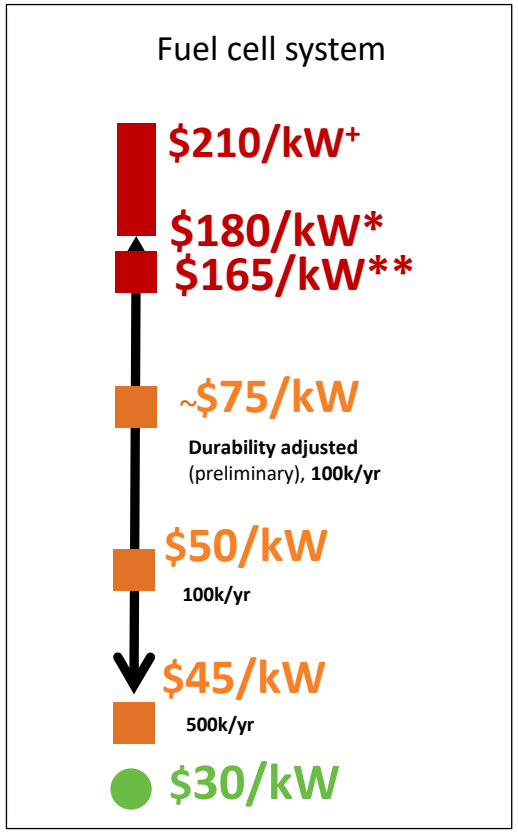
Over 25 CRADA projects with private sector

Just Announced: $64M for 18 projects including R&D and demonstrations at ports and datacenters, and a workforce development program . Includes collaboration with Advanced Manufacturing Office and Vehicles Office in EERE

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

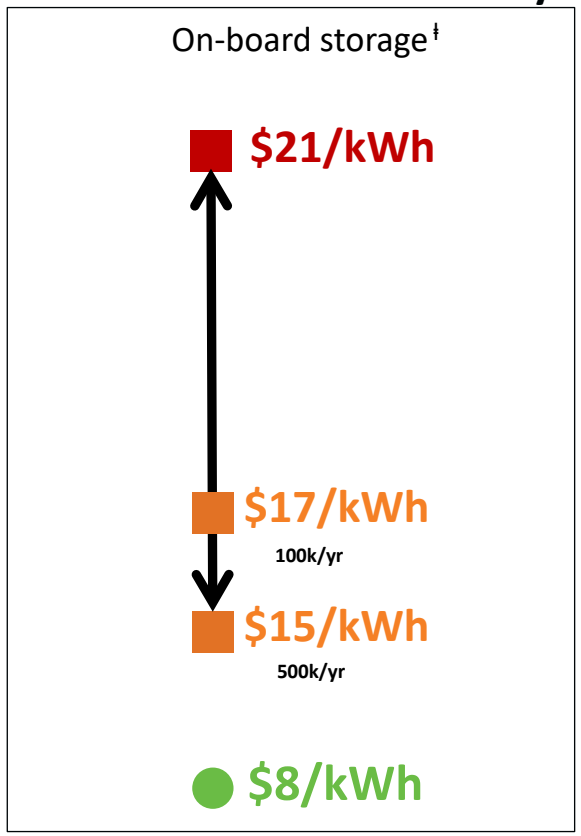
Key Goals: Reduce the cost of fuel cells and hydrogen production, delivery, storage, and meet performance and durability requirements – guided by applications specific targets

Fuel Cell R&D

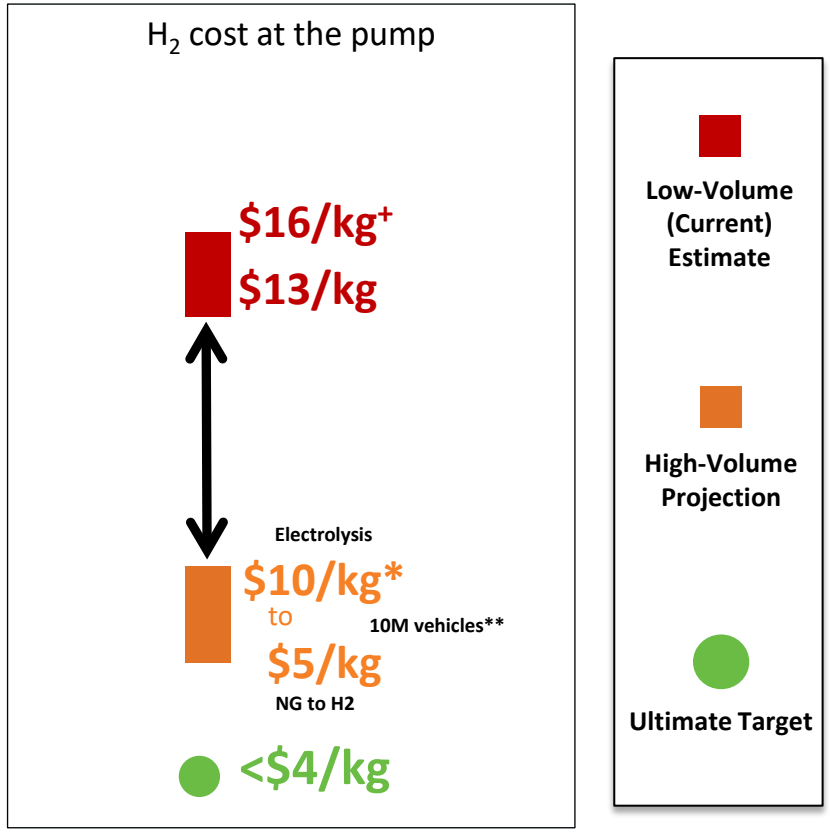


†Based on commercially available FCEVs
*Based on state of the art technology
**Based on commercial FCEV analysis at 3,000/yr

Hydrogen R&D



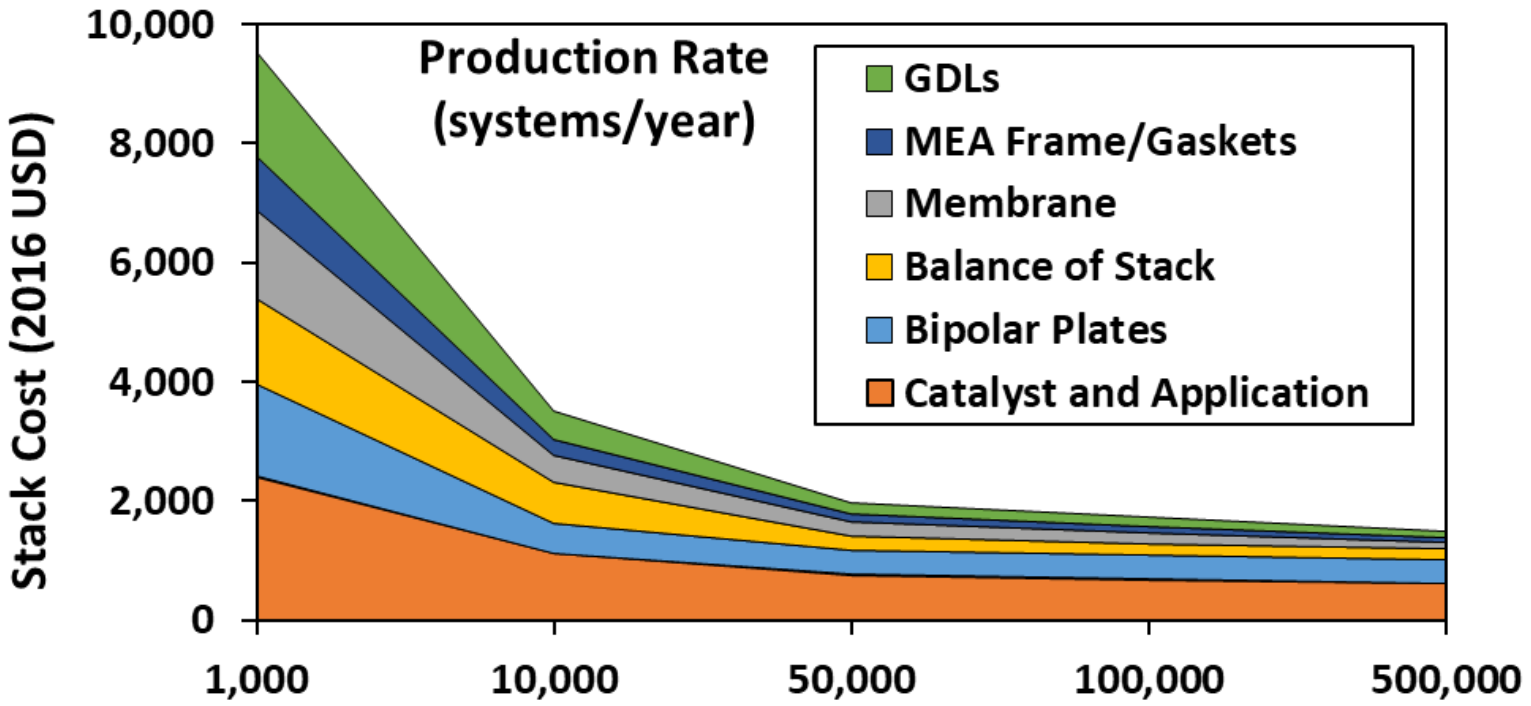
‡Storage costs based on preliminary 2019 storage cost record



†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

Fuel Cell Cost Drivers

Example of cost drivers for fuel cell stack (automotive systems)



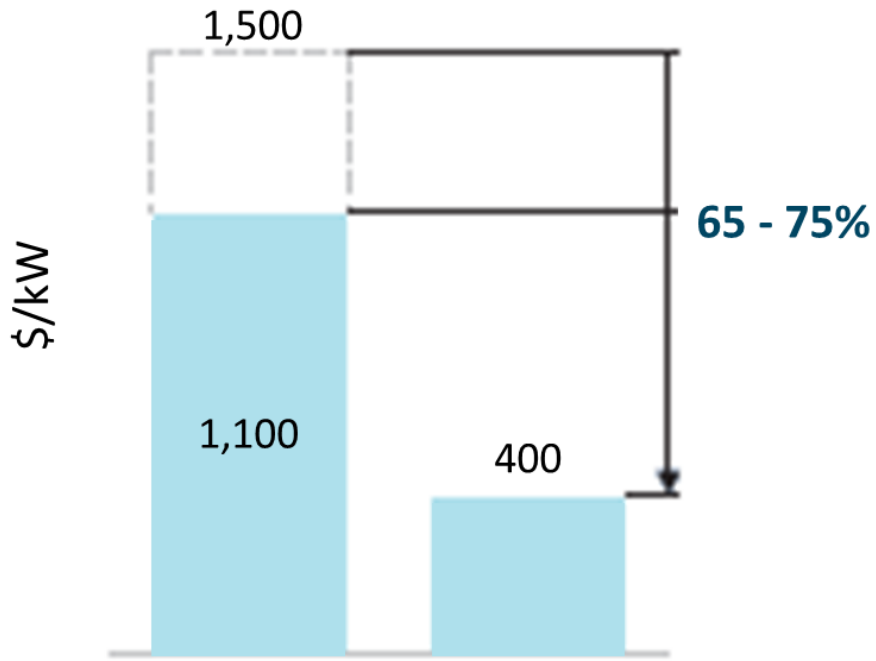
New efforts focus on heavy duty truck targets:

Targets: $80/kW, 25,000 hour durability, 68% efficiency by 2030

$60/kW and 30,000 hour durability – ultimate targets

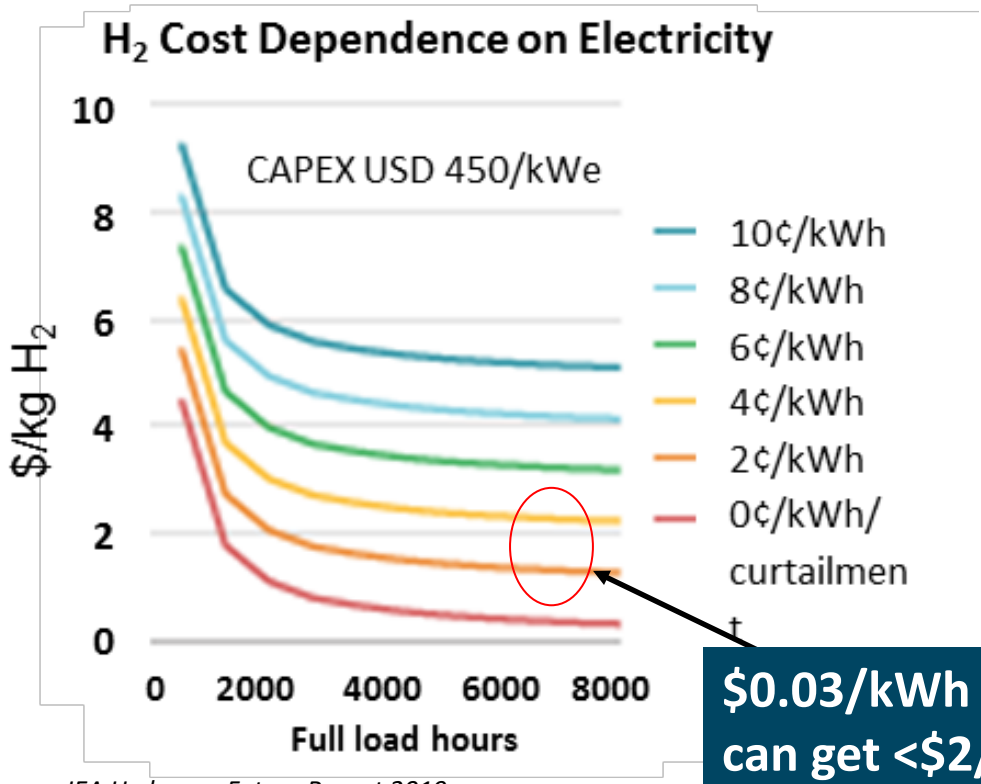
Electrolysis Cost – Recent Independent Analyses

Today's Polymer Electrolyte Membrane (PEM) electrolyzers require 65 75% cost reduction



Source: US Industry H2 Roadmap, March 2020

$2/kg H2 is achievable at about $0.03/kWh electricity cost and high utilization

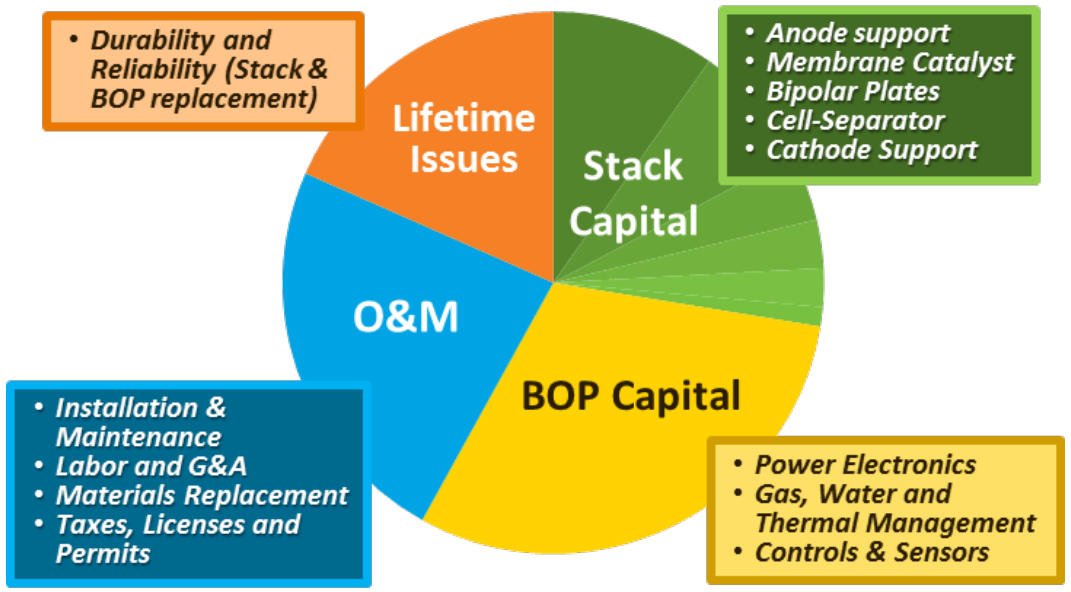


Source: IEA Hydrogen Future Report 2019

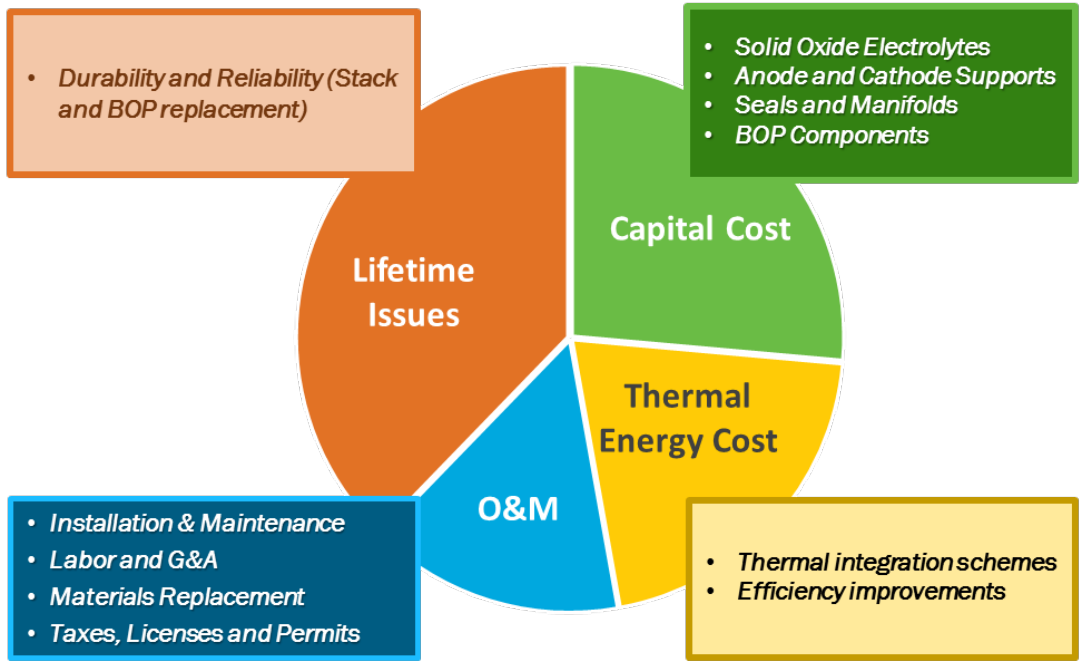
Today's hydrogen cost from PEM electrolyzers: ~ $5 to $6/kg at $0.05 to $0.07/kWh

Key Cost Contributors to Low Temp and High Temp Electrolyzers

Cost Breakdown for Low Temperature (PEM) Electrolyzers



Cost Breakdown for High Temperature Electrolyzers (SOECs)



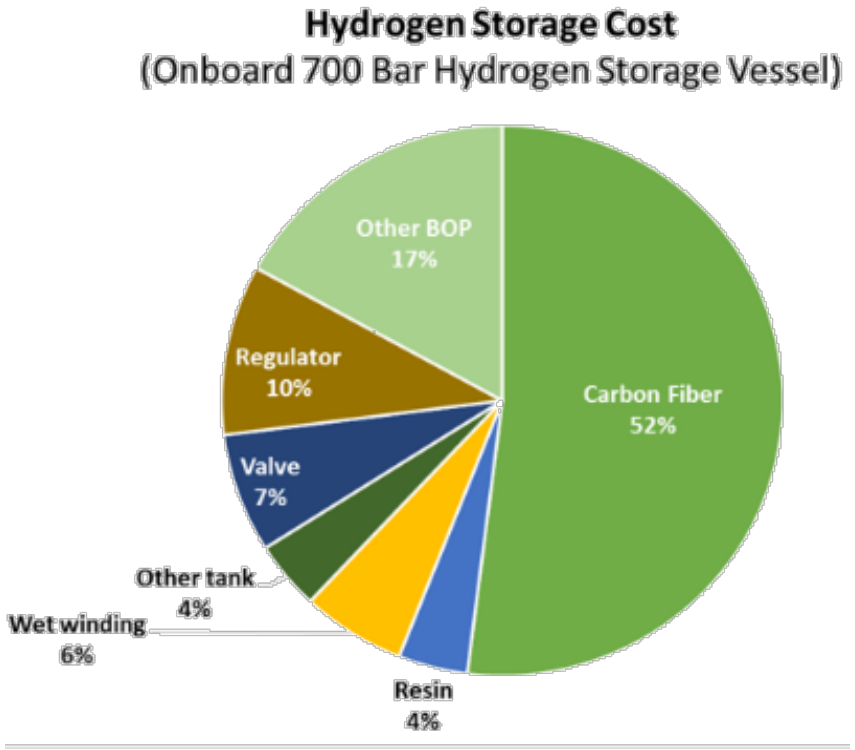
Excludes electricity cost

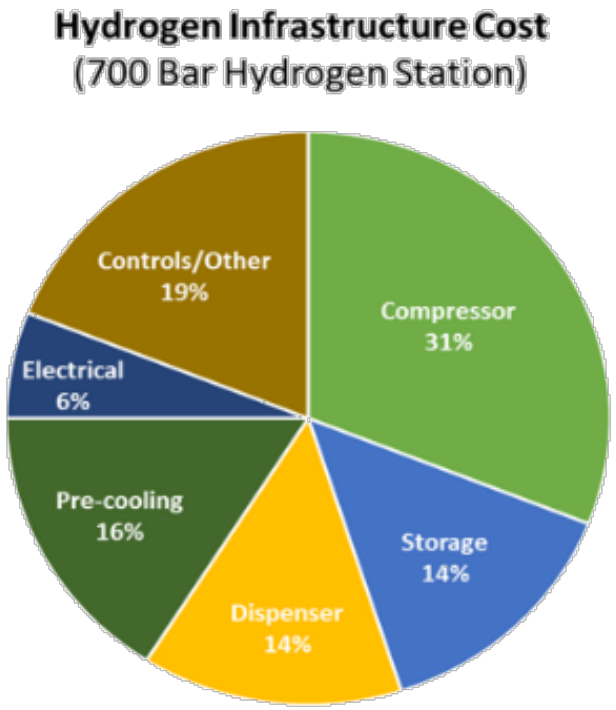
Source: DOE, Hydrogen and Fuel Cell Technologies Office, Updated analysis underway

Identifying Hydrogen Cost Drivers is Key

H_2 Onboard Storage Cost Drivers: Carbon Fiber Precursors and Processing

H_2 Infrastructure Cost Drivers: Compressors, Storage and Other Components



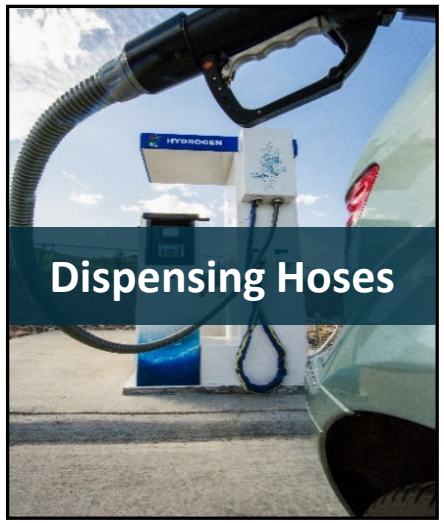


Source: DOE, Hydrogen and Fuel Cell Technologies Office, 2018-2019, Updated analysis underway; Station cost- one example; multiple station designs underway

Cross-cutting Materials Compatibility R&D

H-Mat SM Hydrogen Materials Compatibility Consortium

H-Mat Consortium conducts R&D on hydrogen effects on polymers and metals



- **Enabling the safe use of hydrogen across applications and the development of harmonized codes and standards**
- **Addressing hydrogen blending with natural gas, reducing expansion of seals, improving life of vessels through improved understanding of crack nucleation, enhancing fracture toughness of high-strength steels, and more**
- **Over 25 partners with industry, labs, universities**

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

Website: energy.gov/eere/fuelcells/h-mat-hydrogen-materials-consortium

Email: h-matinfo@pnnl.gov

20% hydrogen blends could enable a doubling[1] of U.S. renewables consumption

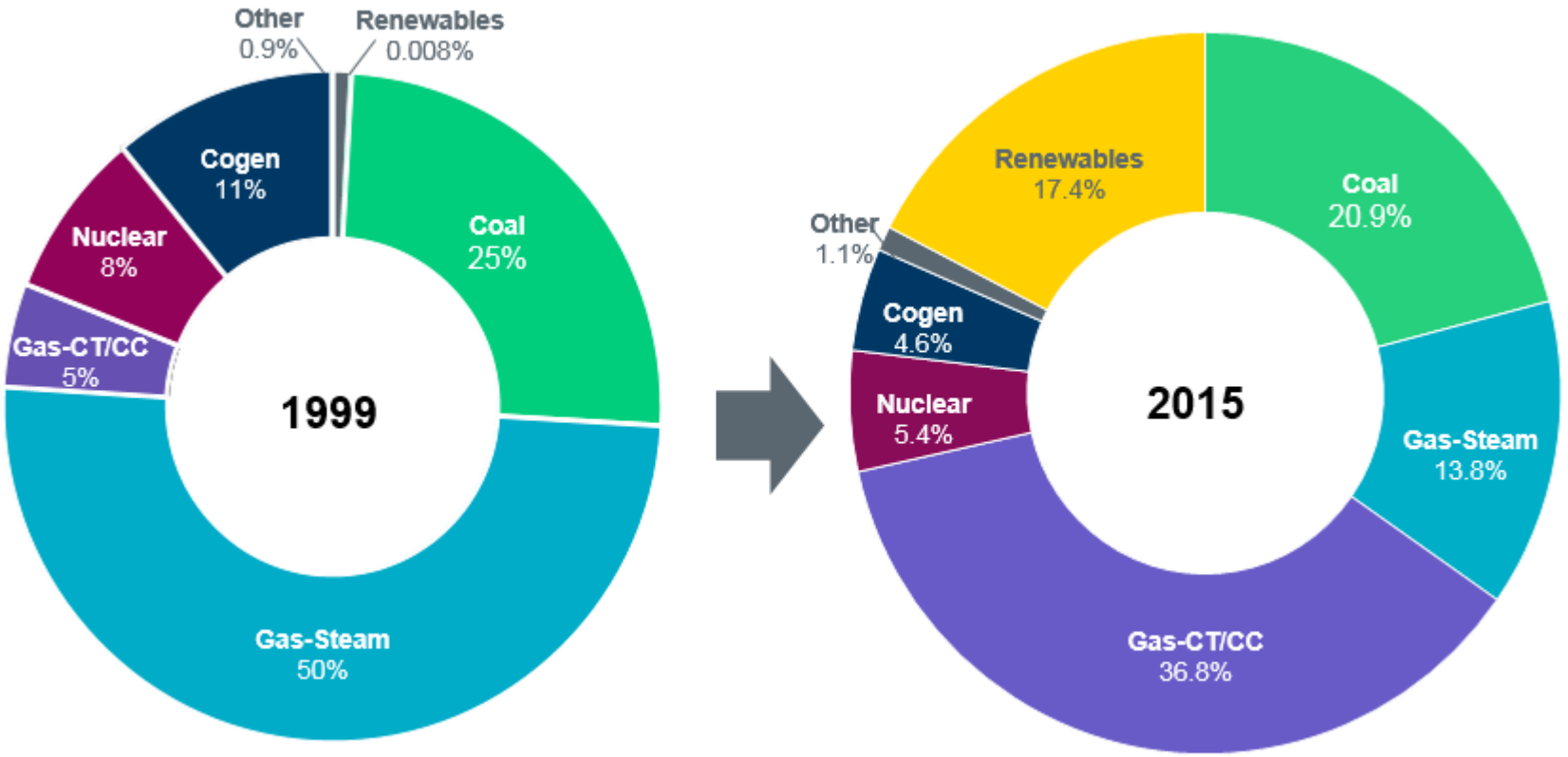
% H2/NG blends vary widely from <1% to 30%. Up to 15% may be feasible without significant modification to existing infrastructure

Launched HyBlend: R&D project to enable H_2 blending and address challenges

1. U.S. Projected Renewable Energy Consumption in Power Generation in 2019: 702.7 TWh (Source: AEO 2020)
20% hydrogen blend in the U.S. by volume = 16 MMT/year, which would require ~750 TWh of electricity if produced via electrolysis. (Source: Elgowainy, et al, 2020)

Renewables are coming on line and low cost is enabling hydrogen

Example: Installed Capacity in Texas



Source: ERCOT, DOE H2@Scale Workshop, TX

Rapid deployment of renewables and cost reduction (eg, $0.03/kWh)

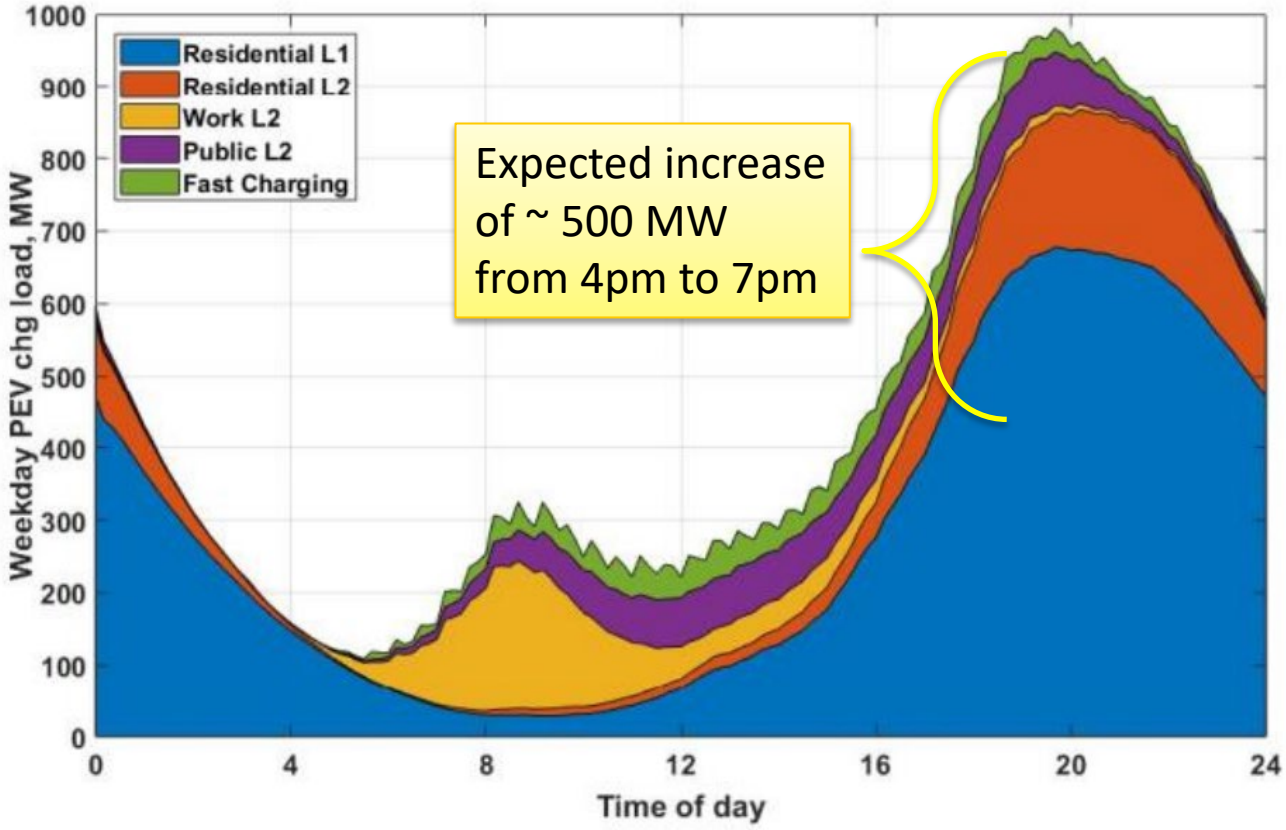
Increased interest in hydrogen production, storage and use

H_2 is at $5 to $6/kg from electrolysis at $0.05 to $0.07/kWh

Additional Value of Hydrogen: Grid Services and Resiliency

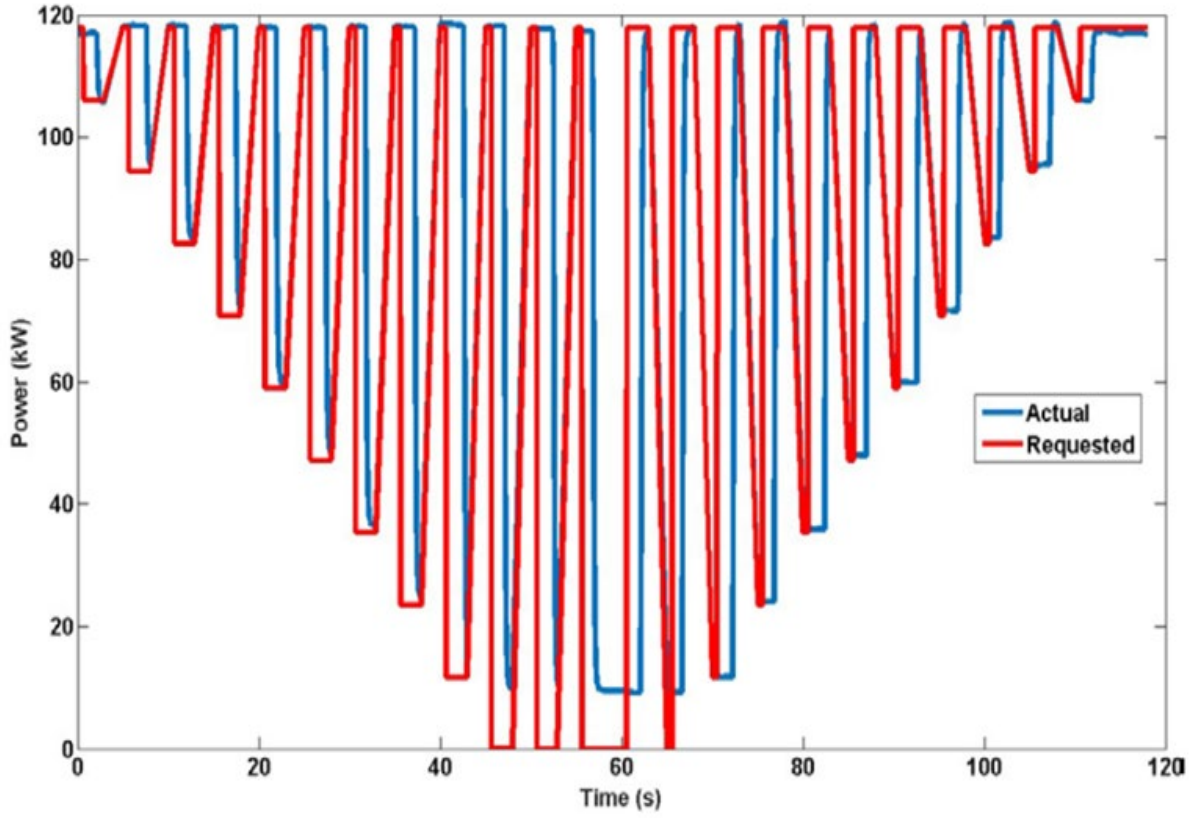
Flexibility will be needed to address grid challenges: high ramp rates and demand fluctuations

Predicted 2025 California EV Charging Load Profile (Weekday) shows impact of demand profiles on the grid



Source: CEC/NREL Report
https://www.nrel.gov/docs/fy18osti/70893.pdf

DOE national lab tests show dynamic response potential of electrolyzers



Idaho National Lab & National Renewable Energy Lab results. Direct fast charger impact project underway 2020-2021


Collaboration

“No one can whistle a symphony. It takes a whole orchestra to play it.”

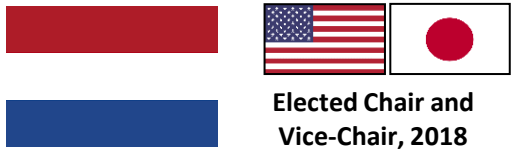
- H. Luccock

Examples of Global Collaboration

Coordinating across global partnerships: IPHE, Ministerials, Mission Innovation, IEA, etc.
Global Center for Hydrogen Safety established to share best practices, training resources and information

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

New Chair: Dec 2020: The Netherlands
Vice Chairs: U.S. Japan

www.iphe.net

Formed in 2003

Over 20 countries

Key Activities: Harmonization of codes & standards, Information sharing on safety, policies, regulations, analysis, education. Task force on developing H_2 production analysis methodology to facilitate international trade, global RD&D monitoring

Hydrogen and Clean Energy Ministerials	Mission Innovation Hydrogen Challenge	International Energy Agency

www.aiche.org/CHS

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

IPHE
Hydrogen Council
hySafe
AIChE
Pacific Northwest NATIONAL LABORATORY

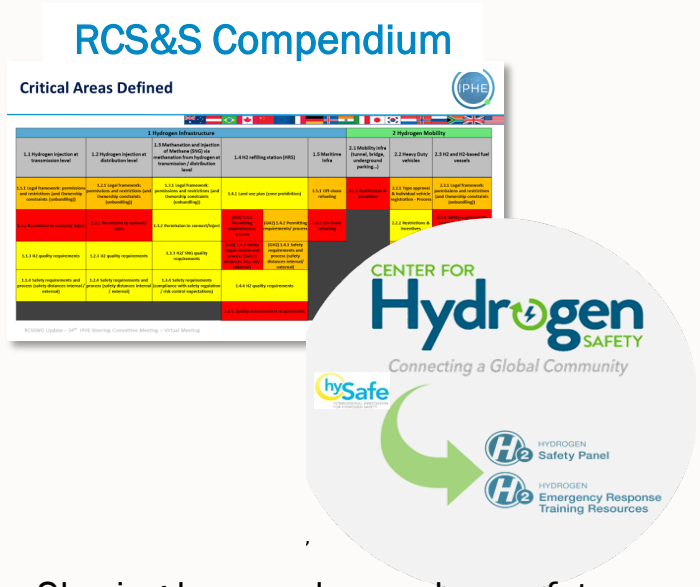
Includes over 40 partners from industry, government and academia

Access to >110 countries, 60,000 members

CENTER FOR Hydrogen SAFETY
Connecting a Global Community
HYDROGEN Safety Panel
HYDROGEN Emergency Response Training Resources

Current Activities within IPHE Working Groups

Regulations, Codes, Standards, Safety (RCSS)

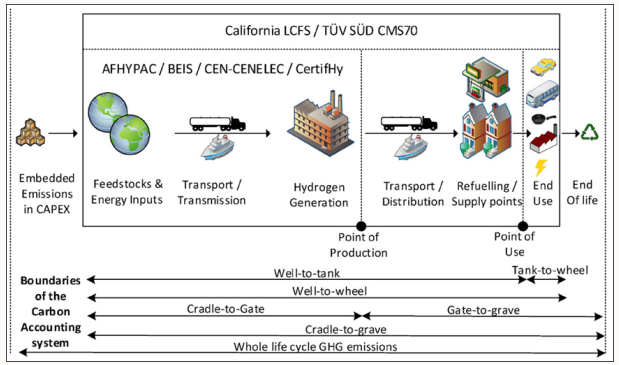


- Sharing lessons learned on safety
- Reports, workshops
- Assessing gaps in RCS to enable harmonization and identify key priorities

H_2 Production Analysis (H2PA)

Task Force on analysis to facilitate international trade of hydrogen

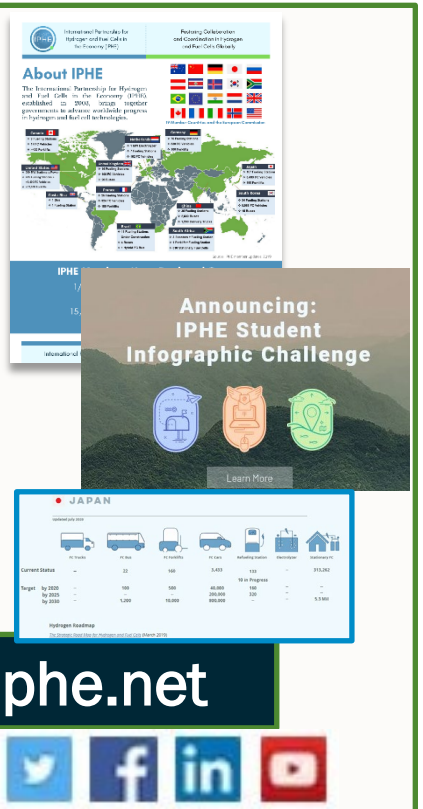
- Developing a common analytical framework to determine emissions footprint for hydrogen
- Harmonizing approach across countries and pathways



(Source: Abad et al., Energy policy 138 (2020) 111300)

Education & Outreach (E&O)

- Workshops, webinars
- Events
- Fellowship
- Early Career Chapter
- Infographic Challenge
- Tracking & disseminating progress



www.iphe.net

SUBSCRIBE

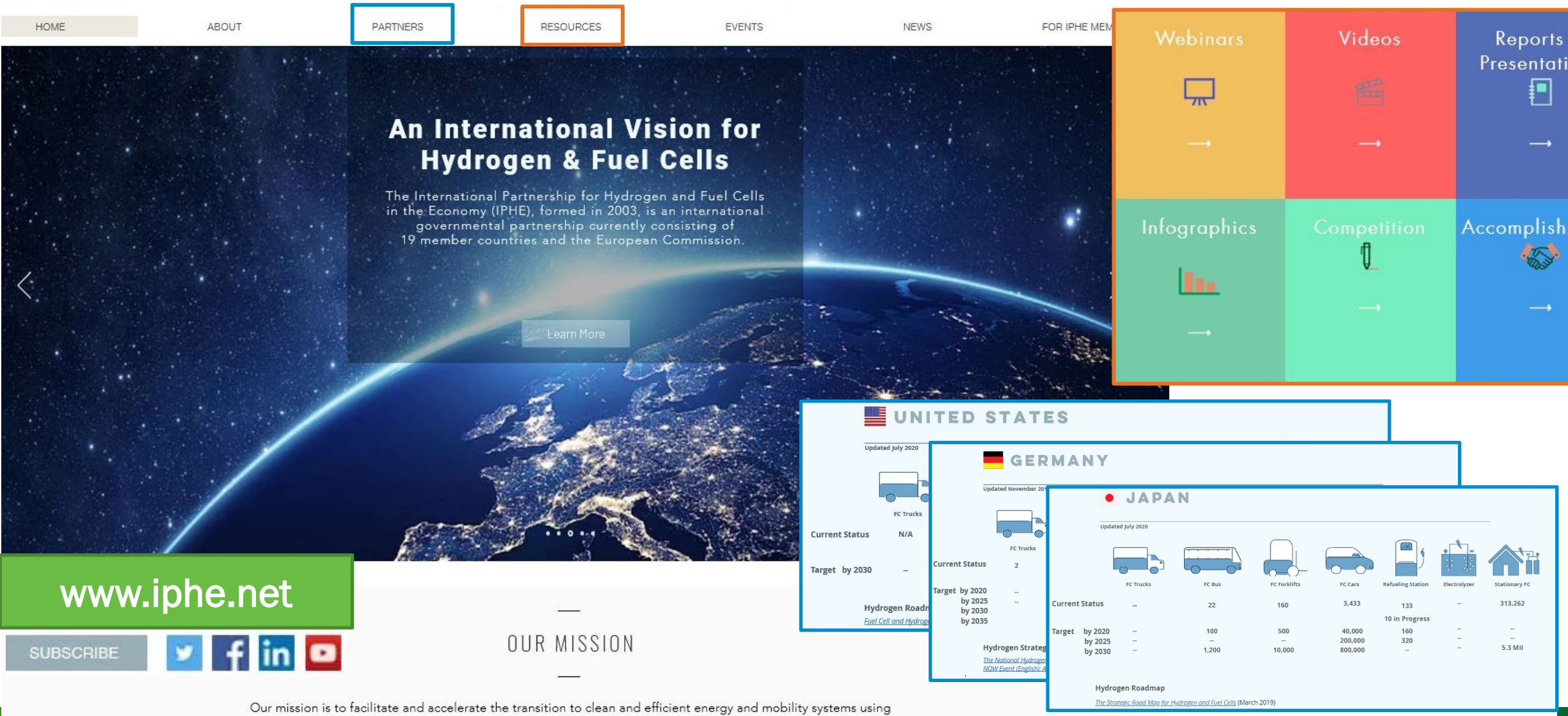
Sharing information, resource development, country updates, policy forums, convening other partnerships to coordinate activities, tracking progress for Global Action Agenda and dissemination

What can you do?

Get involved, coordinate, leverage, help with education and outreach!

Follow @the_iphe

IPHE website on hydrogen status in over 20 countries



IPHE E&O Working Group Early Career Chapter

- **Established by IPHE's Education & Outreach (E&O) Working Group** to promote international H_2 and fuel cell awareness and launch a platform for the next generation of H_2 and fuel cell leaders
- **Open to students, post-docs and early career** professionals

Stephanie Azubike
Chair

Learn more: iphe.net/early-career-chapter

Membership form: https://forms.gle/gUnWyV7gU4QqoHLm7

Priya Buddhavarapu
Co-Chair

#HydrogenNow

#FuelCellsNow

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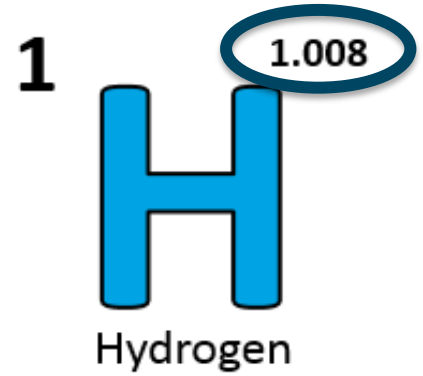
Resources and Events

Save the Date

June 8th week, 2021 Annual Merit Review and Peer Evaluation Meeting for the DOE Hydrogen and Fuel Cells Program

Oct 8 - Hydrogen and Fuel Cells Day

(Held on its very own atomic weight-day)



Resources

INCREASE YOUR H2IQ

Join Monthly
H2IQ Hour Webinars

Download
H2IQ For Free

energy.gov/eere/fuelcells/fuel-cell-technologies-office-webinars

energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Visit H2tools.Org For Hydrogen Safety And Lessons Learned
https://h2tools.org/

Learn more:

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 AND www.hydrogen.energy.gov

Thank You

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