U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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

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SEC World Hydrogen Summit

March 11, 2021

President's Plan for a Clean Energy Economy: 9 Key Elements

1. **Take executive action** on Day 1
2. Enact an irreversible path to **economy-wide net-zero emissions by 2050**
3. **Act and lead globally**
4. **Public investment in clean energy** and innovation
5. **Accelerate the deployment of clean technology** throughout our economy
6. **Make environmental justice a priority** for all federal agencies
7. **Require public companies to disclose climate risks** and GHG emissions
8. **Create millions of good-paying jobs** with the choice to join a union
9. **Fulfill our obligation to communities** and workers that have risked their lives to produce fossil fuels

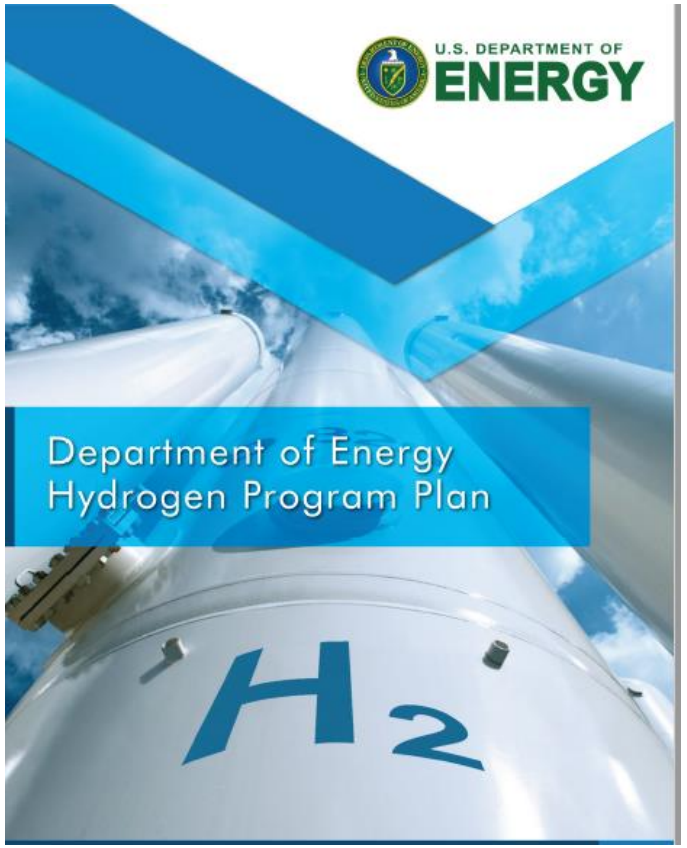
100% carbon-pollution-free electric sector by 2035

from Executive Order on
Tackling the Climate Crisis signed Jan 27, 2021

whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

US DOE Hydrogen Program Plan Released November 2020

Hydrogen is one part of a broad portfolio of activities



www.hydrogen.energy.gov

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

Portfolio Includes Hydrogen Production from Diverse Sources and Pathways

EERE HFTO areas of focus

FOSSIL RESOURCES

- Low-cost, large-scale hydrogen production with CCUS
- New options include byproduct production, such as solid carbon

Coal Gasification with CCUS

Natural Gas Conversion with CCUS

BIOMASS/WASTE

- Options include biogas reforming and fermentation of waste streams
- Byproduct benefits include clean water, electricity, and chemicals

Biomass Conversion

Waste to Energy

H_2O SPLITTING

- Electrolyzers can be grid-tied, or directly coupled with renewables
- New direct water-splitting technologies offer longer-term options

Direct-Solar

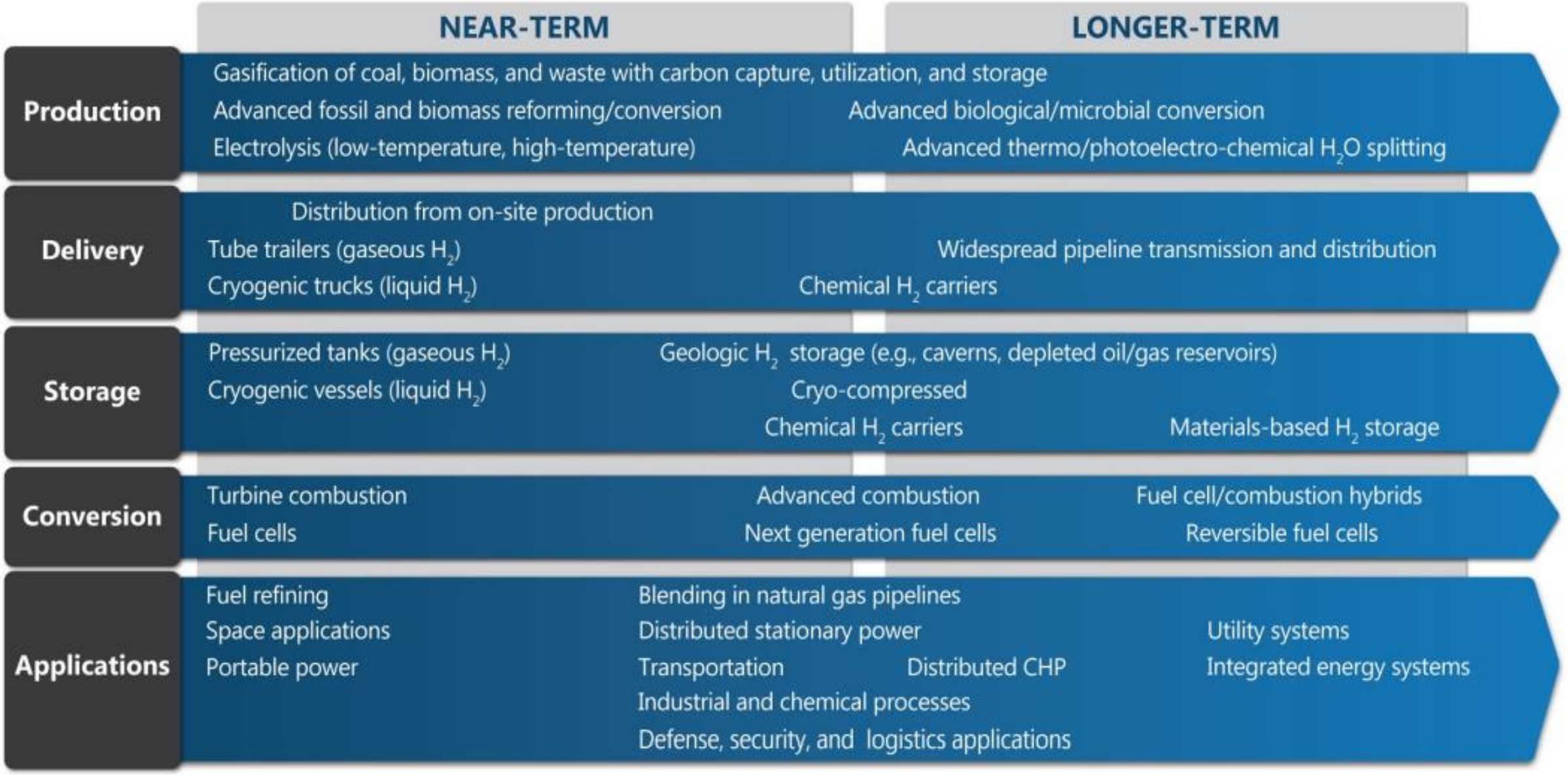
High Temp. Electrolysis

Low Temp. Electrolysis

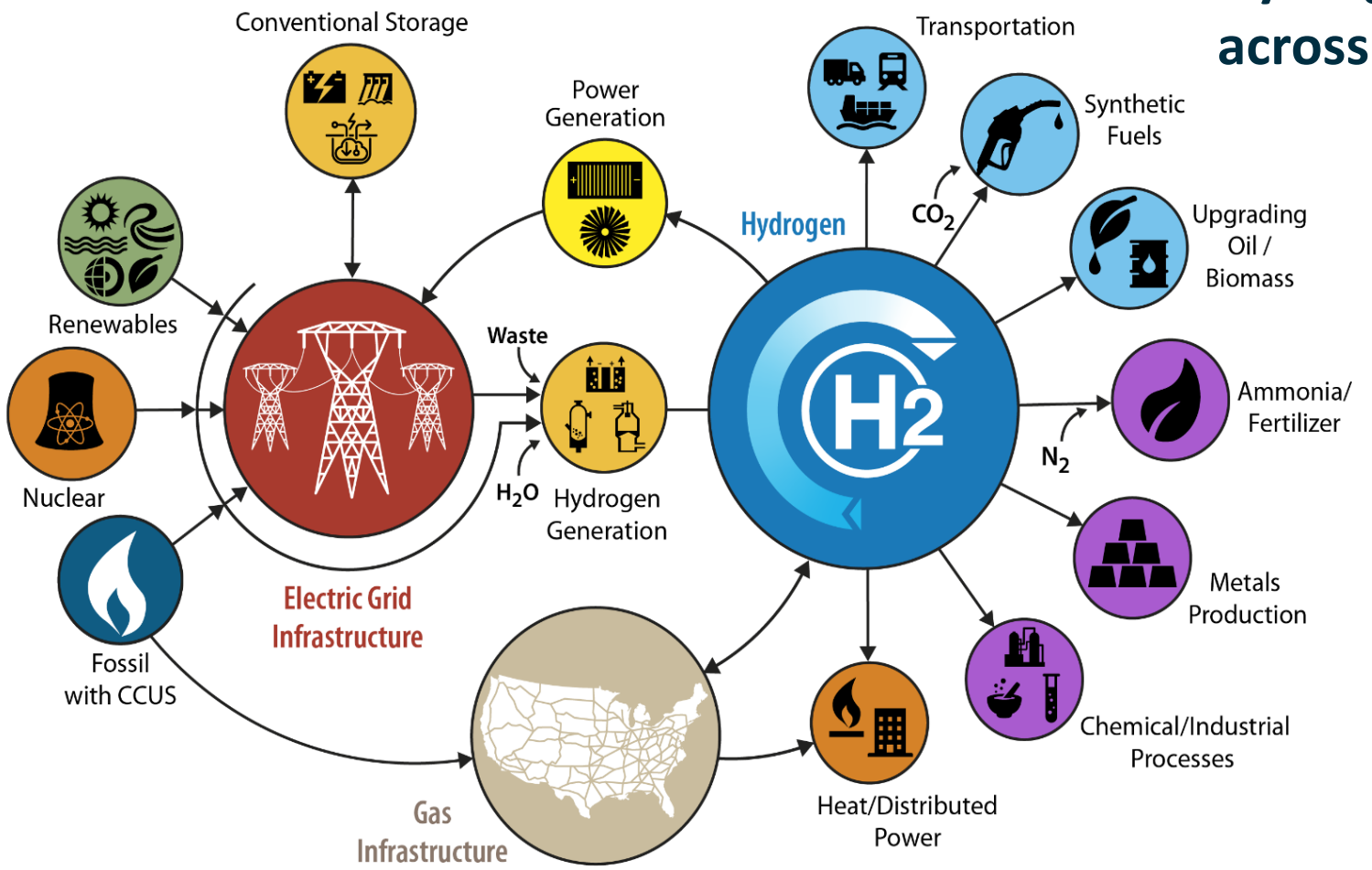
*SMR: Steam Methane Reforming

*ADR: Anaerobic Digester Gas

Key Hydrogen Technology Options



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
- **R&D** to reduce cost, improve performance, reliability $1 to $2/kg H_2
- **Address enablers,** including harmonization of codes, standards, safety, global supply chain, workforce development, sustainable markets

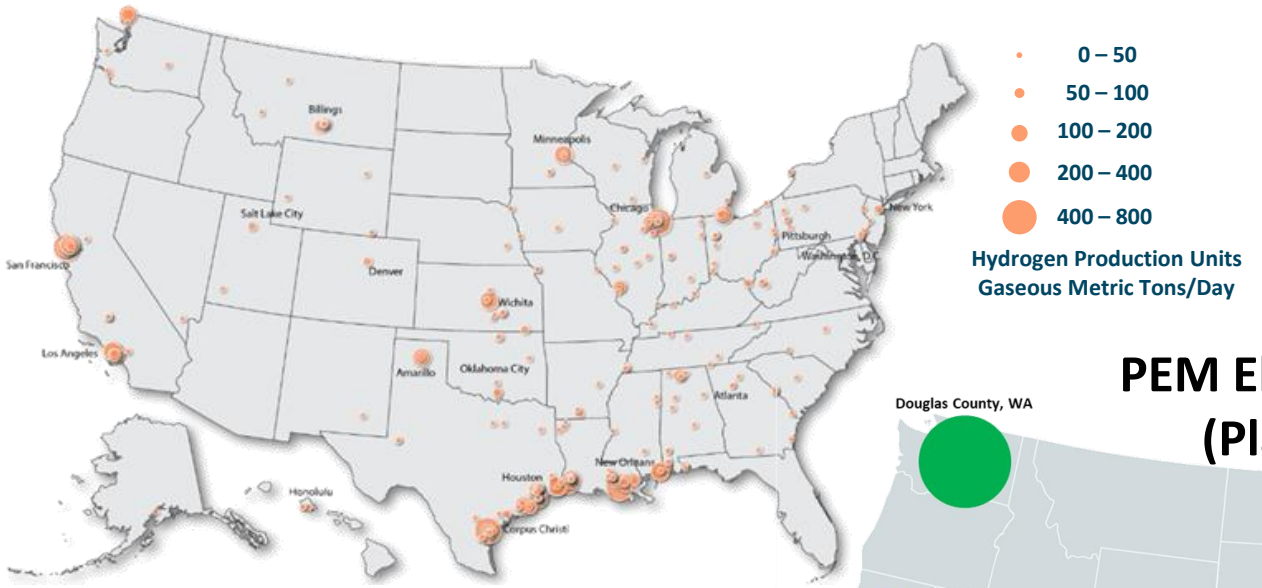
Source: U.S. DOE Hydrogen and Fuel Cell Technologies Office, https://www.energy.gov/eere/fuelcells/h2scale

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

Examples of Applications

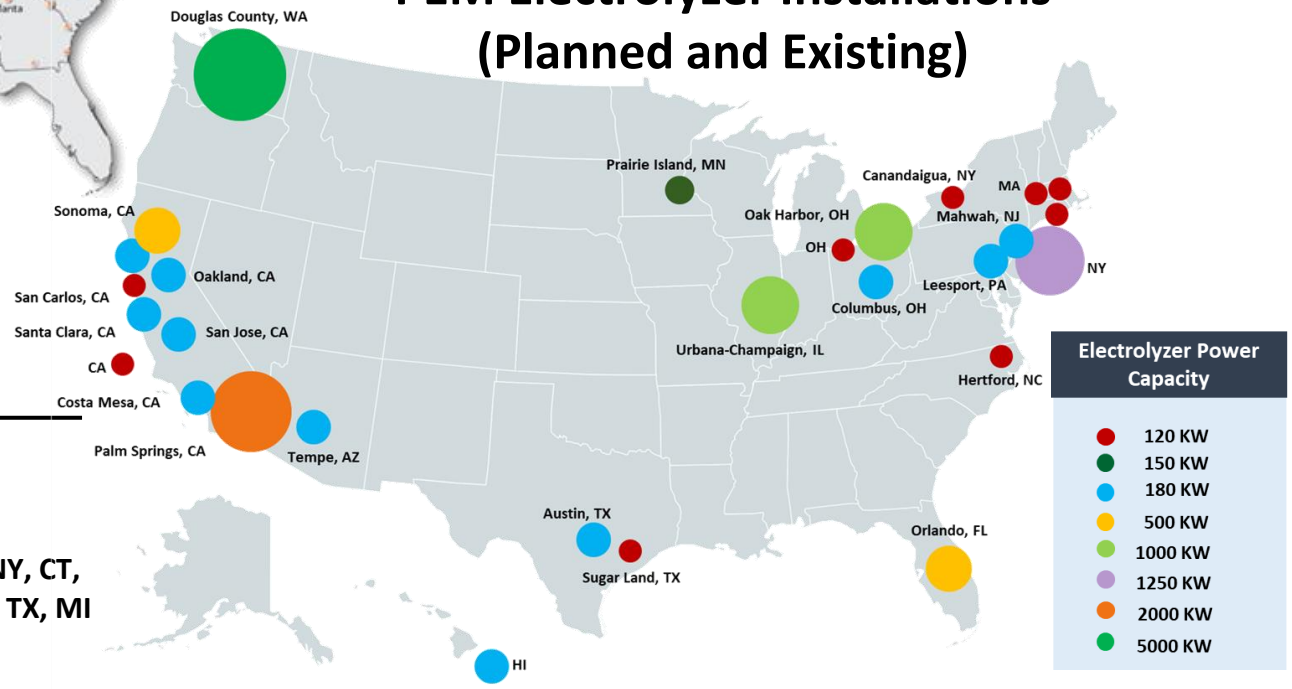
- **>500MW** — Backup Power
- **>35,000** — Forklifts
- **>14 MW** — PEM* Electrolyzers
- **>60** — Fuel Cell Buses
- **>45** — H_2 Retail Stations
- **>9,000** — Fuel Cell Cars

Hydrogen Produced



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

PEM Electrolyzer Installations (Planned and Existing)



* Polymer electrolyte membrane

Hydrogen Stations 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

Fuel Cell Forklifts for Material Handling Applications

More than **35,000 forklifts**

Over **20 million refuelings**

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

Heavy Duty Applications Emerging

Several companies developing long haul Class 8 fuel cell trucks

Fuel cell buses in CA surpass 20M passengers

High-speed fuel cell ferry under development in the US

Fuel cell parcel truck demonstration projects by DOE + industry

Fuel cell delivery truck projects by DOE + industry

Fuel cell commuter rail in Europe, and Asia- first planned in the US

Budget and Focus Areas

Hydrogen and Fuel Cell Technologies Office Funding FY 2021

EERE HFTO Subprograms	FY 2021
Fuel Cell Technologies	$25M
Hydrogen Technologies	$71M
Systems Development & Integration (Tech Acceleration)	$51M
Data, Modeling and Analysis	$3M
Total	$150M

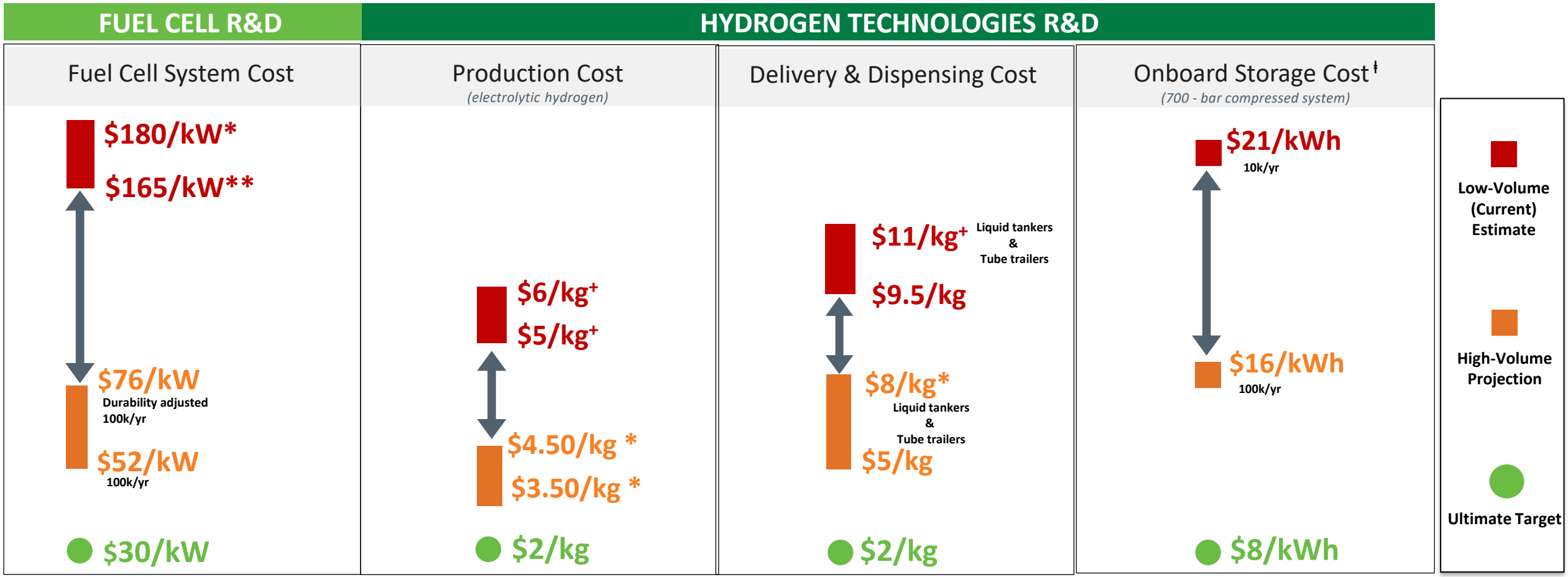
- **Production:** Water splitting – electrolysis (high and low temperature), PhotoElectroChemical (PEC), SolarThermoCHemical (STCH), biomass/biological
- **Infrastructure:** Materials, delivery, components & systems
- **Storage**: materials-based, carriers, tanks, liquid
- **Fuel Cells**: materials, components, systems, reversible FC
- **Systems Development & Integration:** Tech Acceleration includes hybrid/grid integration, new markets, heavy duty, energy storage, manufacturing industrial applications (e.g. steel) safety, codes, standard, workforce development

Coordination with additional funds and activities in DOE Offices of Fossil Energy, Nuclear Energy, ARPA-E, Electricity, and Science

Note: Office of Fossil Energy covers fossil fuels to H_2

Cost reduction required- targets guide R&D activities

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



*Based on state of the art technology

** Based on commercially available fuel cell cars at 3,000 systems/year

‡5 to 7 cents/kWh, 90% capacity factor at $1500/kW
*5 to 7 cents/kWh, 90% capacity factor at $460/kW

†For range: Delivery and dispensing at today's (2020) stations with capacity ~450 kg/day
*For range: Delivery and dispensing at today's (2020) stations with capacity 450-1,000 kg/day at high volume manufacturing

‡Storage costs based on 2019 storage cost record

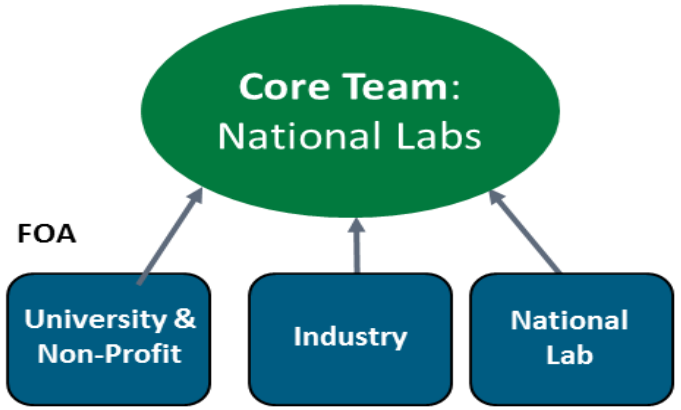
All costs based on $2016

Note: Graph is not at scale. For illustrative purposes only

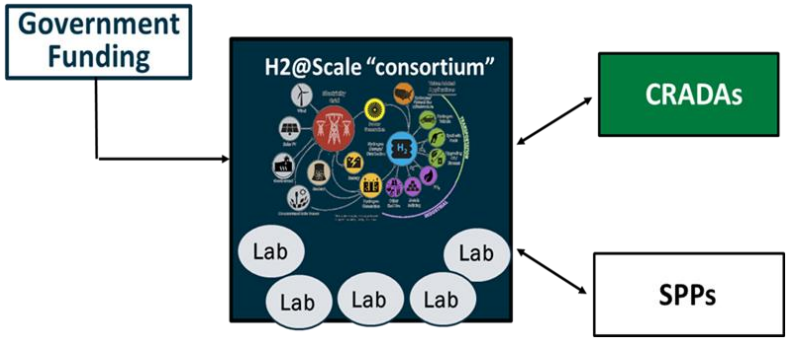
Key Programmatic Areas

<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

Recent round of H2@Scale projects announced (July 2020):
$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

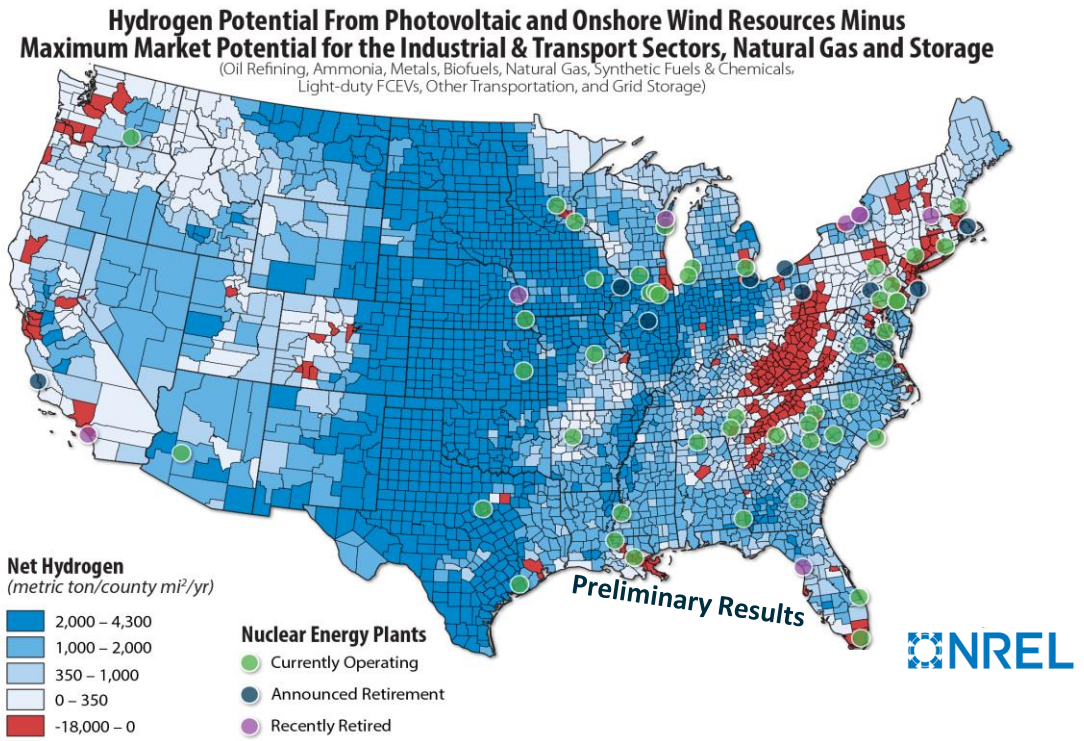
Examples of H2@Scale Analysis and Demonstration Projects

Assessing resource availability.
Most regions have sufficient resources.

New H2@Scale demonstration projects cover range of applications

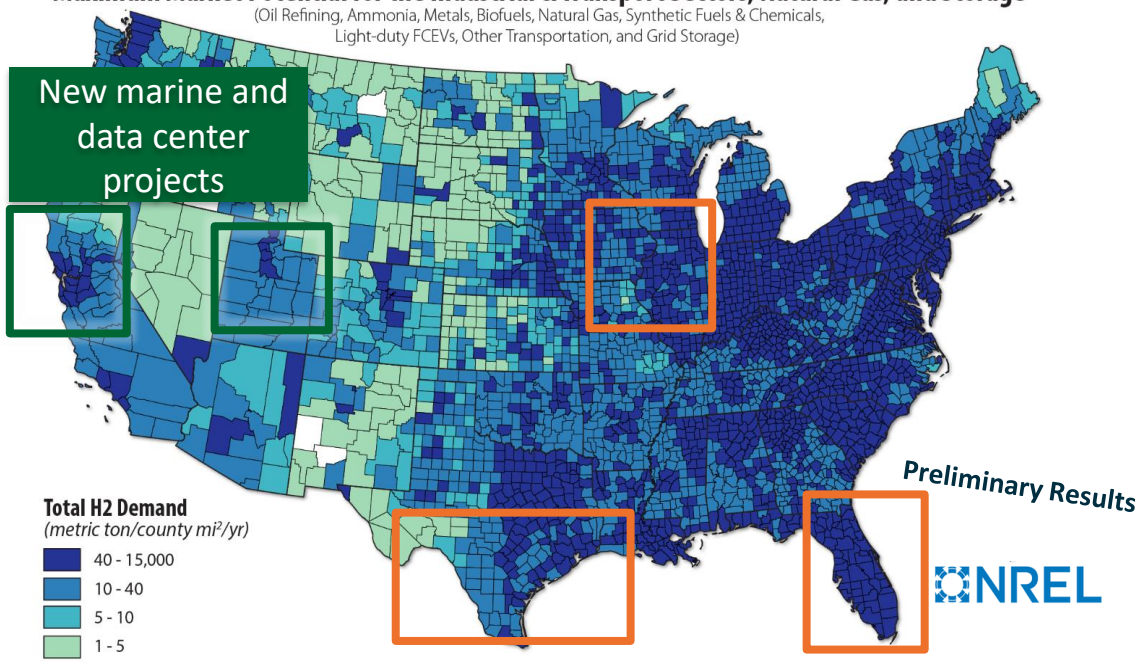
*Includes 1 project by Office of Nuclear Energy

Hydrogen Availability



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

Hydrogen Demand Potential



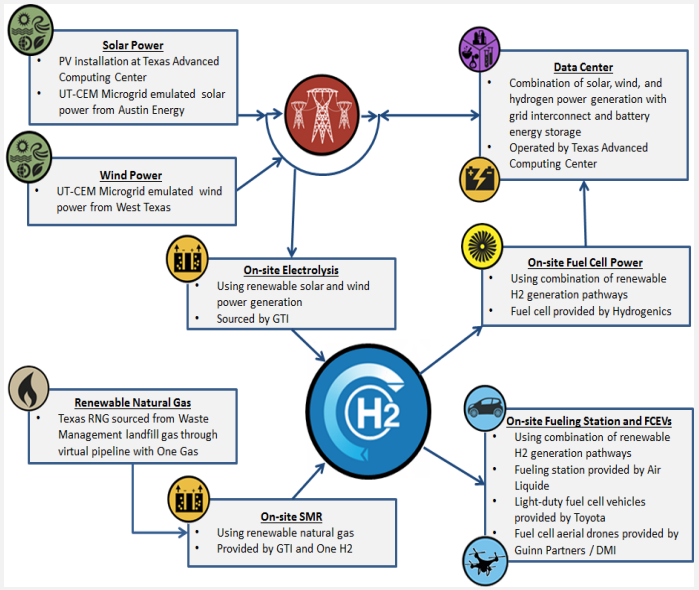
Example of H2@Scale Demonstration Projects

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

Texas

Total Budget
$10.8M

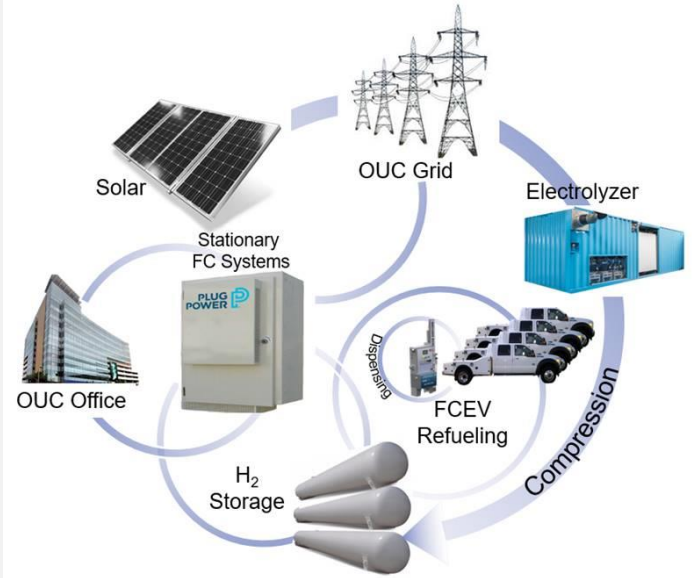
Wind, Solar, RNG/Waste



Florida

Total budget
$9.1M

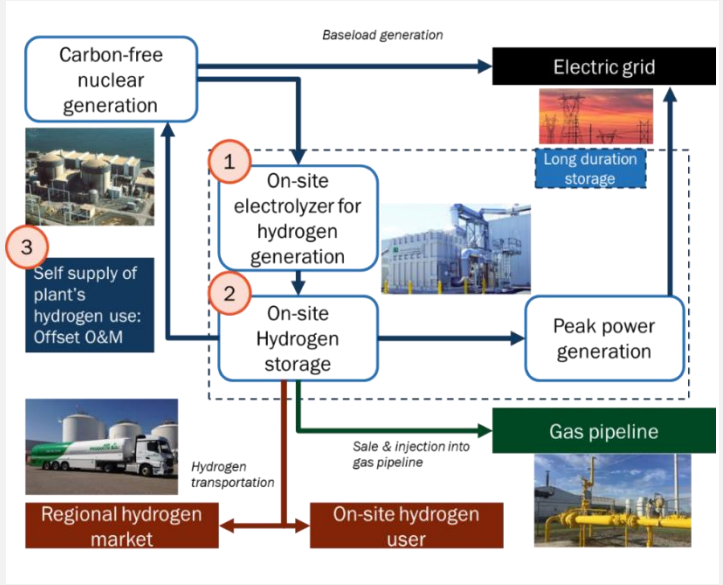
Solar-to-H_2 with End Uses



Site selection in process

Total Budget
$7.2M

Nuclear-to-H_2 for at-Plant Use



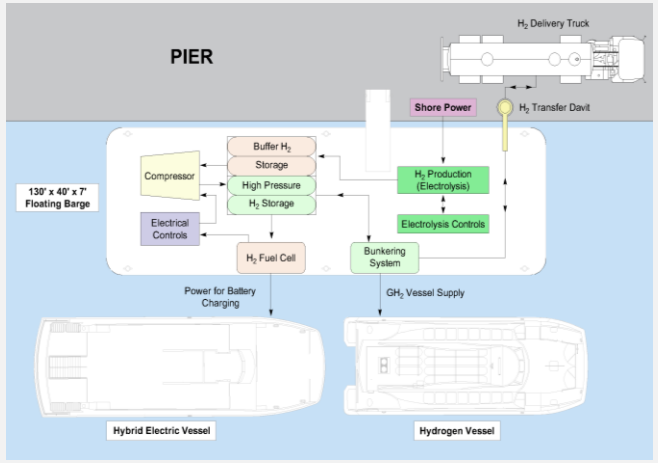
Examples of H2@Scale Demonstration Projects -2020

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

Marine Application

Total Budget $16M

Electrolyzer and fuel cell for marine application

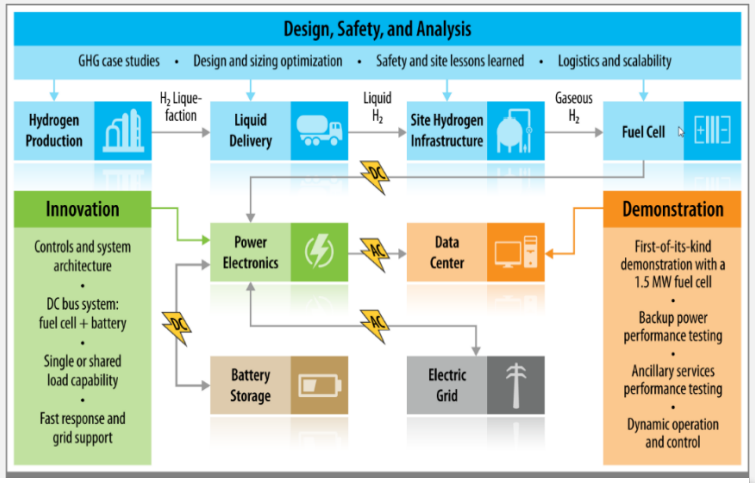


1st-of-its-kind maritime H_2 refueling on floating barge - up to 530 kg H_2 /day

H_2 for Data Center

Total Budget $13.7M

PEM fuel cell for data center power

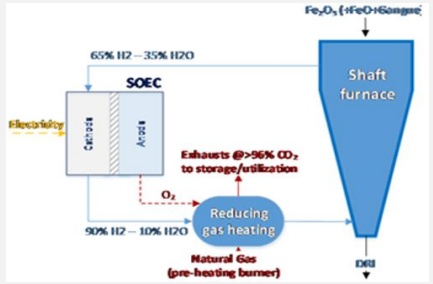


1.5MW fuel cell to meet data center requirements and future scale up

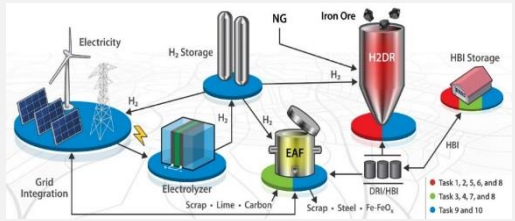
H_2 for Steel Production

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


Collaboration

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

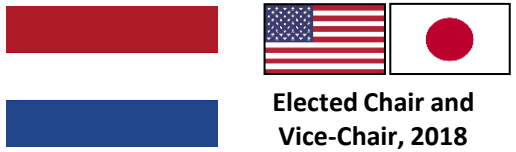
- H. Luccock

Examples of how HFTO engages in international collaboration on hydrogen to enable progress

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

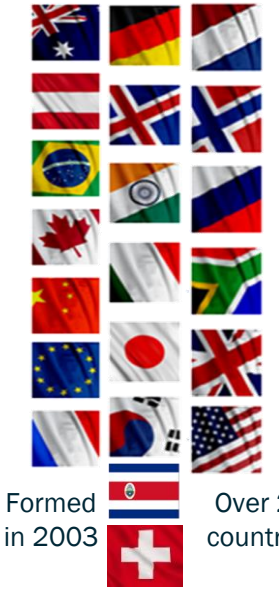
Enabling the global adoption of hydrogen and fuel cells in the economy



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

IPHE E&O Working Group Early Career Network

- **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

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#FuelCellsNow

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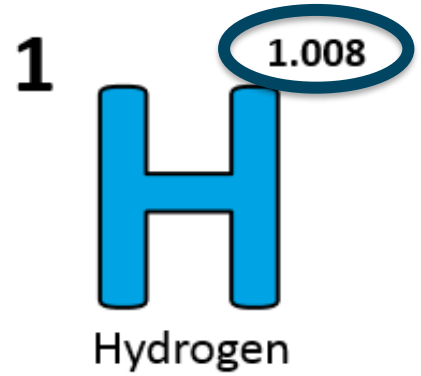
HFTO connects with stakeholders through events, webinars, website resources and communications activities

Save the Date

Week of June 7, 2021 Annual Merit Review and Peer Evaluation Meeting for the Hydrogen and Fuel Cells Program in Arlington, VA

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
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Thank You

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