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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Resources for the Future (RFF) - Hydrogen Conference

March 9, 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

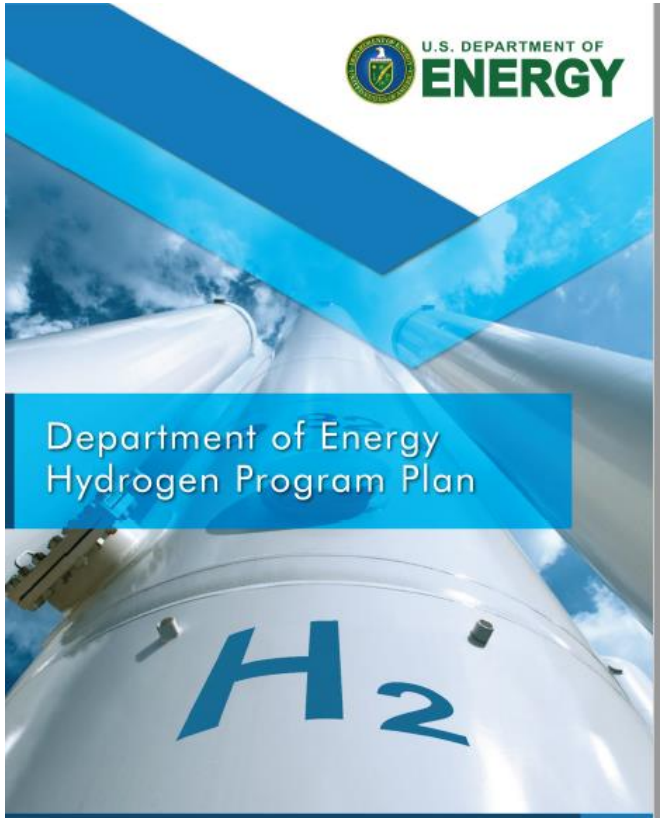
100% carbon-pollution-free electric sector by 2035

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



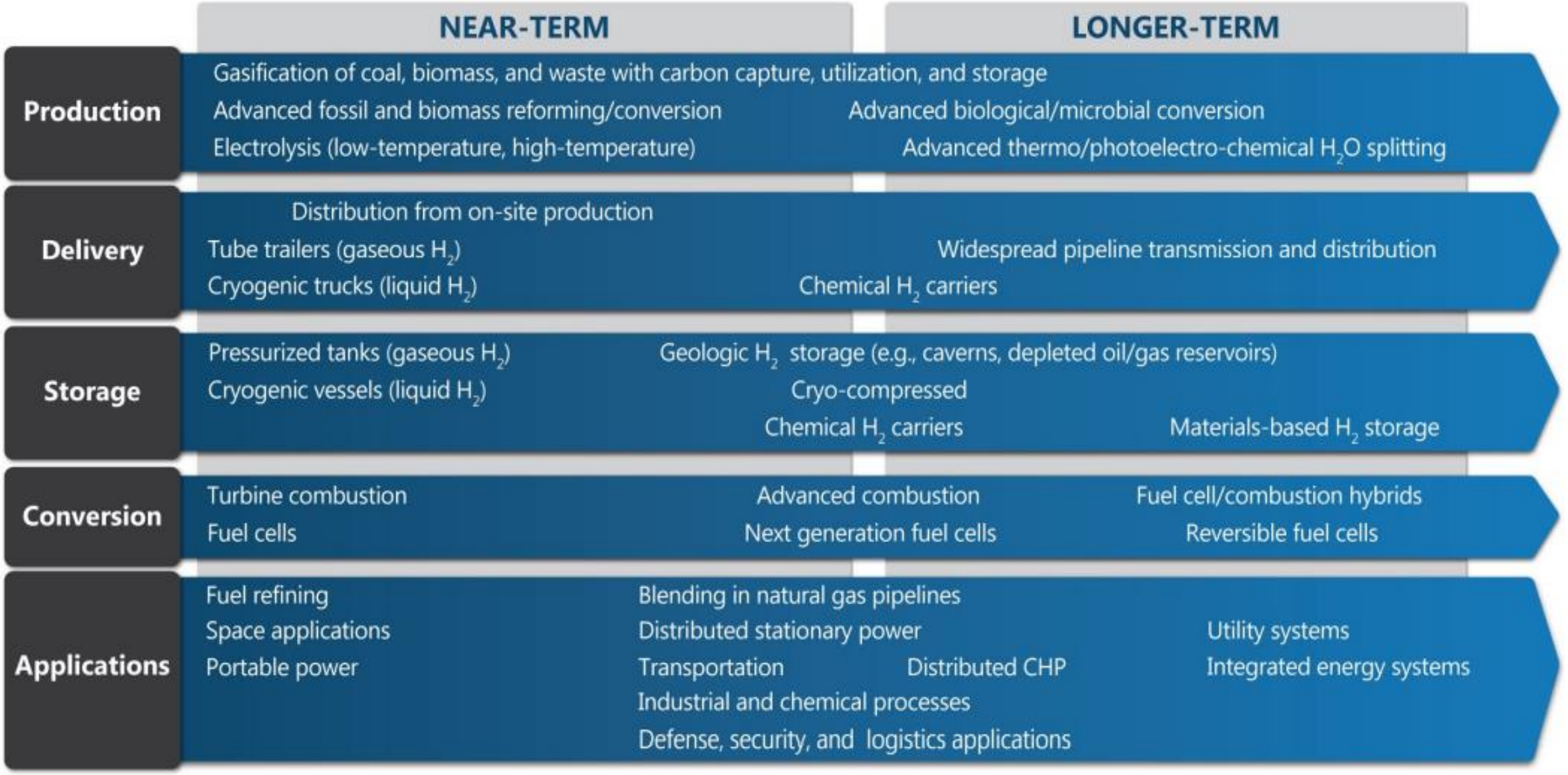
www.hydrogen.energy.gov

Examples of Key DOE Hydrogen Program Targets

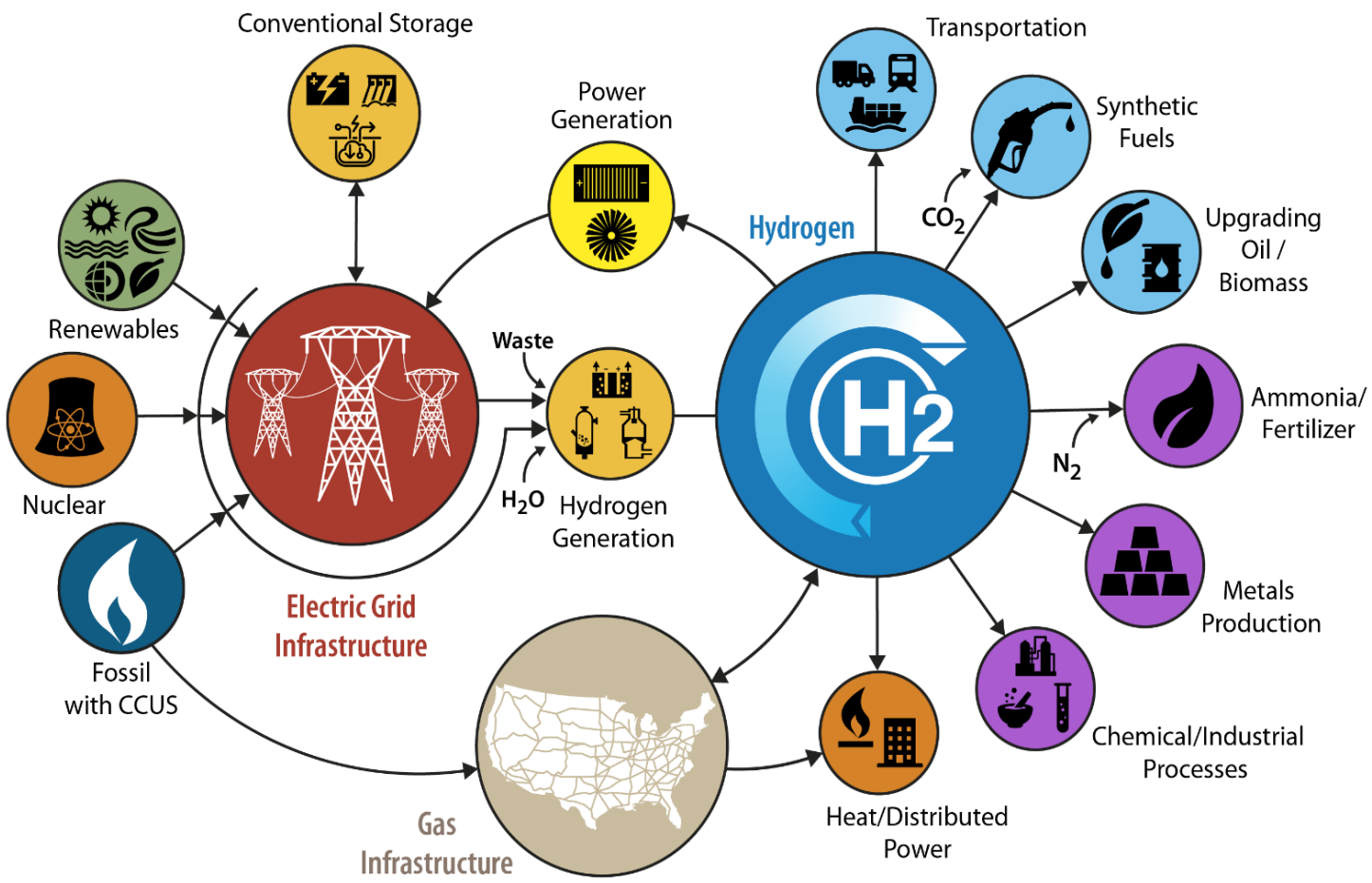
DOE targets are application-specific and developed with stakeholder input to enable competitiveness with incumbent and emerging technologies. These targets guide the R&D community and inform the Program's portfolio of activities. Examples include:

- $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

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
- Continue R&D to reduce cost and improve performance, reliability $1 to $2/kg H_2
- 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

Examples of DOE-Funded Innovation and Impact

Impact due to HFTO Funding

Innovation

1,110 patents
H_2 and fuel cell
enabled by HFTO funds

Approx. 35% of H_2 and fuel cell patents
come from National Labs

Market Impact

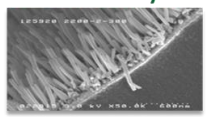
More Than 30 Technologies
Commercialized
by private industry

And Over 65 with potential
to be commercial in
the next 3 – 5 years

Can be traced back to HFTO R&D

Examples of Technologies Enabled

Fuel Cell Catalysts



Catalyst and Supports for PEM Fuel Cells
3M

Hydrogen Tube Trailers

Hydrogen Tube Trailers
Hexagon Lincoln

Forklifts

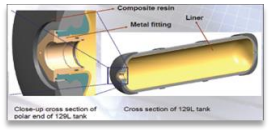
Class-1, -2, and -3 Forklifts
Plug Power (GenDrive FCs)

Electrolyzers

Electrolyzer System
Proton Series

PEM Electrolyzer System
Giner

Hydrogen Tanks



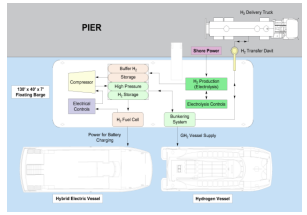
Optimized 129L Tank
Quantum Technologies

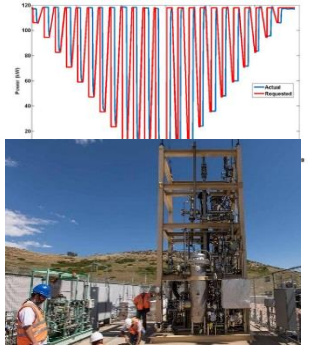
- Small scale H_2 fueler now available
- 5 to 20 kg unit, 700 bar fueling

$1M H-Prize H2Refuel Winner: SimpleFuel

First-of-a-Kind Demonstrations

- Marine application- ½ ton H_2 fueling for vessel
- Data center- 1.5 MW
- First ground support equipment
- Parcel delivery vans (2x range vs BEVs)
- Mobile H_2 fueler
- First nuclear to H_2 demos
- First tri-gen system
- Dynamic response of electrolyzers and systems integration
- First H_2+CO_2 to renewable methane demo
- H_2/NG blending





Example: American Recovery Act co-funded few hundred fuel cell forklifts and backup power units for cell phone towers

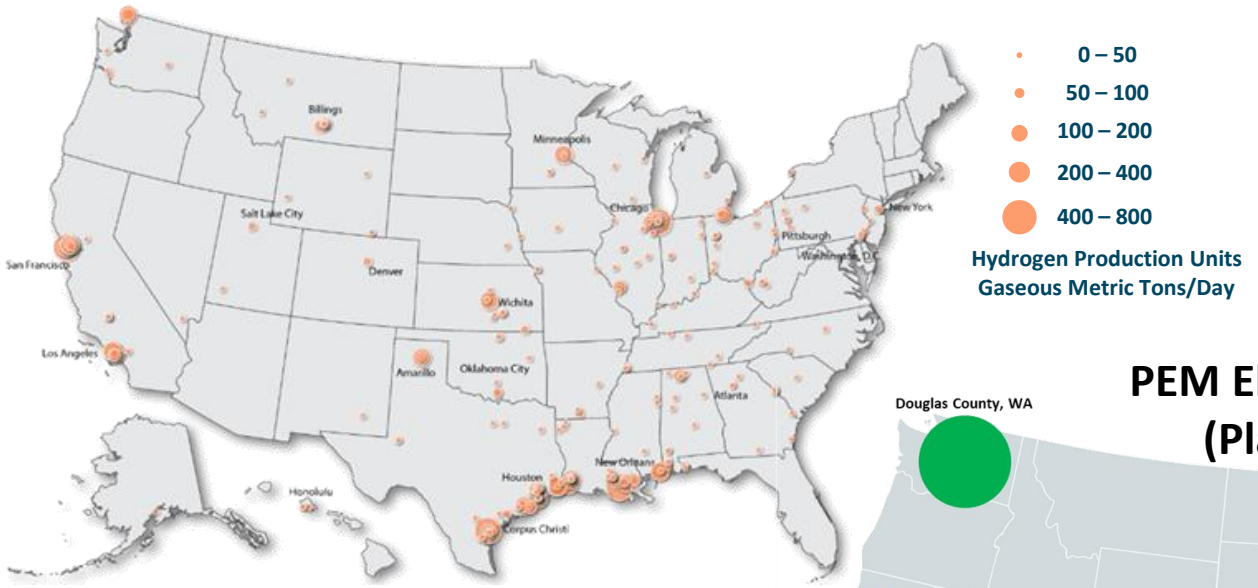
Today ~ 40,000 systems commercially deployed at major companies, millions of H_2 fuelings to date

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

Examples of Applications

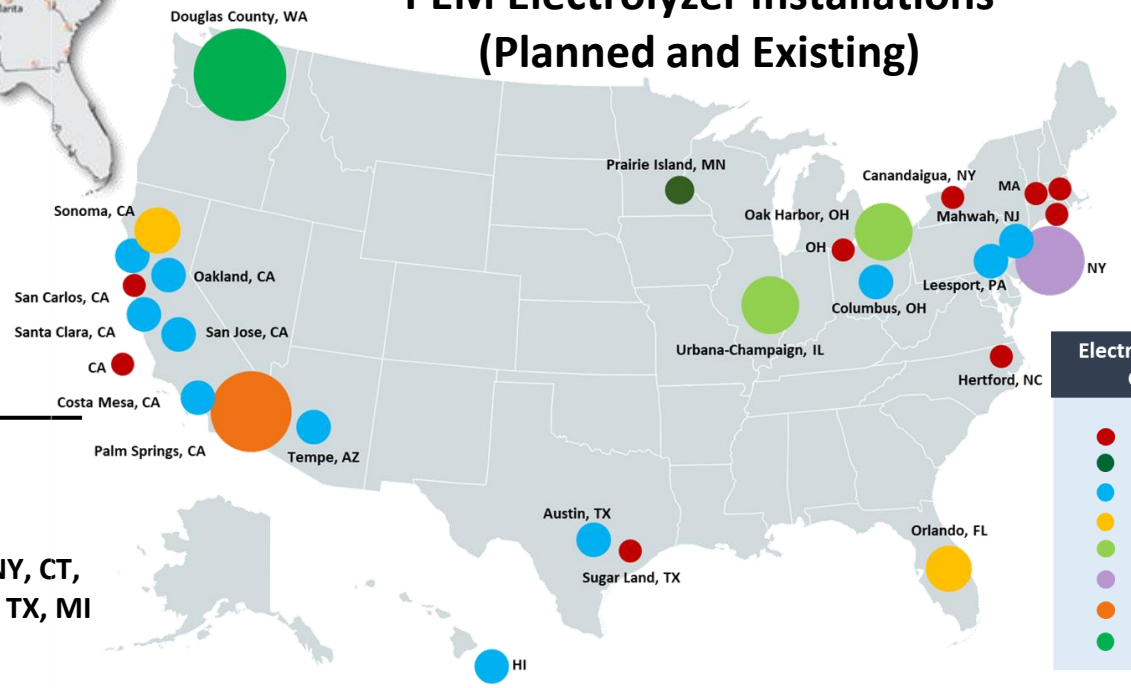
- **>500MW** — Backup Power
- **>35,000** — Forklifts
- **>14 MW** — PEM* Electrolyzers
- **>60** — Fuel Cell Buses
- **>45** — H_2 Retail Stations
- **>9,000** — Fuel Cell Cars

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

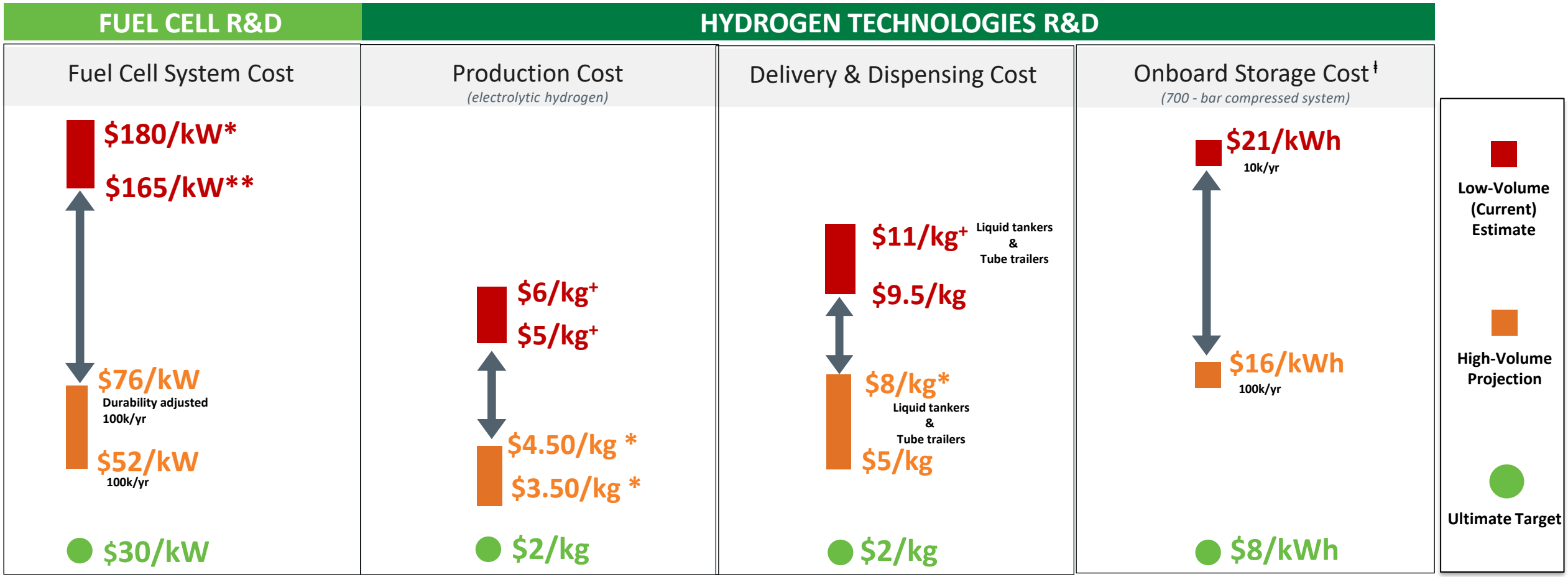
HI, OH, SC, NY, CT, MA, CO, UT, TX, MI

And Others

Cost Reduction Efforts Underway

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



*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

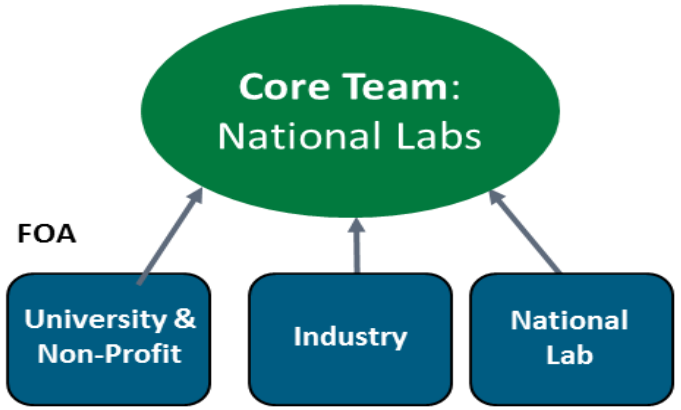
All costs based on $2016

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

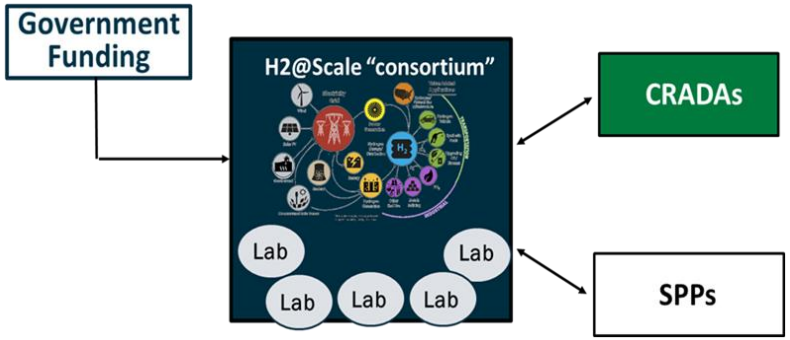
Key Programmatic Areas

<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

Announced FY20: $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

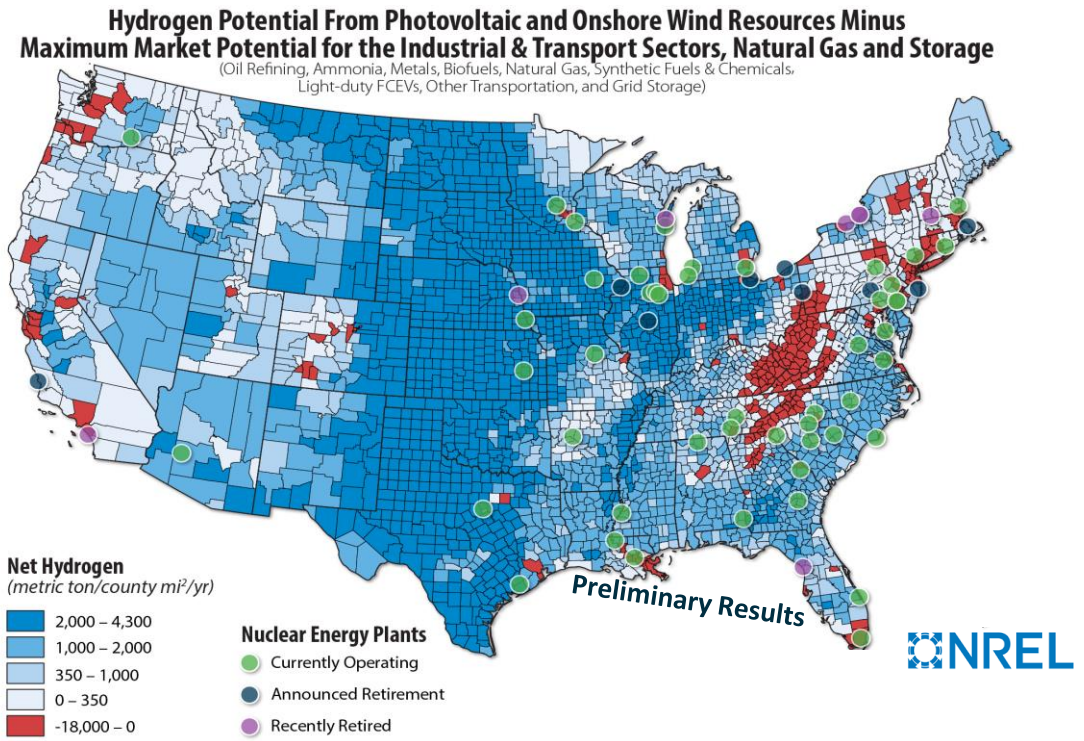
Examples of H2@Scale Analysis and Demonstration Projects

Assessing resource availability.
Most regions have sufficient resources.

New H2@Scale demonstration projects cover range of applications

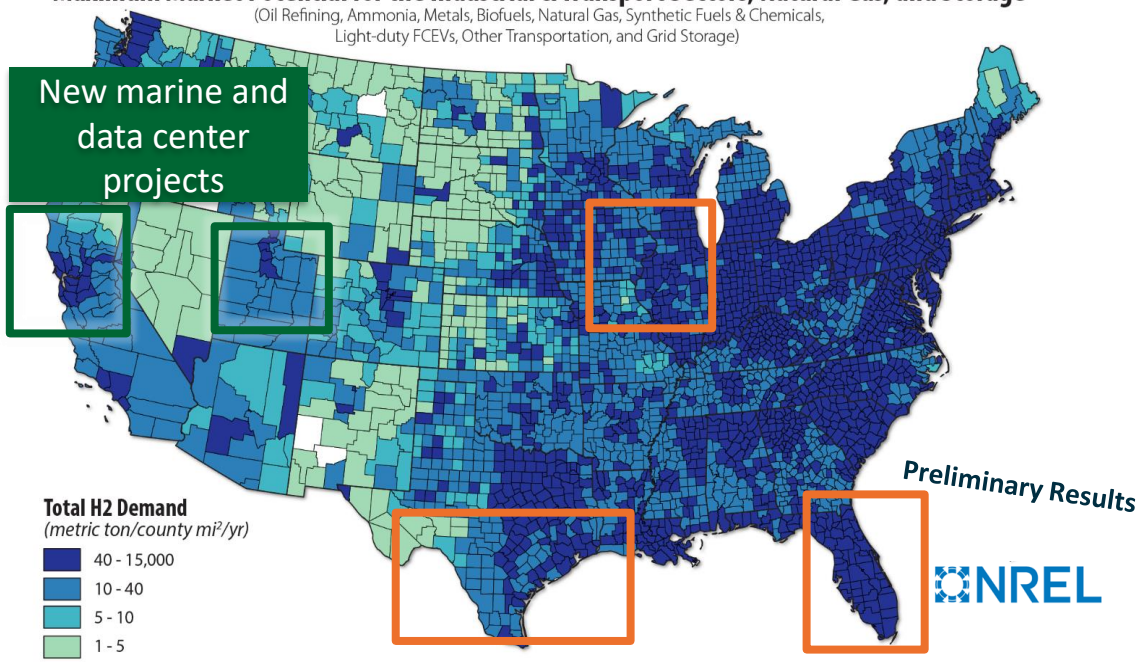
*Includes 1 project by Office of Nuclear Energy

Hydrogen Availability



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

Hydrogen Demand Potential



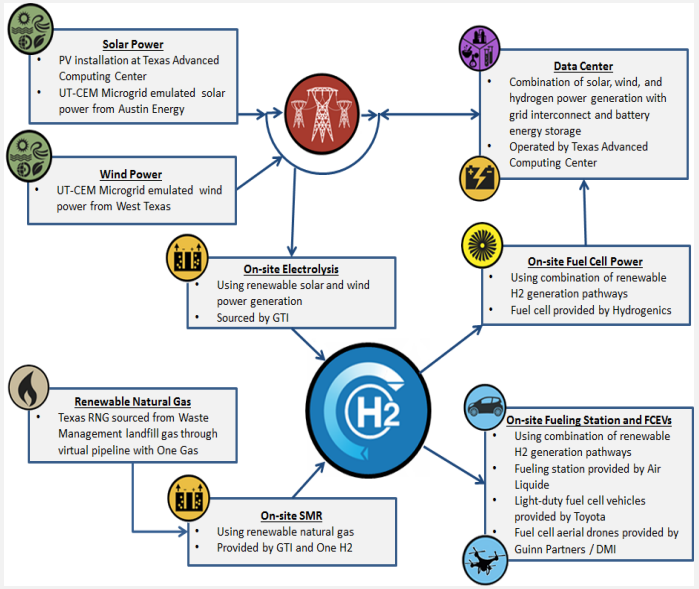
Example of H2@Scale Demonstration Projects

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

Texas

Total Budget
$10.8M

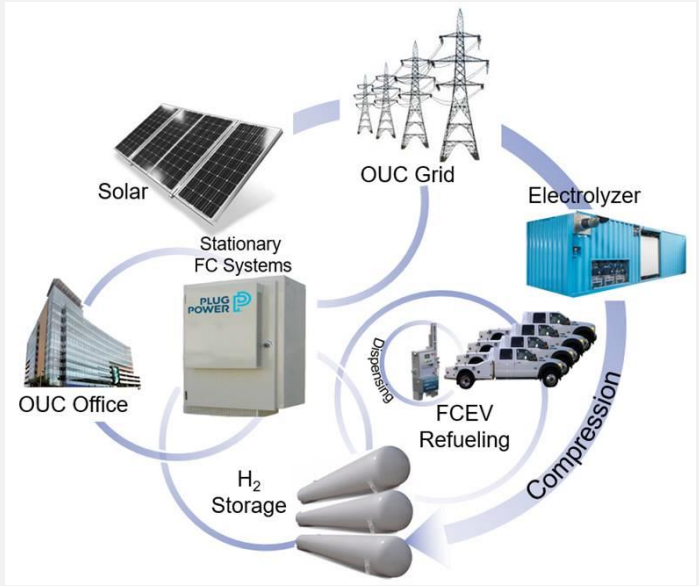
Wind, Solar, RNG/Waste



Florida

Total budget
$9.1M

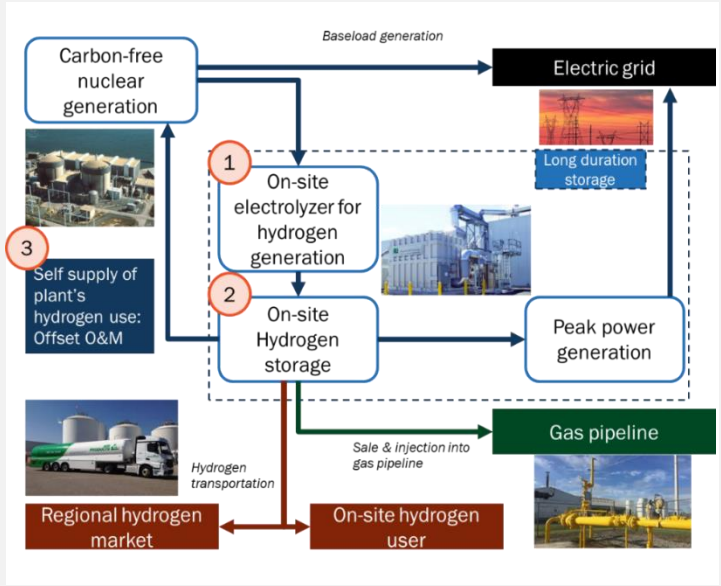
Solar-to-H_2 with End Uses



Site selection in process

Total Budget
$7.2M

Nuclear-to-H_2 for at-Plant Use



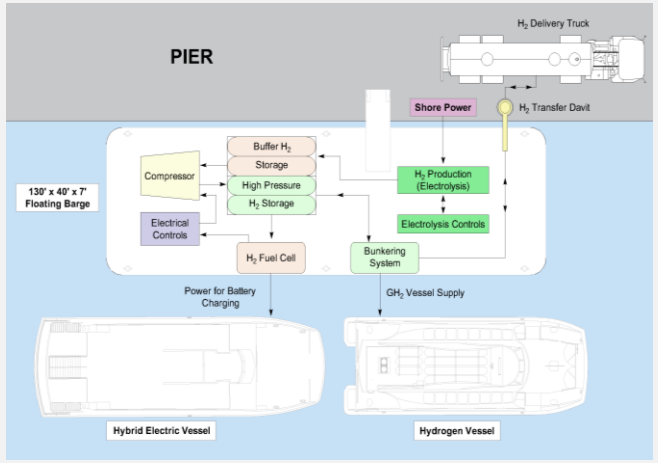
Examples of H2@Scale Demonstration Projects -2020

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

Marine Application

Total Budget $16M

Electrolyzer and fuel cell for marine application

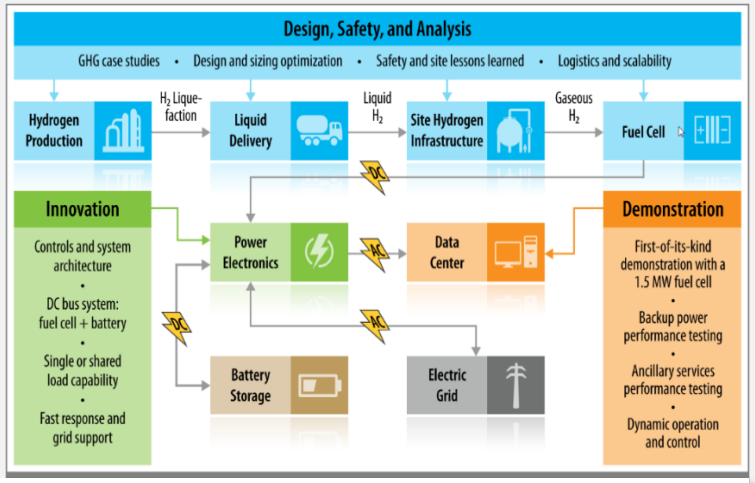


1st-of-its-kind maritime H_2 refueling on floating barge - up to 530 kg H_2 /day

H_2 for Data Center

Total Budget $13.7M

PEM fuel cell for data center power

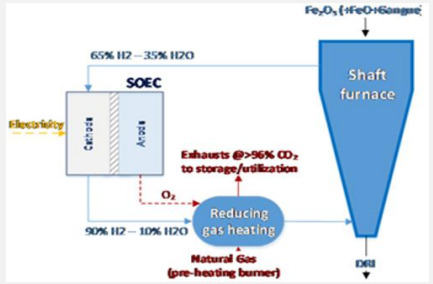


1.5MW fuel cell to meet data center requirements and future scale up

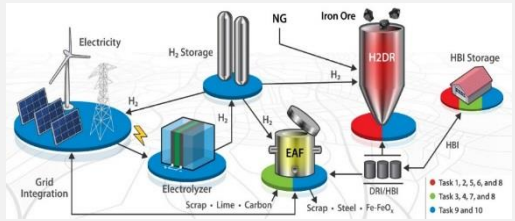
H_2 for Steel Production

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 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

Workforce Development, Training and STEM

Hydrogen Education for a Decarbonized Global Economy (H2EDGE)

Objectives:

- Enhance workforce readiness through training and education (T&E)
- Develop T&E materials and deliver professional training courses and university curriculum content
- Collaborate with industry and university partners to develop certifications, credentials, qualifications, and standards for training and education needs

Recipient: EPRI

Partners include: GTI, OSU, Purdue, UD, EA

June 2020: DOE EERE announces $20M investment at U of TN to advance workforce development in emerging energy fields, partnering with ORNL and Oak Ridge Institute (ORI)

- ORI will develop model workforce development program and partnerships with universities, agencies, and national labs
- Focuses on EERE related technologies including hydrogen and fuel cells

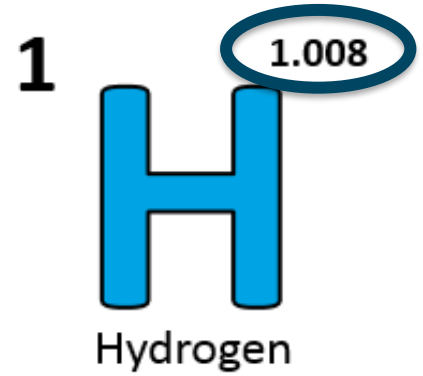
Resources and Events

Save the Date

Week of June 7, 2021
Annual Merit Review and Peer Evaluation Meeting (AMR) 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
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Thank You

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