U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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

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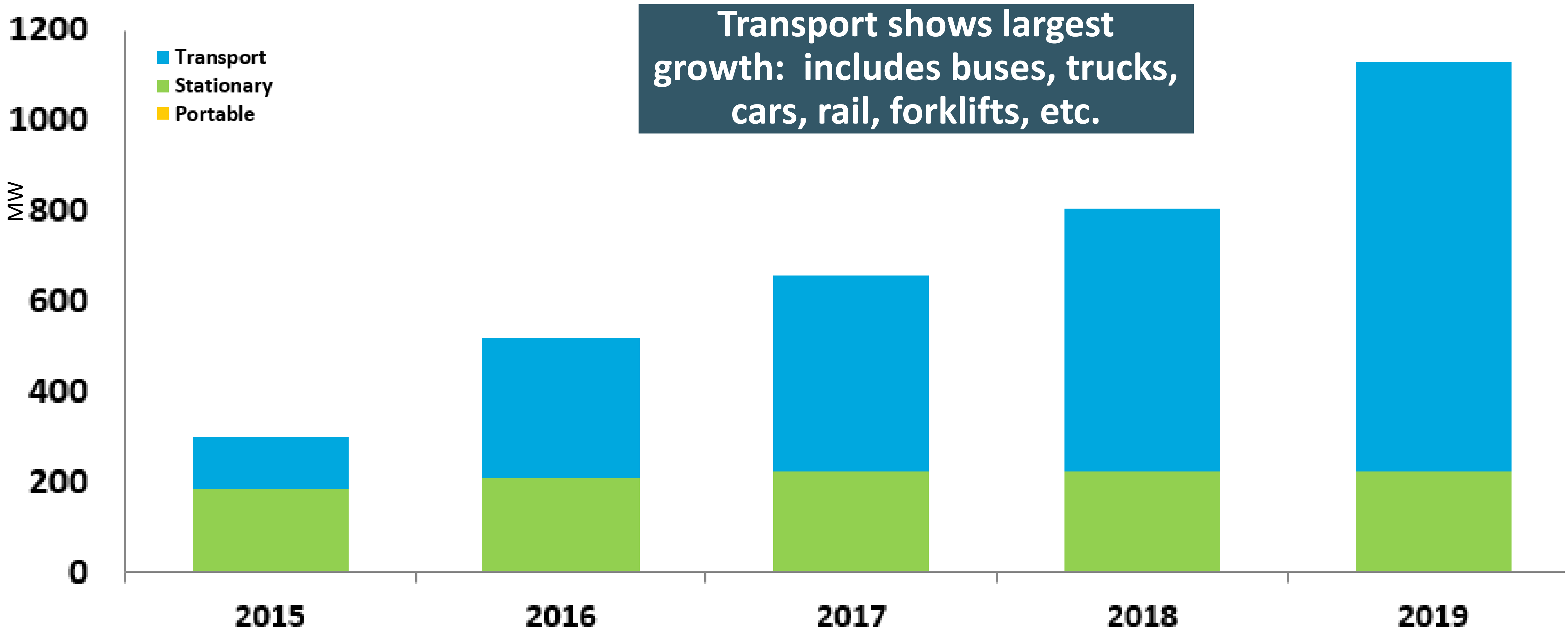
Director, Hydrogen and Fuel Cell Technologies Office

ICEPAG Colloquium on Hydrogen - September 14, 2020

Global Perspectives

Global Fuel Cell Power Shipments Surpass 1 GW



Source: E4tech for DOE analysis project

Examples of Electrolyzer Deployments and Plans… by 2025

Increasing number of regions worldwide

Increasing in size

10 MW India (NEL, Reliance Industries)

11 MW China (Hebei, McPhy, Encon)

20 MW Canada (Air Liquide)

30 MW Port Lincoln, Australia (H2U, Baker Hughes, Thyssenkrupp)

50 MW S. Australia (Neoen and Megawatt Capital, Siemens, Hyundai)

55 MW Pilbara, Western Australia (Yara, Engle)

80 MW Germany (Evonik, Siemens)

100 MW Amsterdam (Tata Steel, Nouryon)

100 MW Germany (Amprion, OGE)

100 MW Germany (Thyssengas, TenneT, Gasunie Deutschland)

200 MW IAE (Dubai Electricity and Water Authority)

4 GW Announced July 2020

Saudi Arabia (Air Products, ACWA Power, Neom)

To be operational by 2025

Will use solar and wind

Largest green H_2 plant in the world

Adapted from various sources, including US Hydrogen Industry Roadmap

Recent Global Stats and Announcements - Examples

25-fold increase in electrolyzers deployed in the last decade

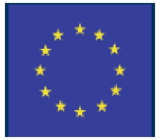
<1MW in 2010 to >25 MW by end of 2019

Global FCEV stock doubled to >25.2K units
>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

European Commission

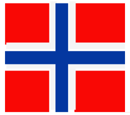


€750B economic recovery package, Green Deal; stimulus includes H_2 technologies

Germany

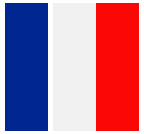
€9B for H_2, with €2B for international partnerships

Norway



€3.6B recovery package includes offshore wind to H_2, focus on maritime sector

France



€7.2B for H_2 and plans for 6.5 GW green H_2 by 2030

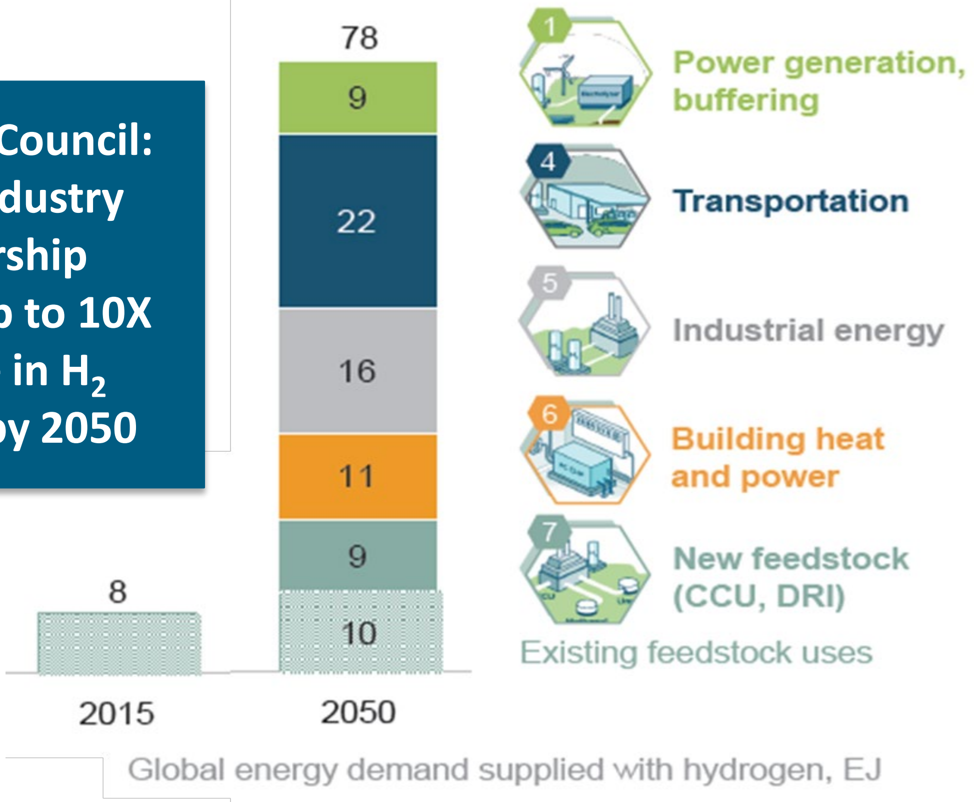
Others include The Netherlands, Japan, ROK, Australia, and more

Roadmaps and Plans Developing Worldwide

Drivers include: Energy security, energy efficiency & resiliency, economic growth, innovation & technology leadership, and environmental benefits

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

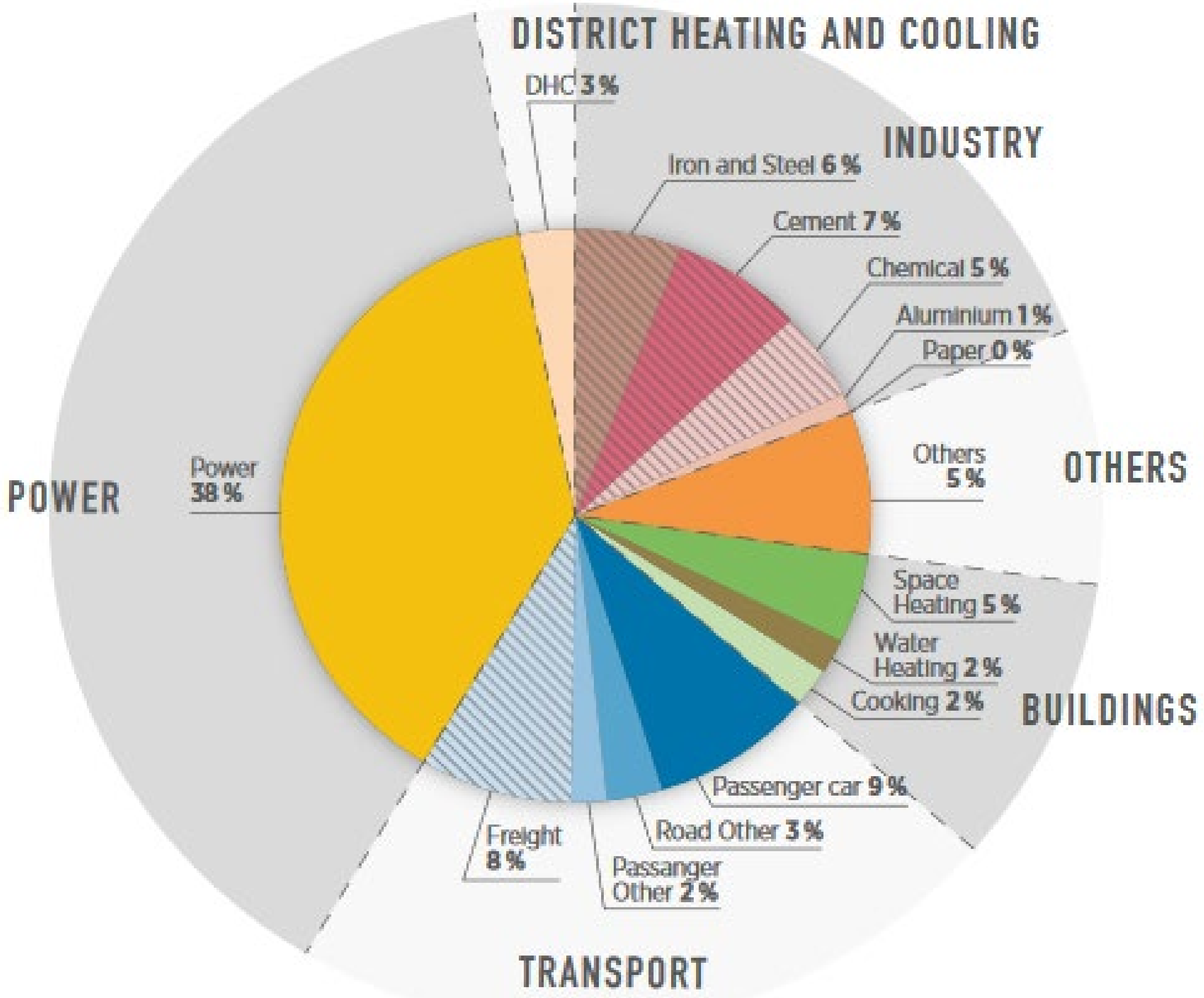
Hydrogen Council: Global industry partnership projects up to 10X increase in H_2 demand by 2050

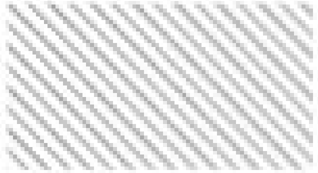


18%	6 Gt	\$2.5 tr	30 m
of final energy demand	annual CO_2 abatement	annual sales (hydrogen and equipment)	jobs created

H2 Council Global Impact Potential by 2050

Global Energy Related Carbon Emissions by Sector



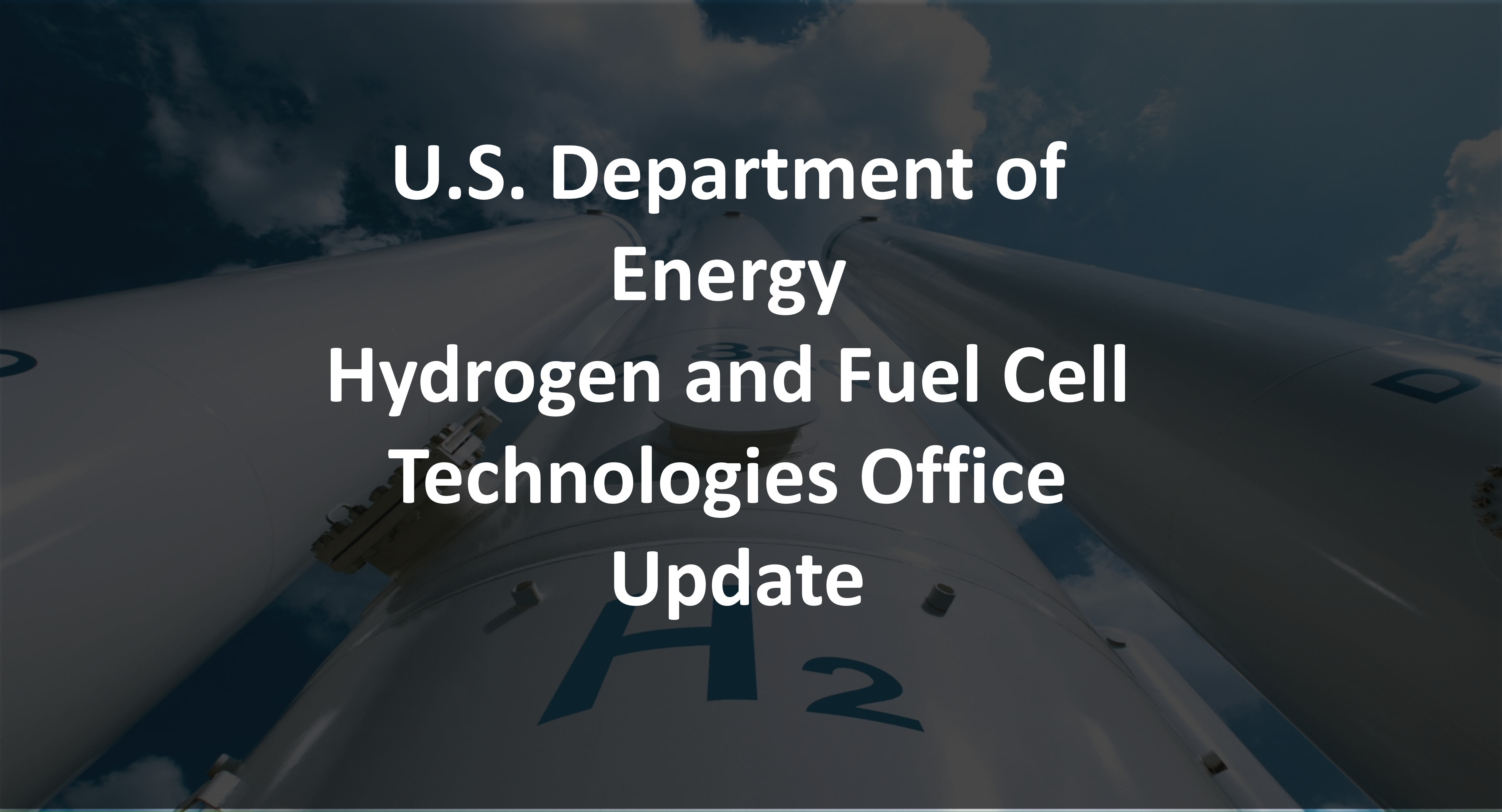


Sectors today with no economically scalable option for deep emission reductions

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

U.S. Emissions by Sector

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



Guiding Legislation and Budget – Hydrogen and Fuel Cells Program

History: DOE efforts in fuel cells began in the mid-1970s, ramped up 1990s, and 2003-2009

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

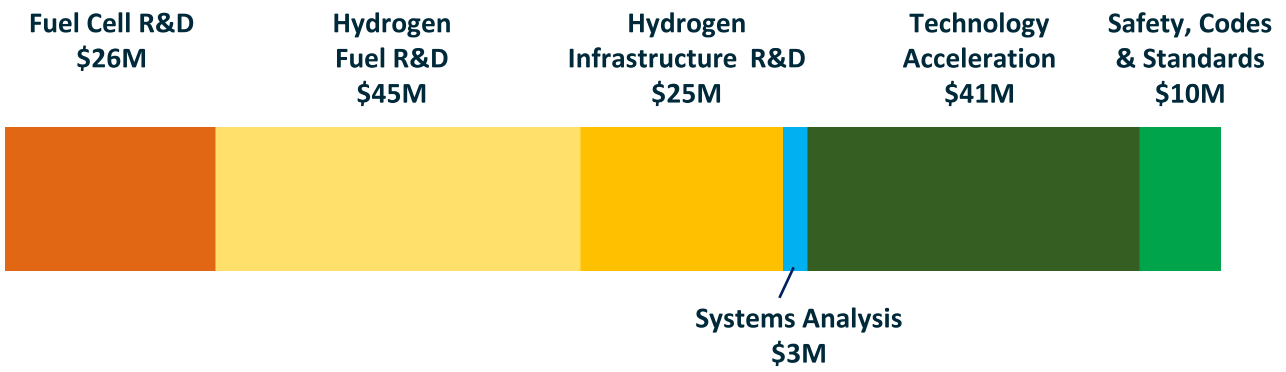
- **>100 organizations & extensive collaborations including national lab-industry-university consortia, led by DOE Hydrogen and Fuel Cell Technologies Office**
- **Includes H_2 production, delivery & infrastructure, storage, fuel cells and cross cutting activities (e.g. safety, codes, standards, technology acceleration, systems integration)**
- **HFTO coordinates with Offices of Fossil, Nuclear, Science, Electricity, and ARPA-E**

Impact: Reduced fuel cell cost 60%, quadrupled durability, reduced electrolyzer cost 80% and other advances, and *enabled over 1,100 patents and* commercial H_2 and fuel cell systems across applications

Budget and Focus Areas in EERE H_2 and Fuel Cell Technologies Office

EERE HFTO Activities	FY 2020 ($K)
Fuel Cell R&D	**26,000**
Hydrogen Fuel R&D	**45,000**
Hydrogen Infrastructure R&D (included in Hydrogen Fuel in FY21)	25,000
Systems Development & Integration (Technology Acceleration)	**41,000**
Safety, Codes, and Standards (included in Systems Development & Integration in FY21)	10,000
Data, Modeling and Analysis	**3,000**
Total	**$150,000**

Hydrogen and Fuel Cells Breakdown FY 2020



- **Production:** Water splitting – electrolysis (high and low temperature), PEC, STCH, biomass/biological
- **Infrastructure:** Materials, delivery, components & systems
- **Storage**: materials-based, carriers, tanks, liquid
- **Fuel cells**: materials, components, systems, reversible FCs
- **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

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

Note: Office of Fossil Energy covers fossil fuels to H_2

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

>8,700
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

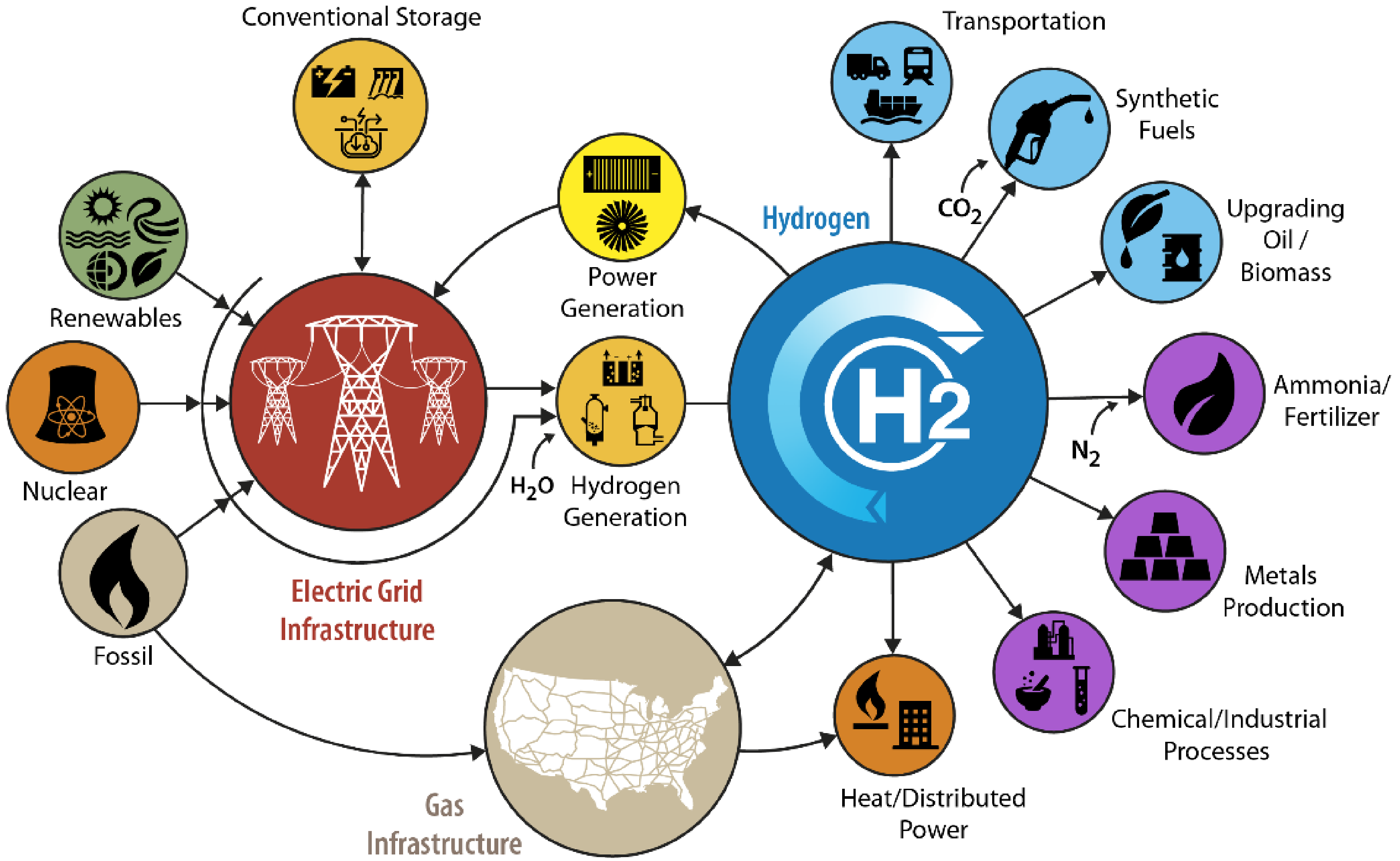
California
200 Stations Planned
CAFCP Goal

Northeast
12 – 20
Stations Planned

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

Key Programmatic Area: H2@Scale

Enabling affordable, reliable, clean, and secure energy across sectors



Today: 10MMT H_2
Economic Potential:
2 to 4x more

Hydrogen Production Pathways: An all-of-the-above portfolio

FOSSIL RESOURCES

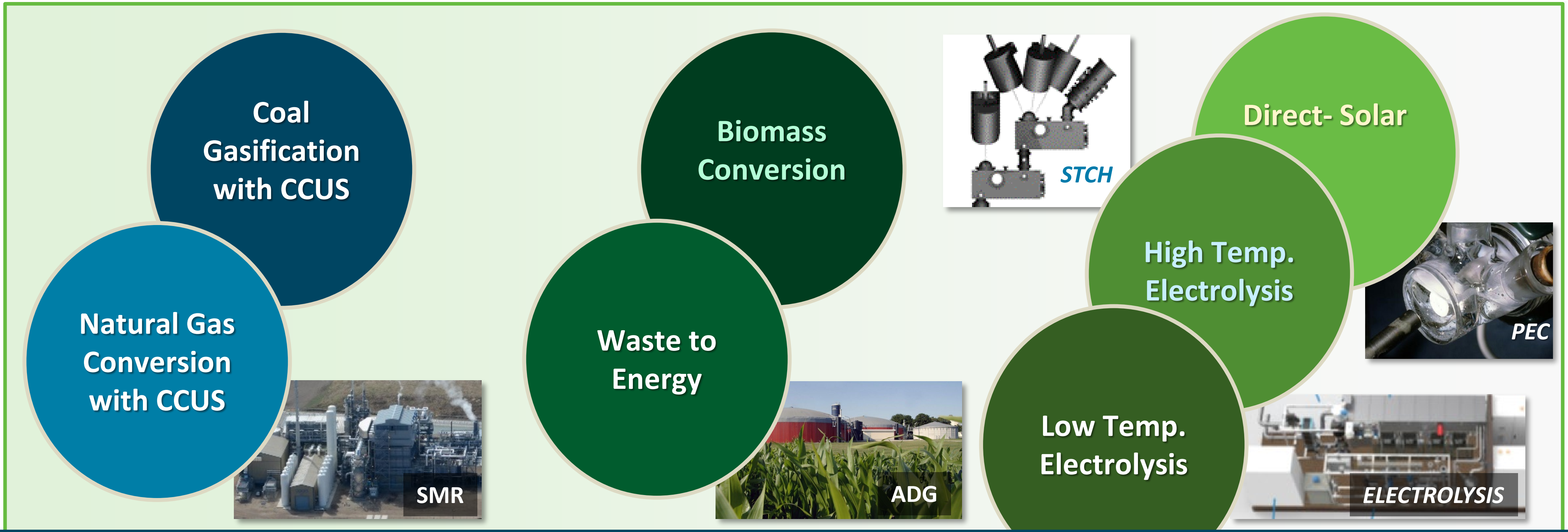
- Low-cost, large-scale hydrogen production with CCUS
- New options include byproduct production, such as solid carbon

BIOMASS/WASTE

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

WATER SPLITTING

- Electrolyzers can be grid tied, or directly-coupled with renewables
- New direct water-splitting options offer long-term sustainable hydrogen

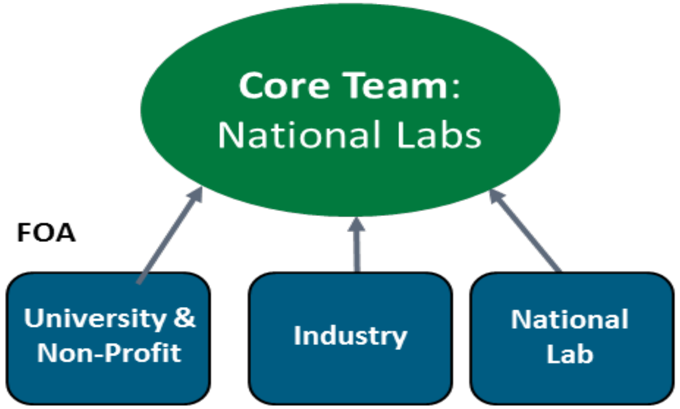


Low-cost hydrogen production from diverse domestic feedstocks & energy resources—enhancing long-term resiliency & opening regional market opportunities

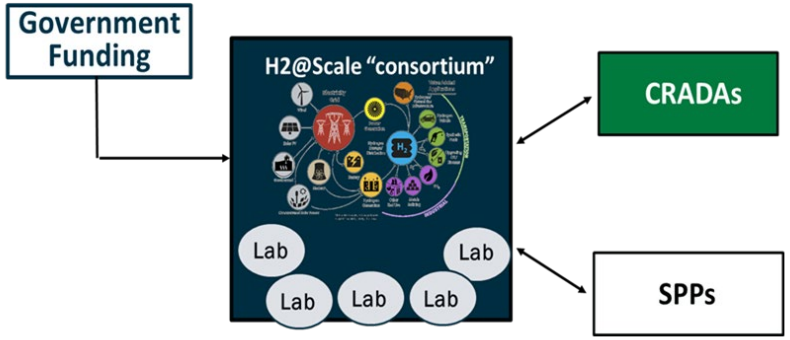
Key Programmatic Areas

<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



HydroGEN Advanced Water Splitting Materials

ElectroCat Electrocatalysis Consortium

HyMARC Hydrogen Materials Advanced Research Consortium

H-Mat™ Hydrogen Materials Compatibility Consortium

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

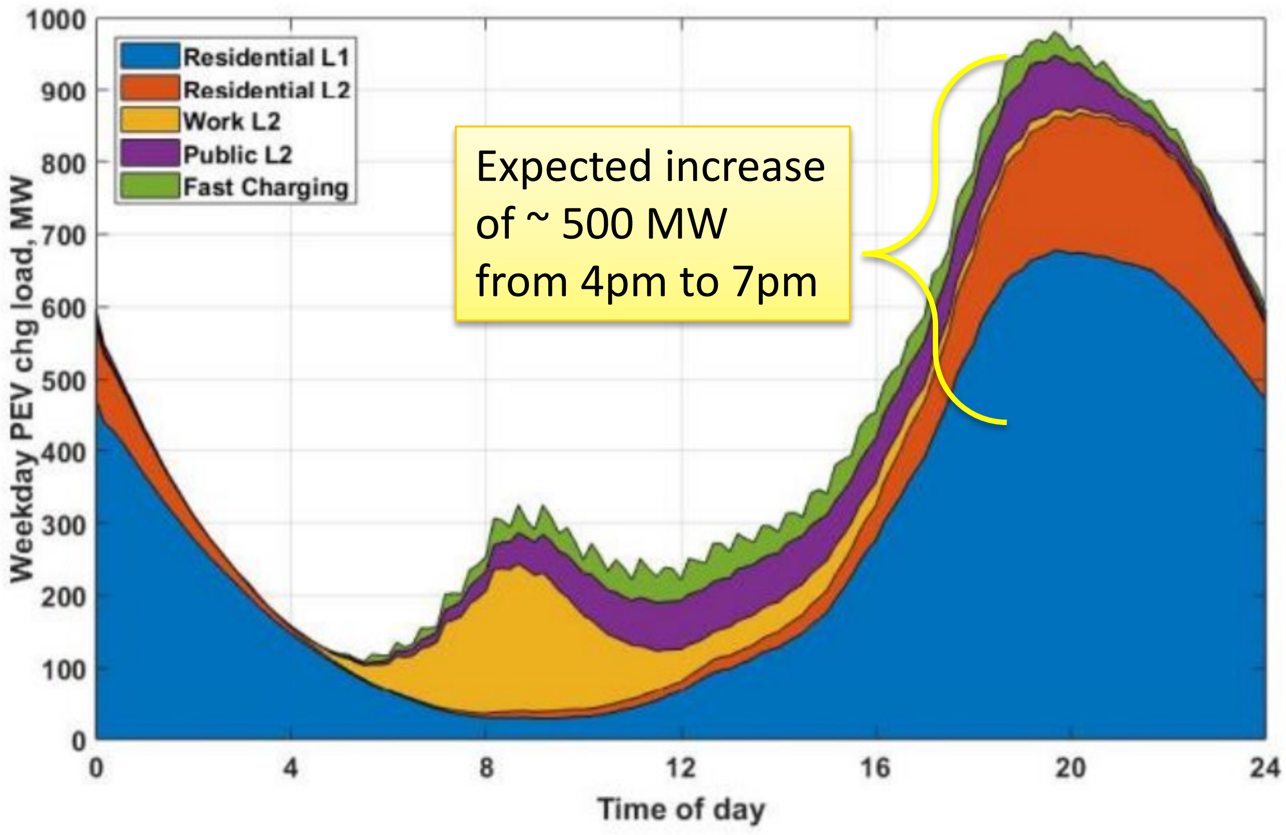
Over 25 CRADA projects with private sector

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

H2@Scale activities include systems and grid integration

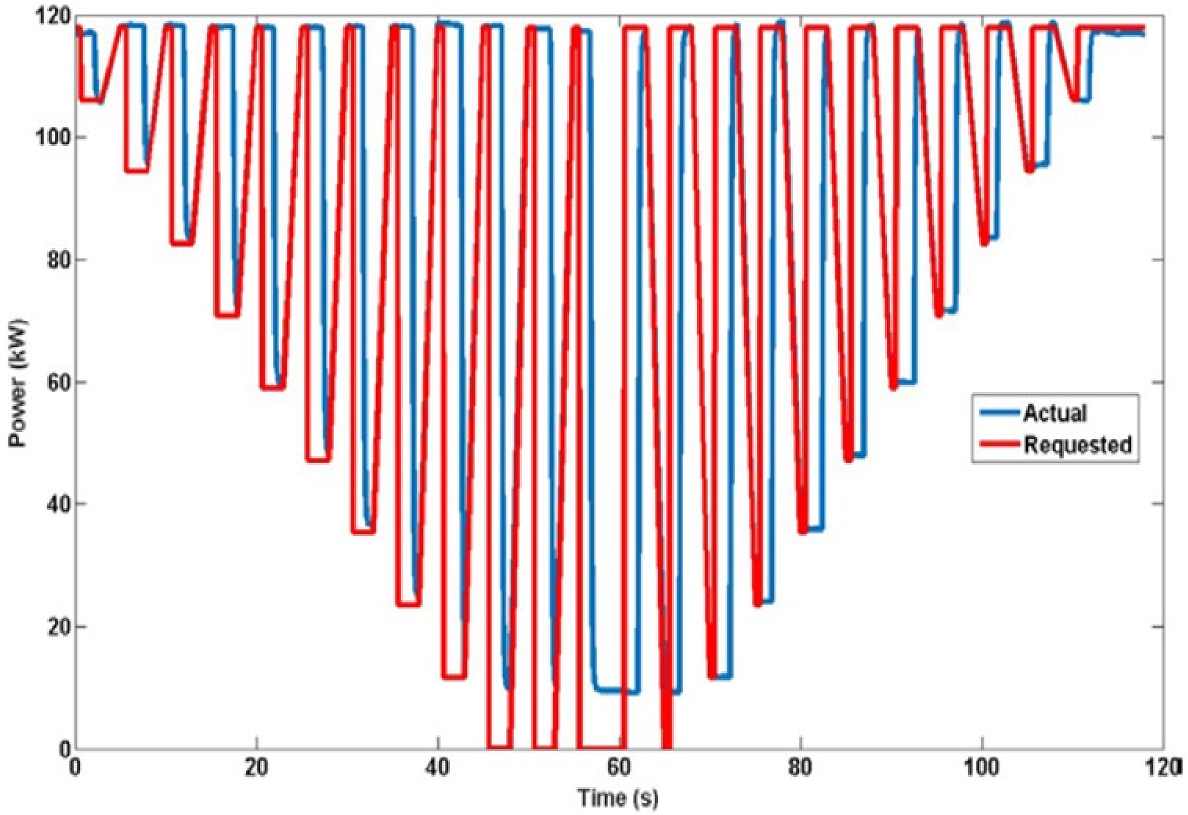
Flexibility will be needed to address grid challenges: high ramp rates and demand fluctuations

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

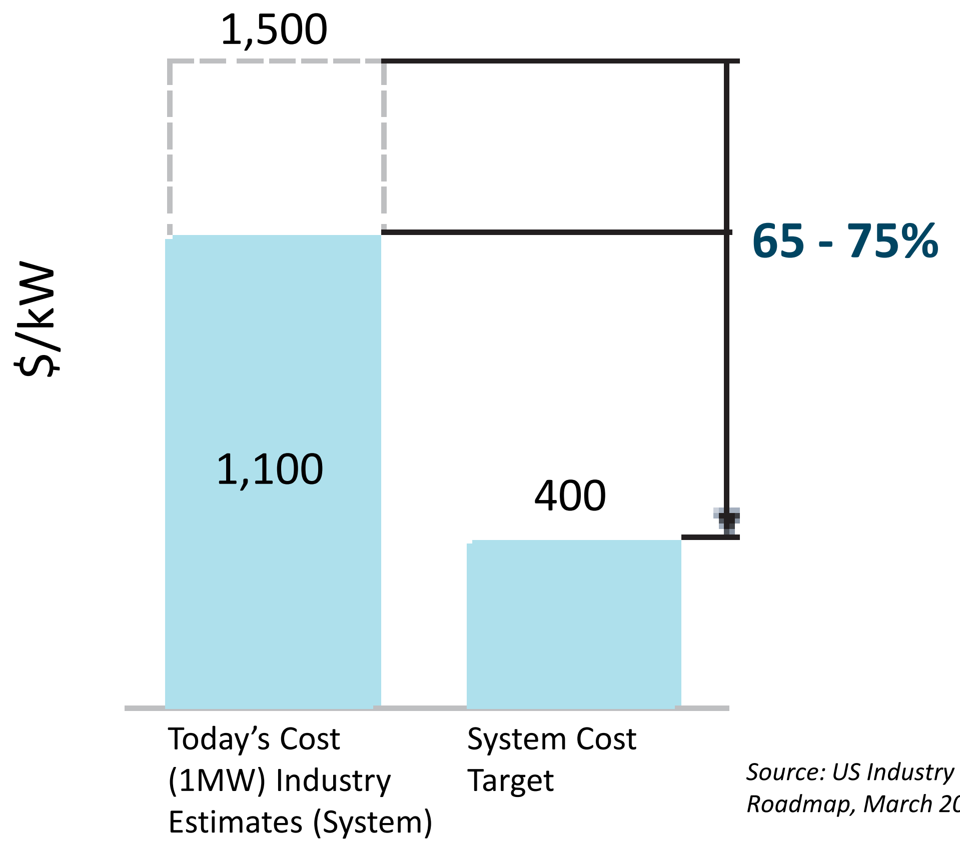
DOE national lab tests show dynamic response potential of electrolyzers. Coupling with EV charger, solar underway



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

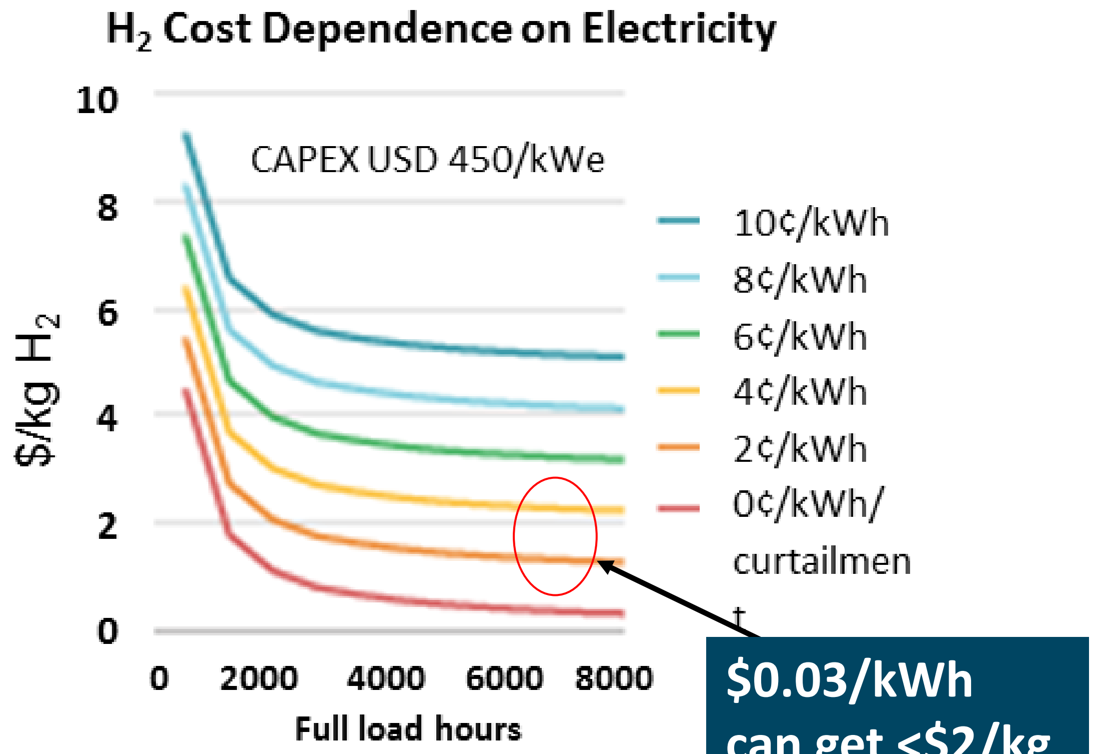
Electrolysis Cost Background – Recent Independent Analyses

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



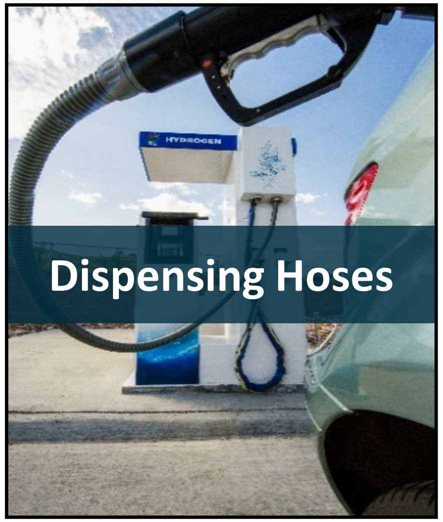
Source: IEA Hydrogen Future Report 2019

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

Cross-cutting Materials Compatibility R&D

H-Mat Hydrogen Materials Compatibility Consortium SM

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

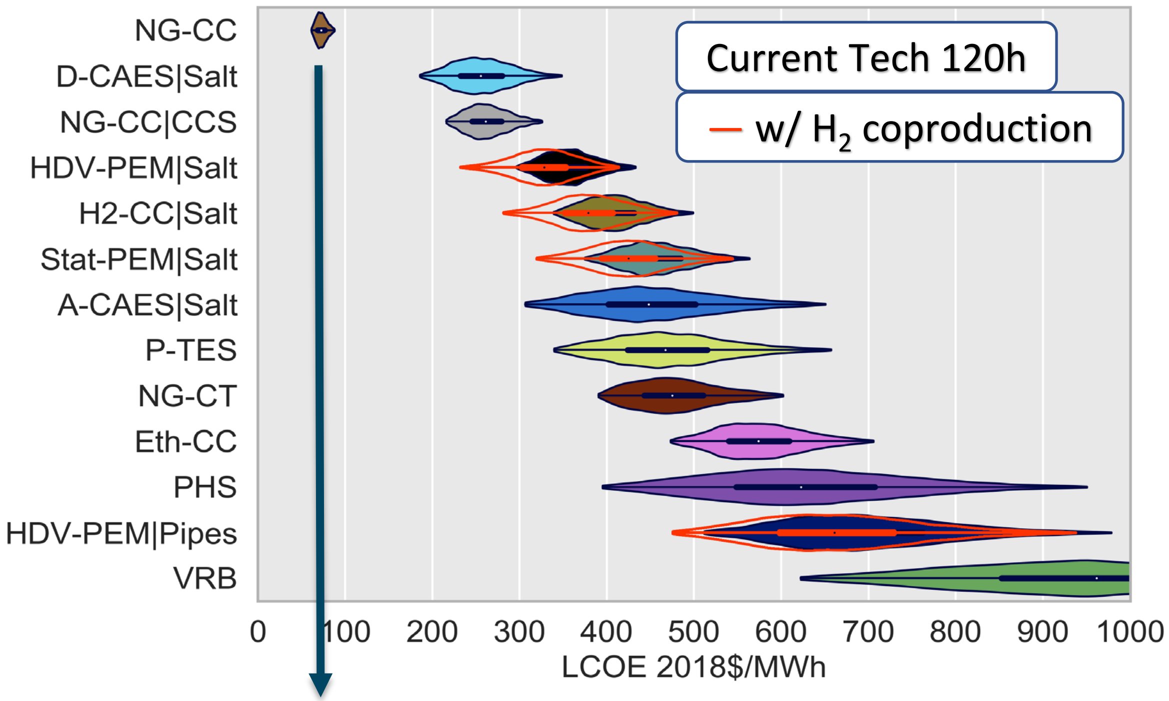
and can enable:

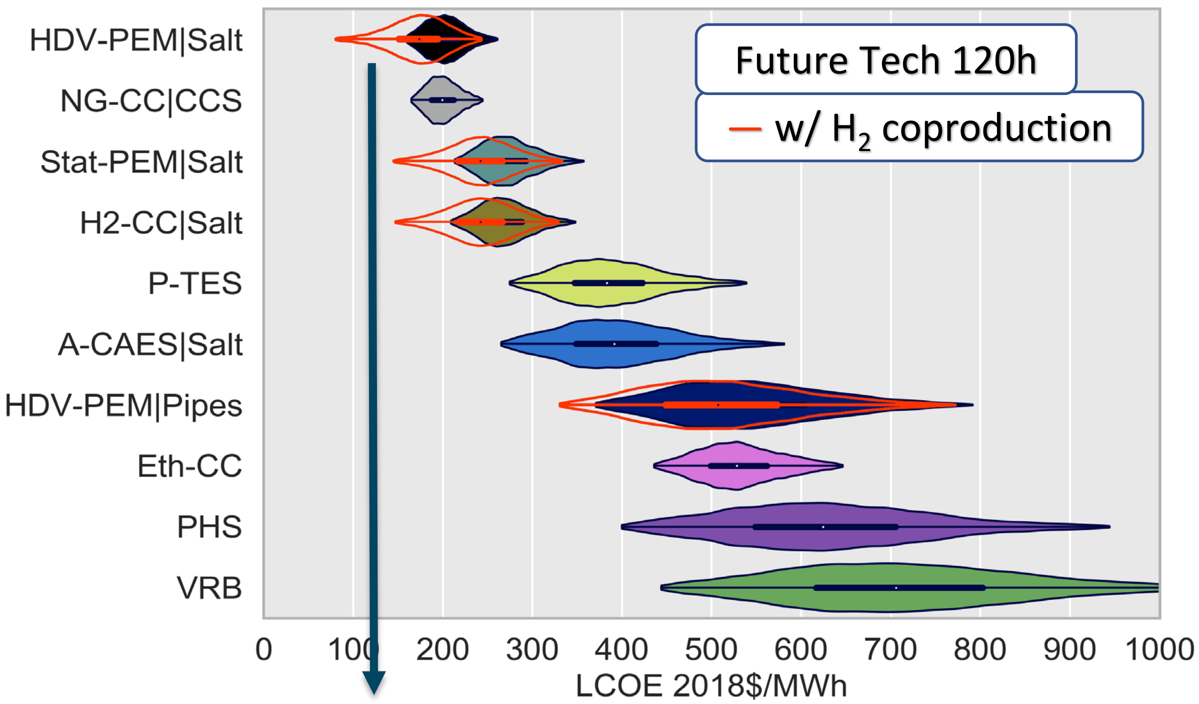
- Cross-sectoral emissions reductions
- Grid resiliency
- Terawatt hours of energy storage

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)

Long Duration Energy Storage and Flexible Power Generation Analysis

NREL's Techno-Economic Analysis of Long Duration Energy Storage- Preliminary Results across Technologies



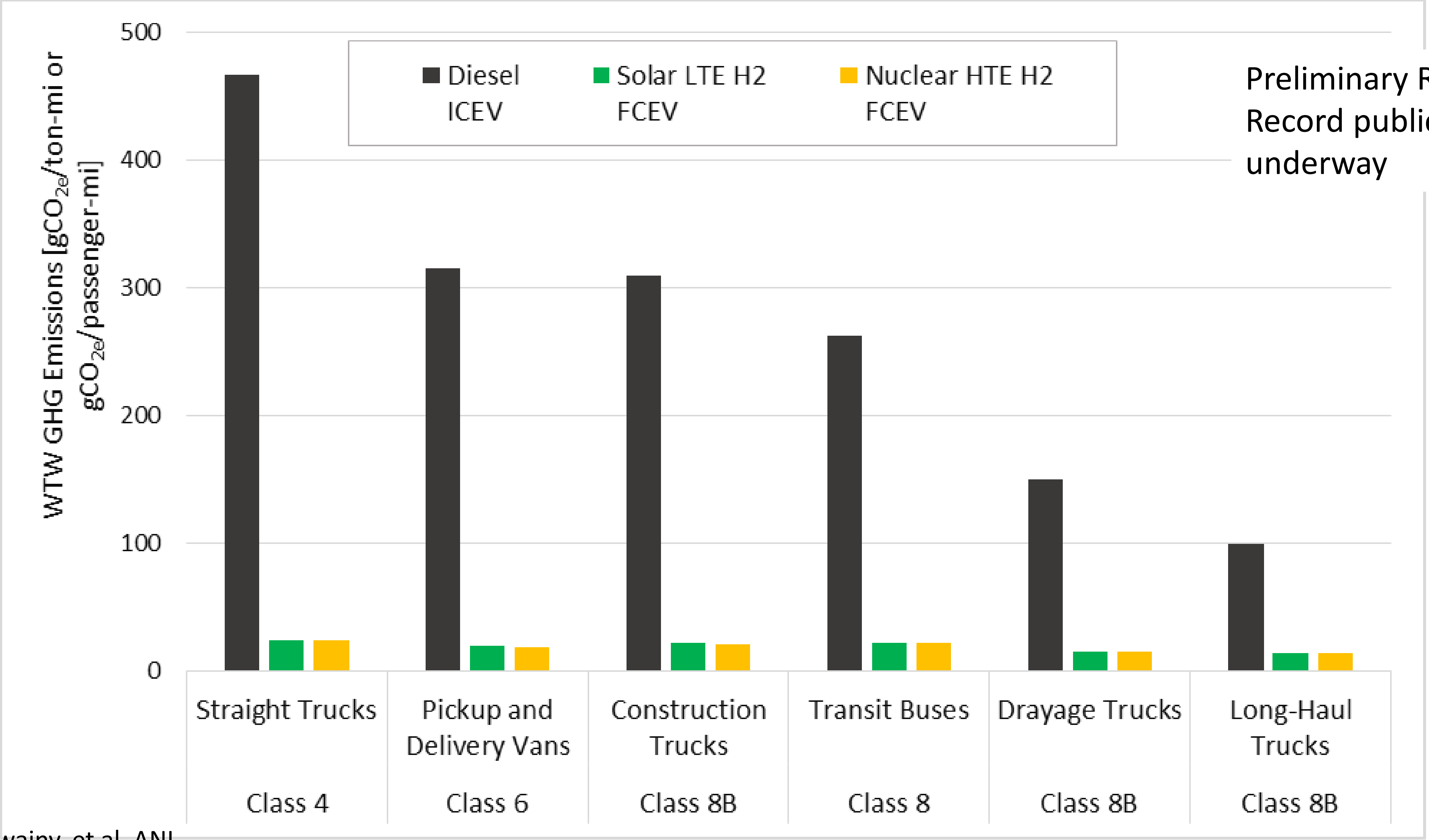


Natural gas combined cycle (NG-CC) is the lowest cost option today
Wide Range of Costs for Various Technologies
$200 to >$1,000/MWh

Future Scenario: Shows PEM fuel cells (for Heavy Duty Vehicle market), salt caverns + co-production of H_2 may be most economically competitive for 120 h storage

Source: Hunter, et. al., 2020, NREL- publication in process

Benefits and Impacts Analyses Underway – Argonne Example



Preliminary Results
Record publication underway

Source: A. Elgowainy, et al, ANL

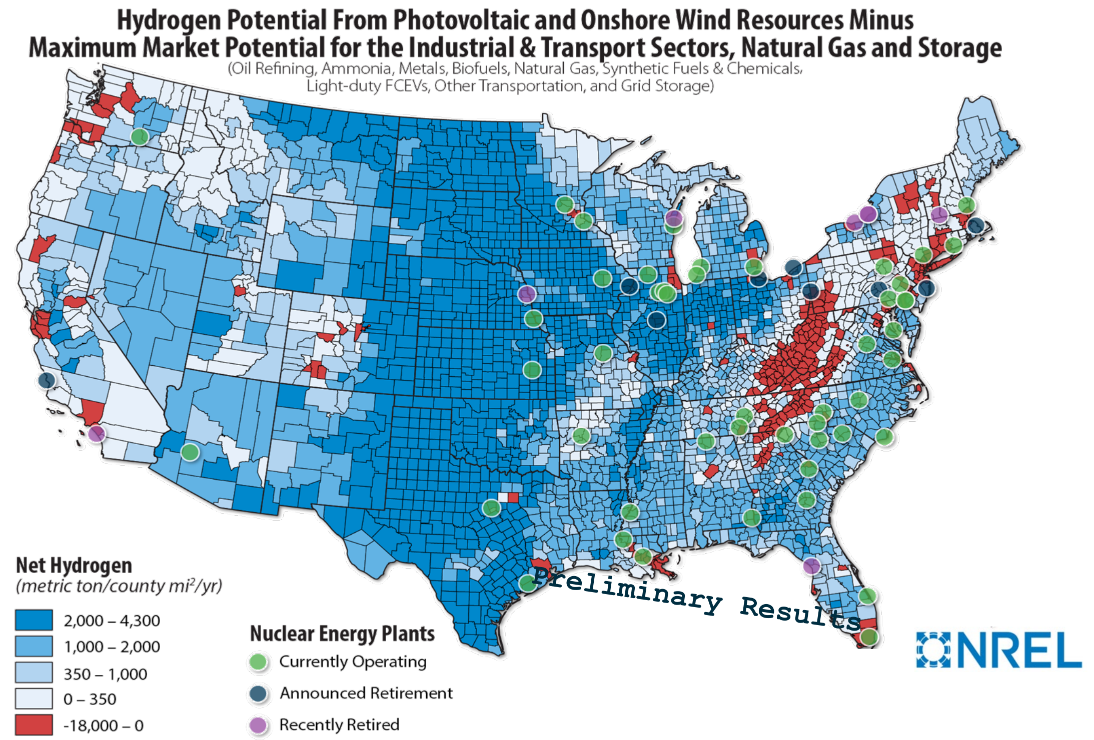
Examples of Activities to Enable H2@Scale

Assessing resource availability.
Most regions have sufficient resources.

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

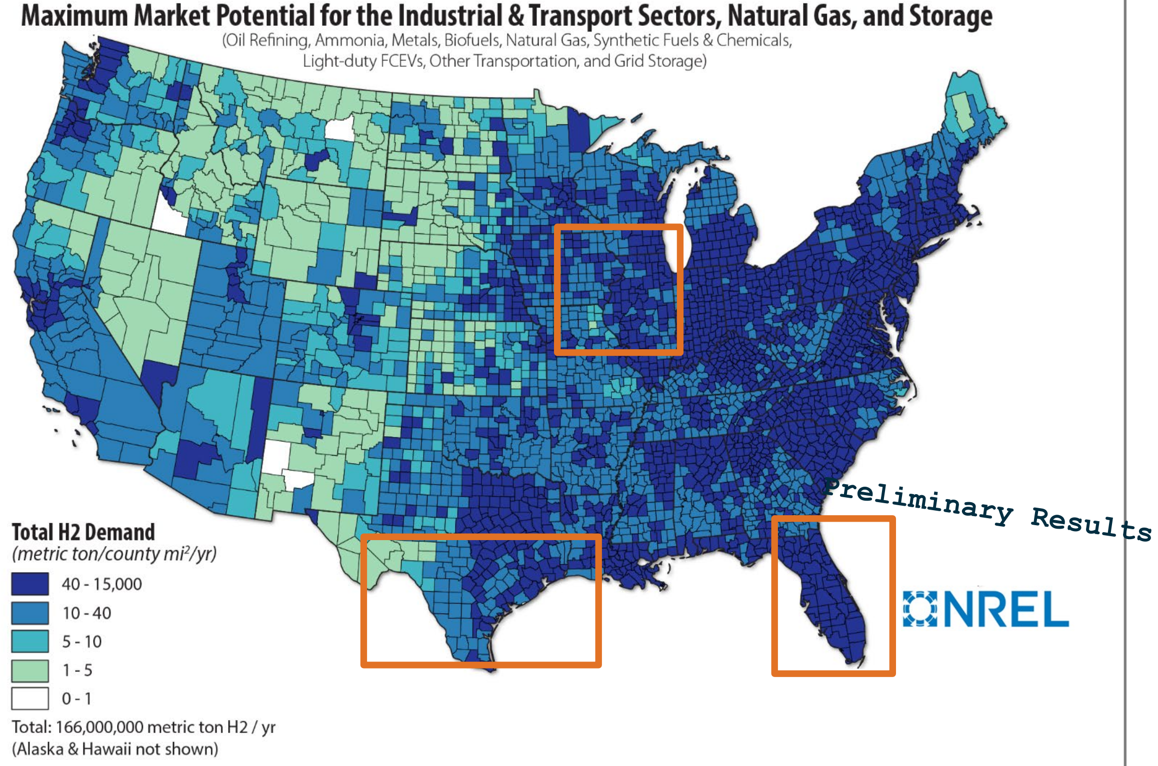
Includes 1 project funded by Office of Nuclear Energy

Hydrogen Availability



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

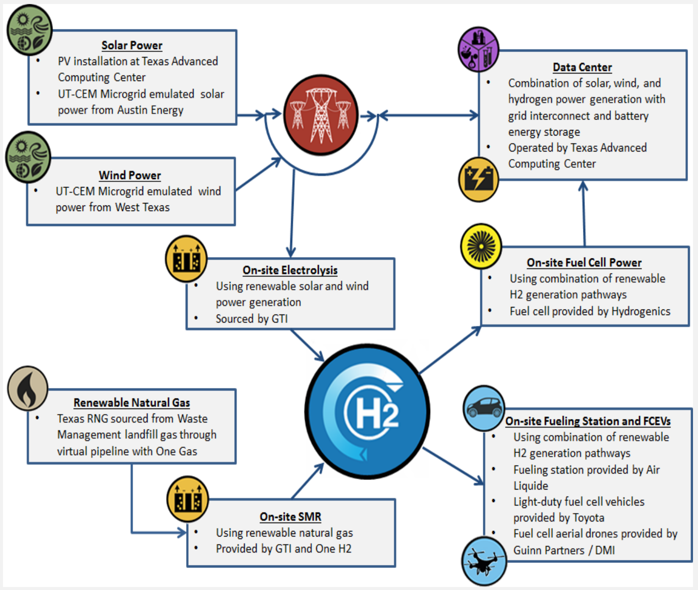
Hydrogen Demand Potential

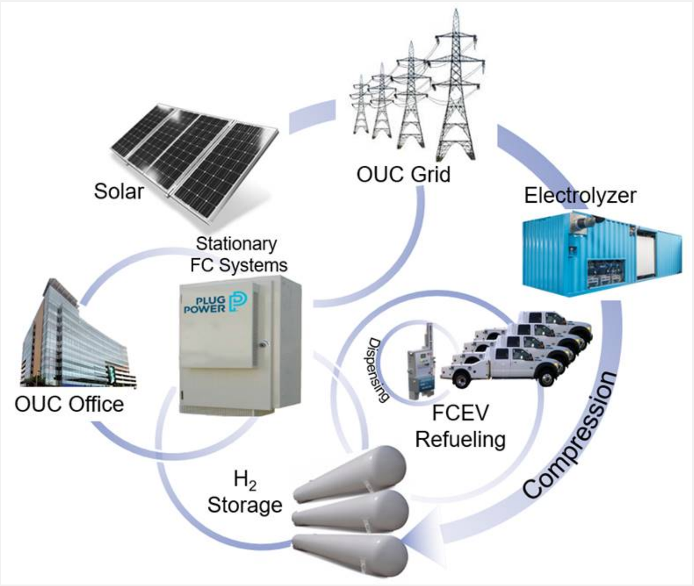


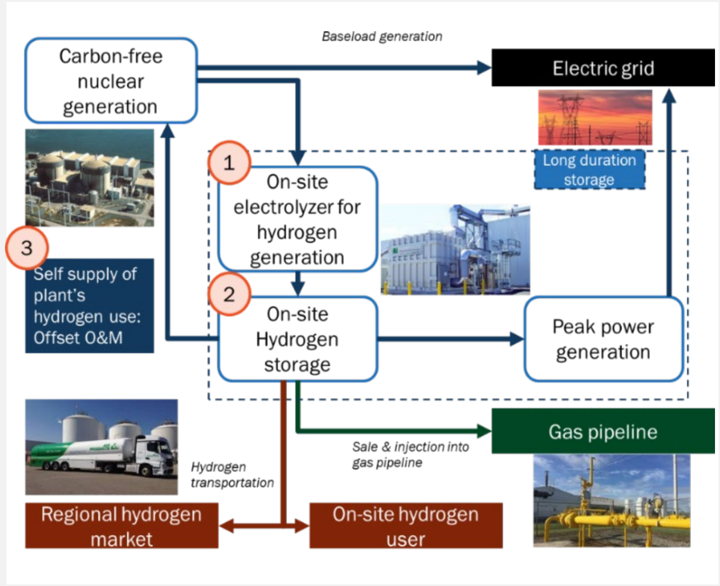
Example of H2@Scale Demonstration Projects

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

Texas		Florida		Site selection in process	
Total Budget $10.8M	Wind, Solar, RNG/Waste	Total budget $9.1M	Solar-to-H_2 with End Uses	Total Budget $7.2M	Nuclear-to-H_2 for at-Plant Use







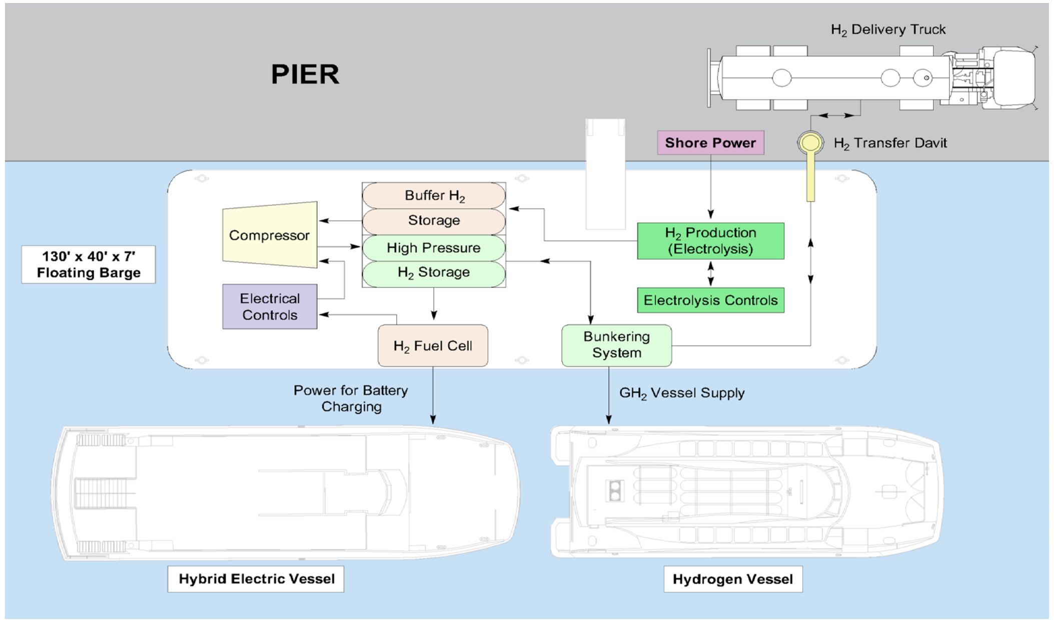
New Maritime and Data Center Selections Just Announced

SF Waterfront Maritime Hydrogen Demo Project

Total Budget

$16M

Hornblower Yachts & partners (SNL, AL, Nel, IGX, Port of San Francisco, et al)



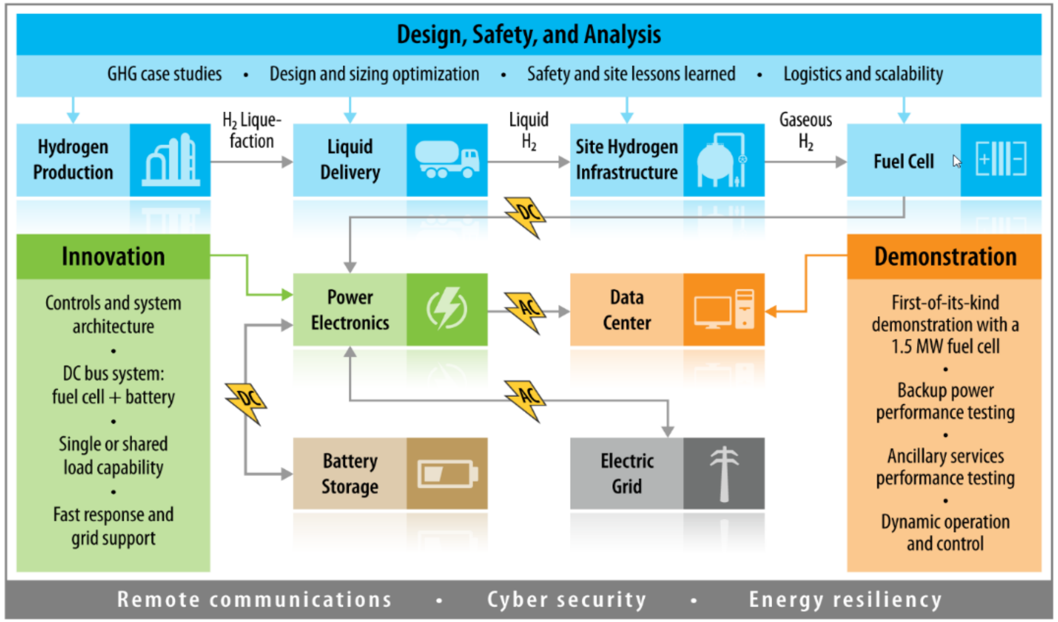
Goals: Demonstrate a first-of-its-kind maritime H_2 refueling infrastructure for up to 530 kg H_2 /day, integrated system of green H2 electrolysis + fuel cell on moveable barge for electricity and H2 production.

PEM Fuel Cell for Data Center Power

Total Budget

$13.7M

Caterpillar & partners (Ballard, Microsoft, NREL)



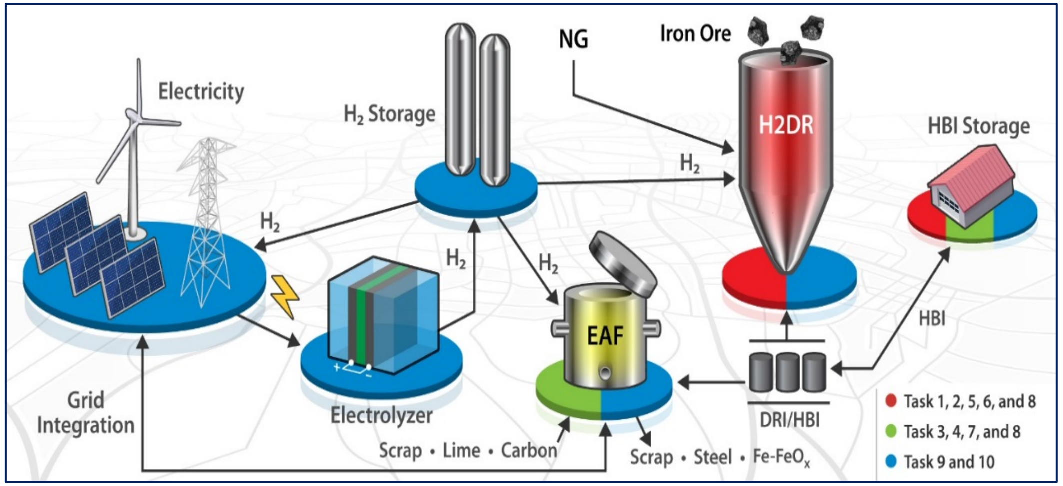
Goals: Demonstrate 1.5MW fuel cell (FC) to meet data center requirements; build capability to scale FCs to multi-MW data centers and provide FC power solutions for other portions of the electric power industry

Two HySteel Selections Just Announced

Grid-Interactive Steelmaking With Hydrogen (GISH)

Total Budget
$7.2M

Missouri University of Science and Technology & multiple industry partners

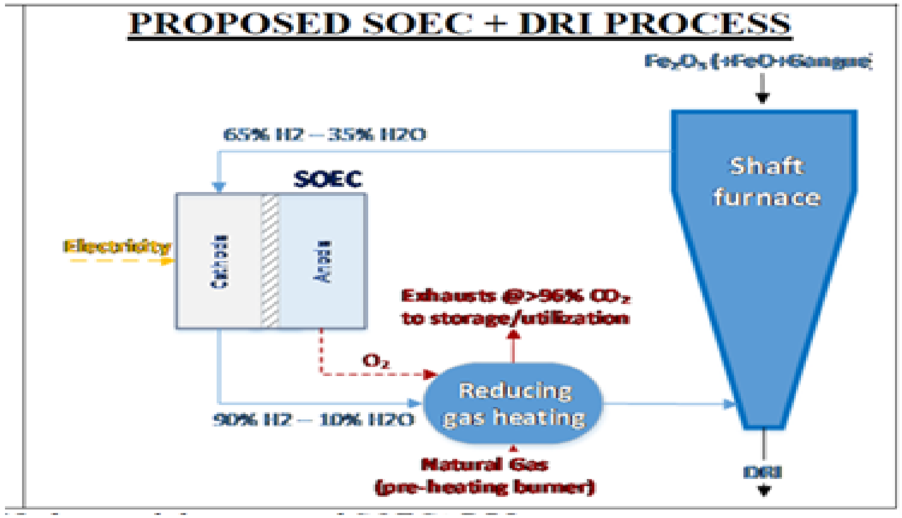


Goals: Assess kinetics, plasmas, metal quality, develop & validate models; demonstrate 1 ton/wk iron production in variable H_2/NG content integrated with EAF, and TEA of integrated process scaled to 5,000 tonnes/day,

SOEC Integrated with Direct Reduced Iron (DRI) Plants

Total Budget
$5.7M

University of California Irvine, FCE, SoCalGas and partners



Goals: Design and demonstrate thermal and chemical integration of SOEC with DRI simulator to enable reduction of 30% in energy and 40% emissions vs conventional DRI processes

First Carbon-Free, "Power-to-Gas" System in U.S.

Flagship Power-to-gas Project

Funded By DOE EERE In Partnership With Southern California Gas Company (SoCalGas)

- Approx. $2.5 million funded through EERE's Solar, Hydrogen and Fuel Cells, and Bioenergy Offices along with cost share by SoCalGas
- Process uses a low-temperature water electrolyzer to produce hydrogen from **renewable power**, then feeds the hydrogen and carbon dioxide into a bioreactor where methanogens produce methane and water
- With minor filtration, the product gas from the bioreactor will meet pipeline quality, allowing it to be injected into the **existing natural gas infrastructure**

Located at NREL, Golden, CO

- **Utilizes H_2+ CO_2 to generate pipeline quality natural gas** (> 97% CH_4)
- **Biocatalyst used in the process** - Methanothermobacter thermautotrophicus

Biomethanation Process:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

- **Industry and lab partners:** Southern California Gas Company, NREL and Electrochaea

Press Release
https://www.nrel.gov/esif/partnerships-southern-california-gas.html

Two New Efforts: 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


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

Formed 2003

19 Countries and EC

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 Hydrogen SAFETY
Connecting a Global Community

Online conference Sept 15-17

IPHE

Hydrogen Council

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

What can you do?

Respond to DOE Request for Information (RFI)
Due September 15, 2020

https://www.energy.gov/eere/articles/energy-department-solicits-feedback-hydrogen-and-fuel-cells-rd-activities-and-strategy

Get involved and help spread the word!

Follow @the_iphe

IPHE Infographic Challenge and IPHE Student/Postdoc Fellowship

Opportunity to apply research and creative skills to share with others hydrogen and fuel cells information, connect with other students and professionals, be highlighted on IPHE social media and win a cash prize!

Who can Enter

- Students (secondary and university) ages 13-18 yrs. from IPHE member countries

Entries Due

- October 8, 2020 - winners to be announced in late November

Submit your entry by Oct. 8 to media@iphe.net

Learn more

IPHE.net/challenge

Purpose of IPHE Fellowship

- Goal to foster future leadership, advance progress in hydrogen and fuel cells, and support global coordination
- Under represented groups in STEM particularly encouraged to apply

Active on LinkedIn? Join the IPHE Youth Group for updates about the #IPHEInfographicChallenge

2020 IPHE Fellow

연세대학교
YONSEI UNIVERSITY

Theodore Ohchan Kwon

EDUCATION

Yonsei University
Seoul, Republic of Korea
Doctor of Philosophy, Chemical Engineering, Aug 2019

Bachelor of Engineering, Chemical Engineering,
Yonsei University, Seoul, March 2008 ~ Aug 2015

Postdoctoral Fellow
Nano Green Energy Priority Research Center, Yonsei University, Seoul, Sep 2019

RESEARCH INTERESTS

- System modification of secondary zinc air batteries
- Synthesis of novel oxygen reduction/evolution catalyst
- Polymer electrolyte membrane fuel cell electrode optimization
- Novel membranes for polymer electrolyte membrane fuel cell application

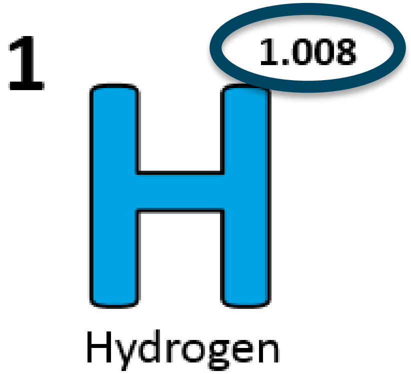
Resources and Events

Save the Date

June 8-10, 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 H_2IQ

Join Monthly
H2IQ Hour Webinars

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

Download
H2IQ For Free

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

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

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Thank You

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