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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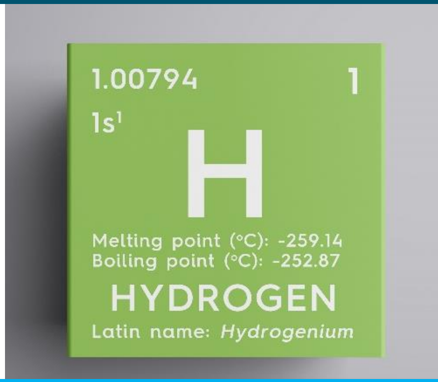
Director, Hydrogen and Fuel Cell Technologies Office

HOC (Hydrogen Online Conference), Mission Hydrogen- October 8, 2020

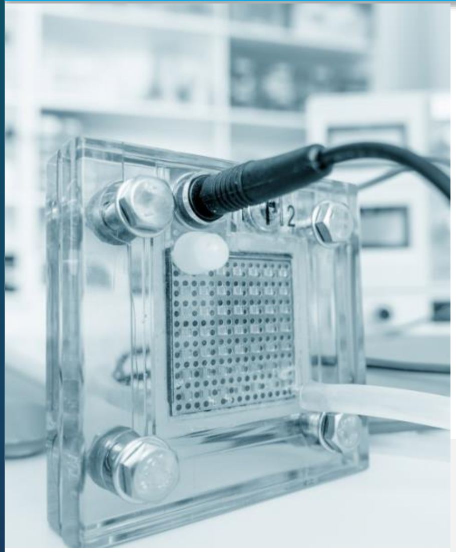

Happy Hydrogen and Fuel Cell Day – A week-long celebration of progress

Hydrogen and Fuel Cell Day October 8 (10.08)

- Represents hydrogen's atomic weight of 1.008
- Celebrated in the U.S. since 2015 with weeklong activities
  - Blogs, announcements
  - Ride and drives, presentations at schools, tech demos
  - Interactive online resources (i.e. 101 quiz, career map)



What can you do?



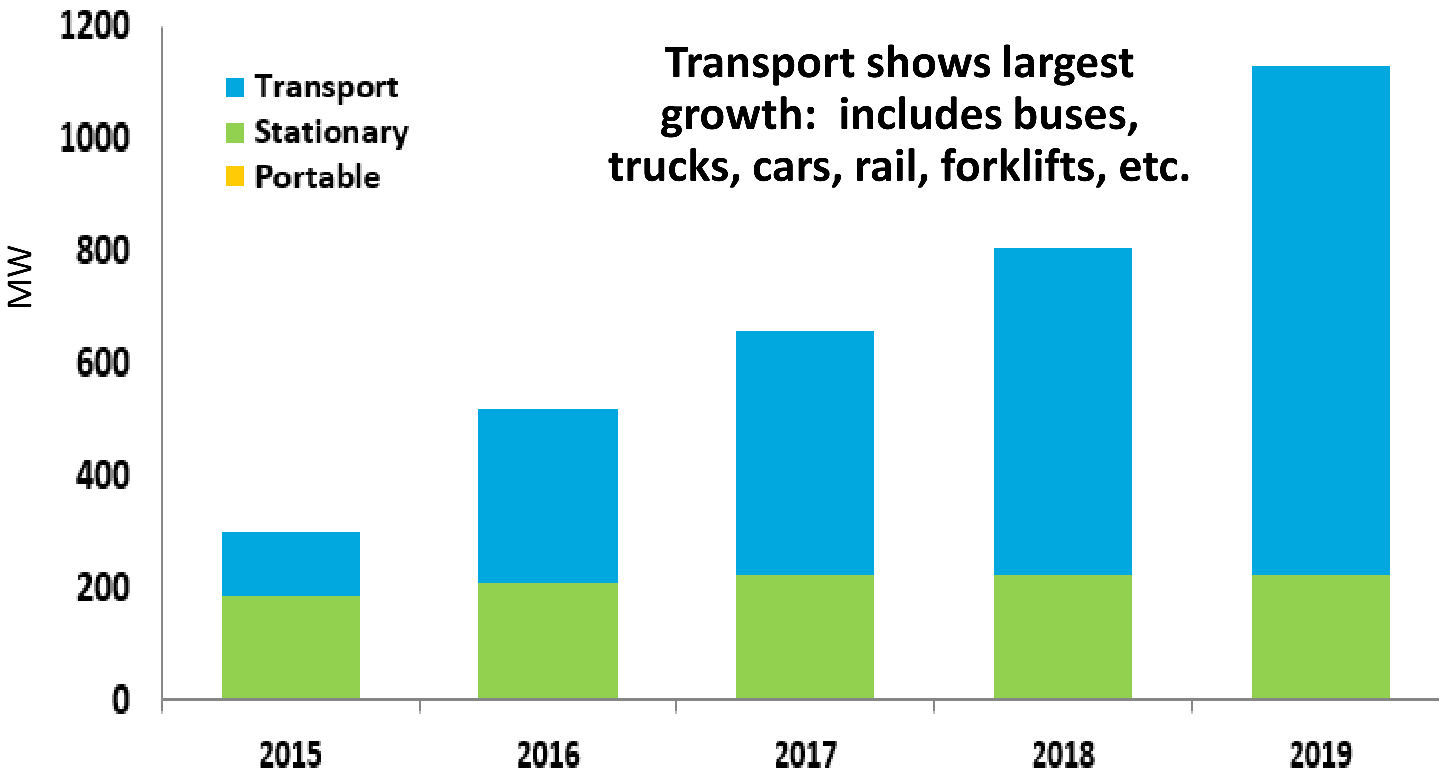
- **Post on social media** and share information, use hashtags!
- **Increase your H2IQ** by tuning in to the monthly H2IQ hours
- **Test your H2IQ** by taking the hydrogen and fuel cell quiz
- **Learn** about fuel cell and hydrogen jobs with the career map
- **Follow @The_IPHE** on twitter for global hydrogen updates

More info: **hydrogen.energy.gov**

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

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

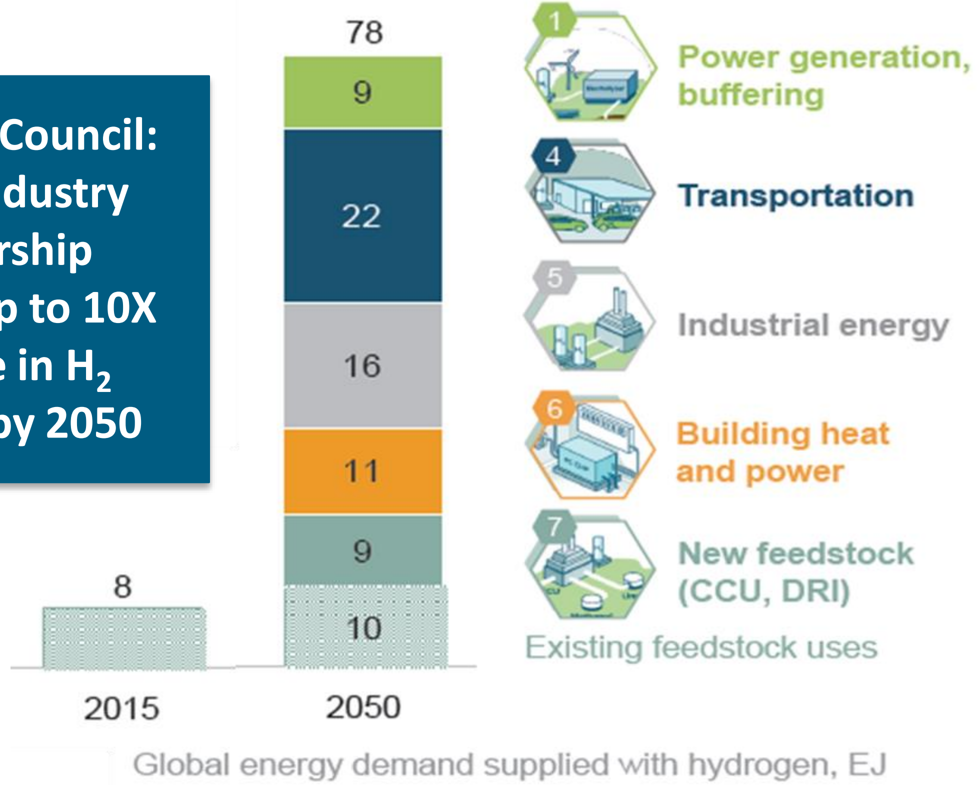
Roadmaps and Plans Developing Worldwide

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

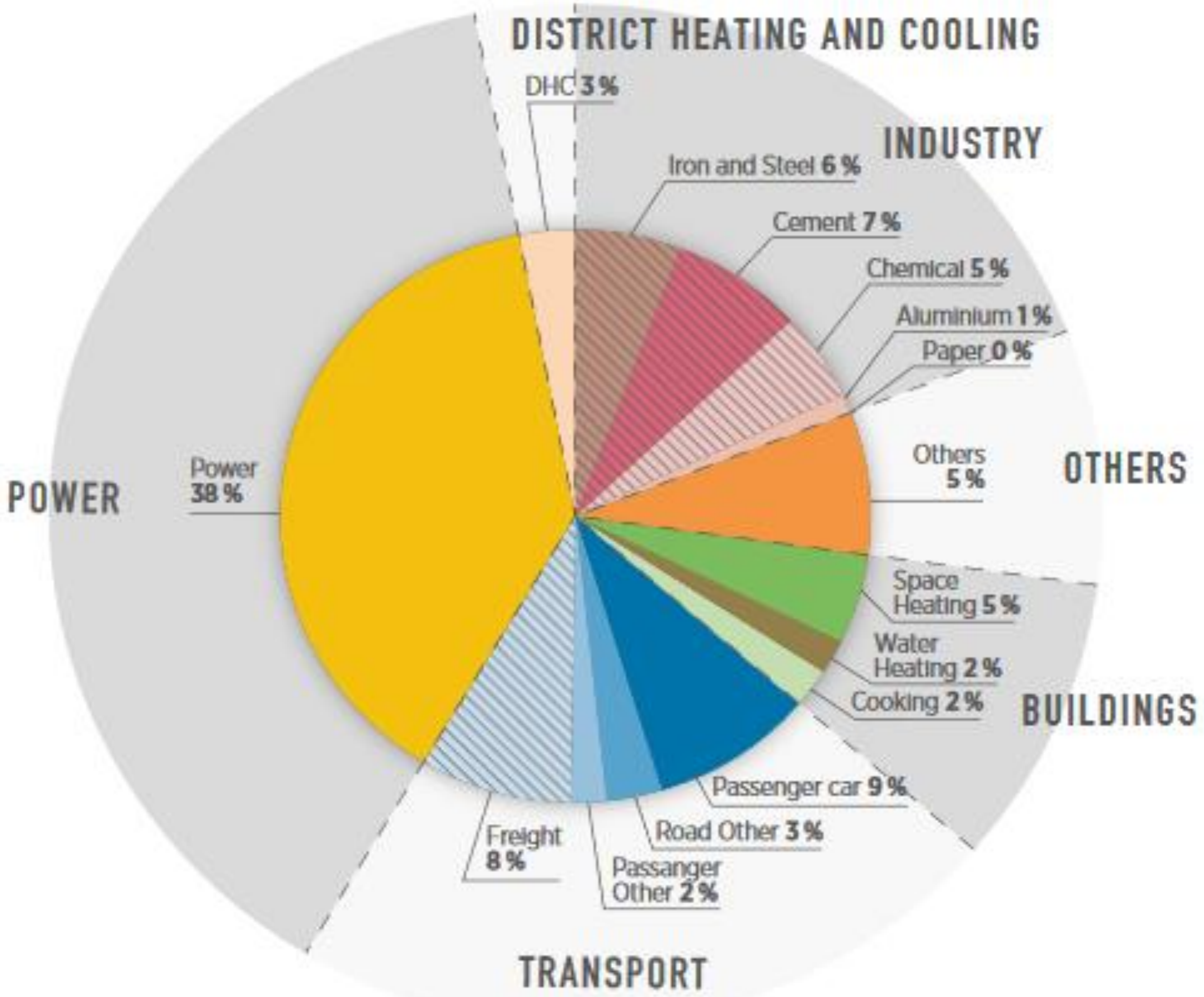
H2 Council Global Impact Potential by 2050

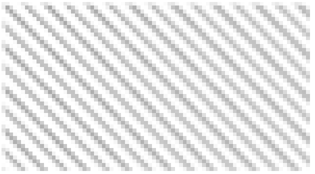
H2 Ministerial Global Action Agenda Goals:
"10, 10, 10"
10M systems, 10K stations, 10 years

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



Global Energy Related Carbon Emissions by Sector

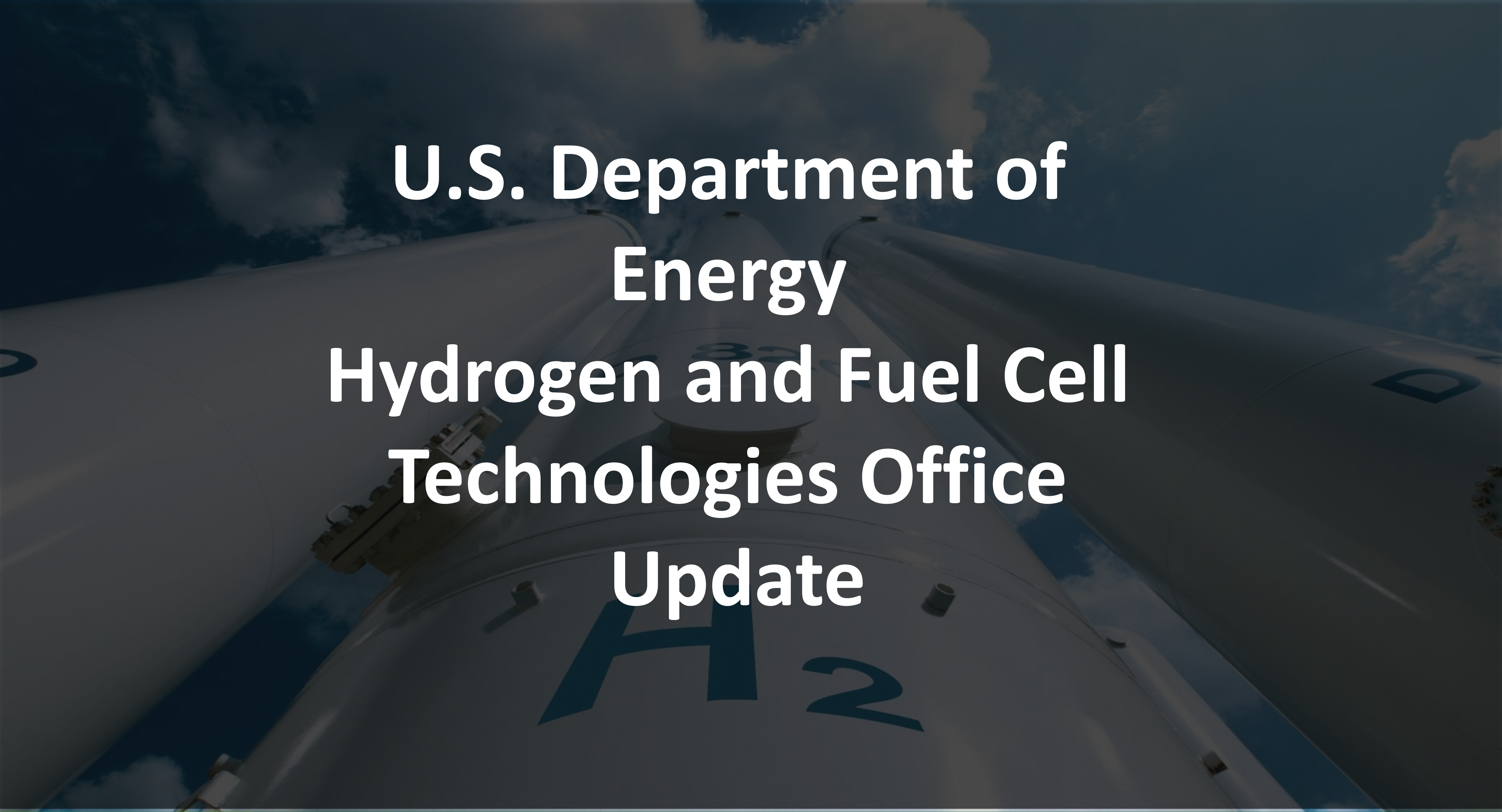




Sectors today with no economically scalable option for deep emission reductions

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

U.S. 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

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	Hydrogen	Systems Development & Integration
• Cost, durability, efficiency • Components (catalysts, electrodes) & systems • Focus on heavy duty applications (trucks, marine, data centers, rail, air, etc.)	• Hydrogen production, infrastructure/delivery, storage (for transport and stationary storage) • Cost, efficiency, reliability & availability.	• 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

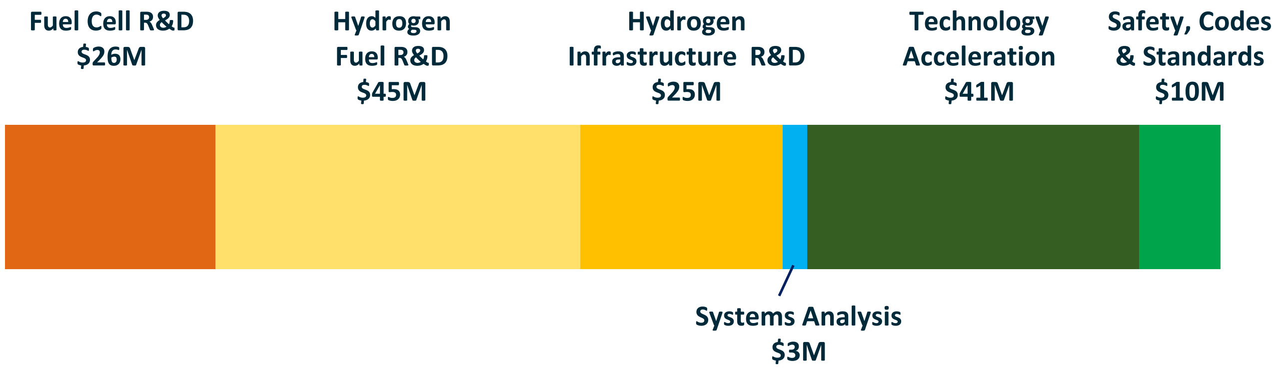
Double energy density for onboard storage to **1.7 kWh/L**

Budget: $150M in FY2020

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

>8,800
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

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

FOSSIL RESOURCES

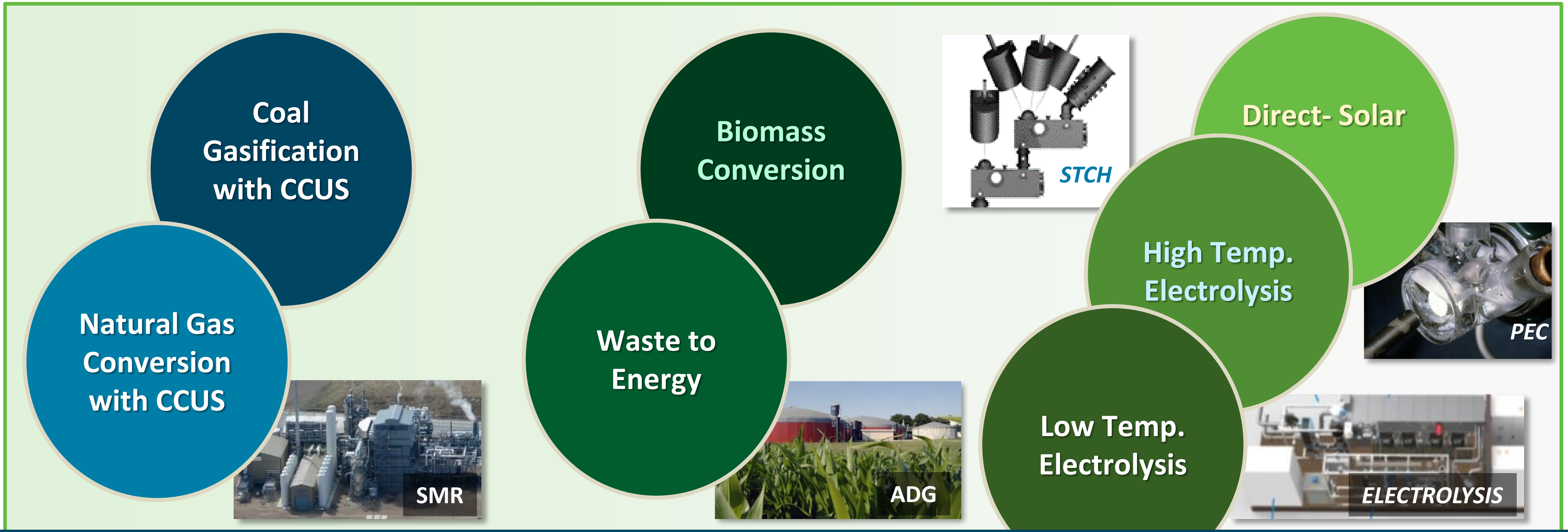
- Low-cost, large-scale hydrogen production with CCUS
- New options include byproduct production, such as solid carbon

BIOMASS/WASTE

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

WATER SPLITTING

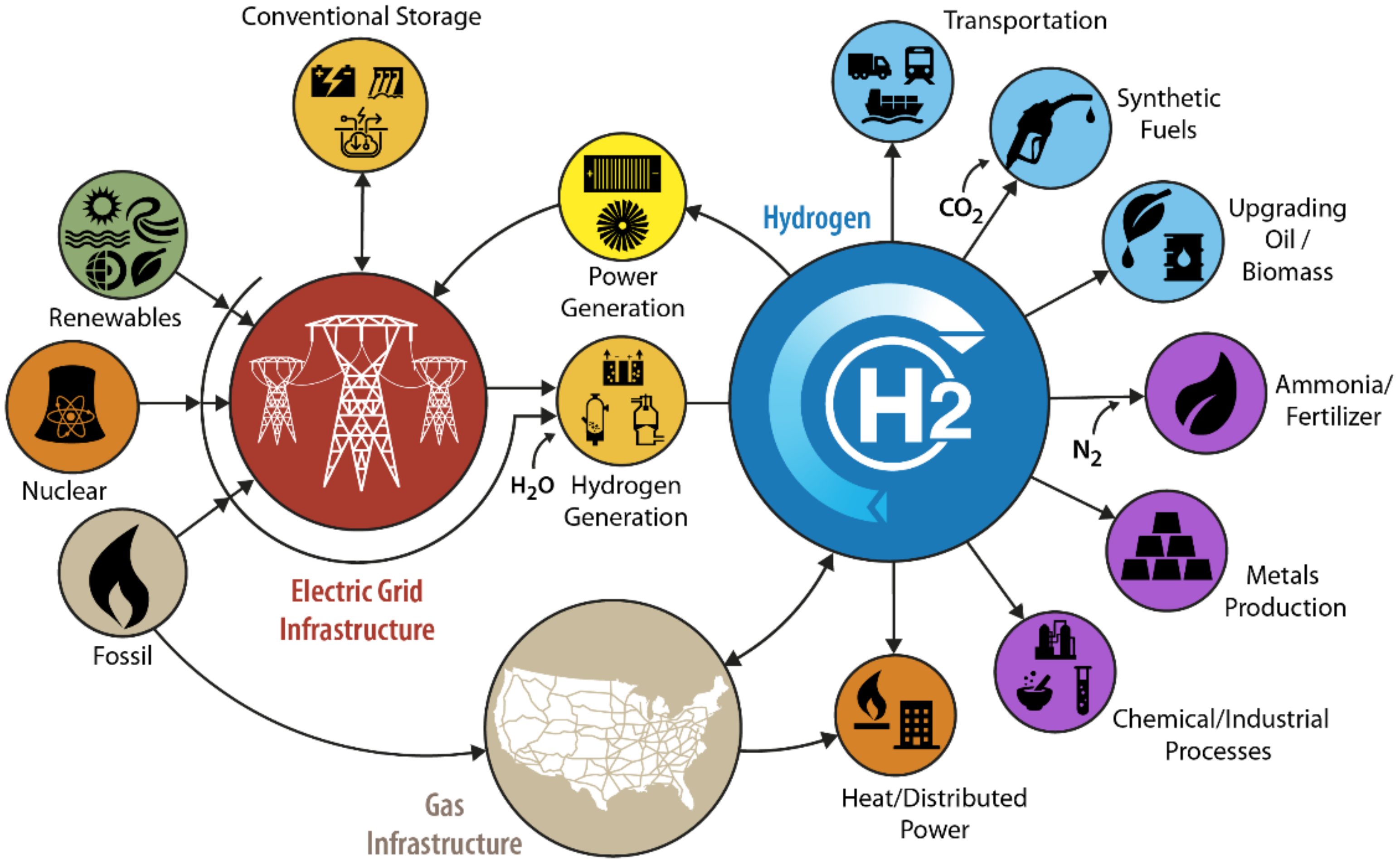
- Electrolyzers can be grid tied, or directly-coupled with renewables
- New direct water-splitting options offer long-term sustainable hydrogen



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

Hydrogen is one part of a Comprehensive Energy Portfolio

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



- **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

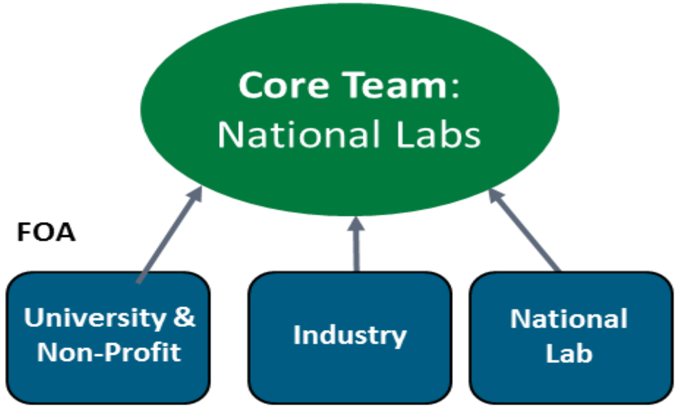
- **Scale up technologies in key sectors**
- **Continue R&D to reduce cost and improve performance, reliability**
- **Address enablers: harmonization of codes, standards, safety, global supply chain, workforce development, sustainable markets**

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

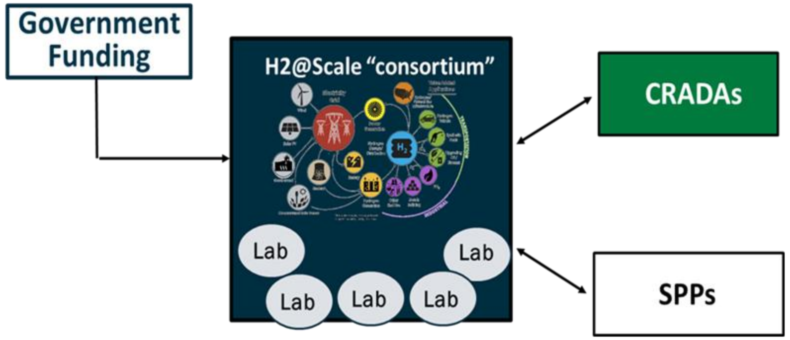
Key Programmatic Areas

<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')

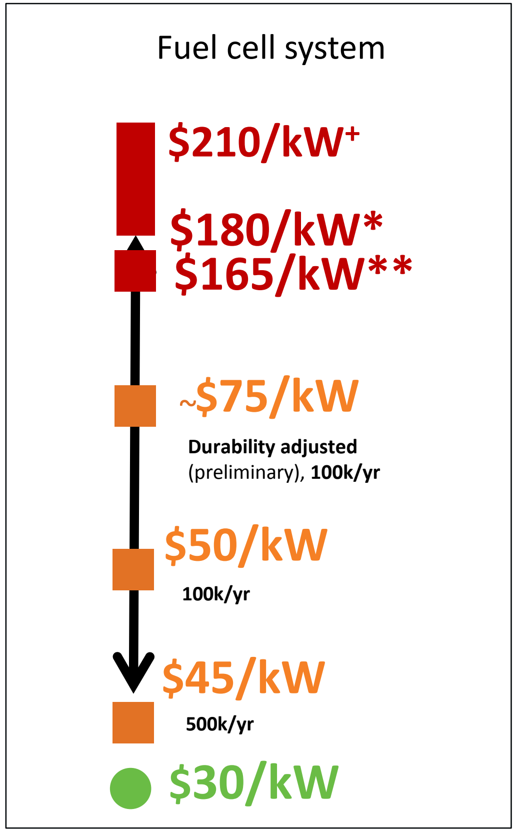
Over 25 CRADA projects with private sector

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

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

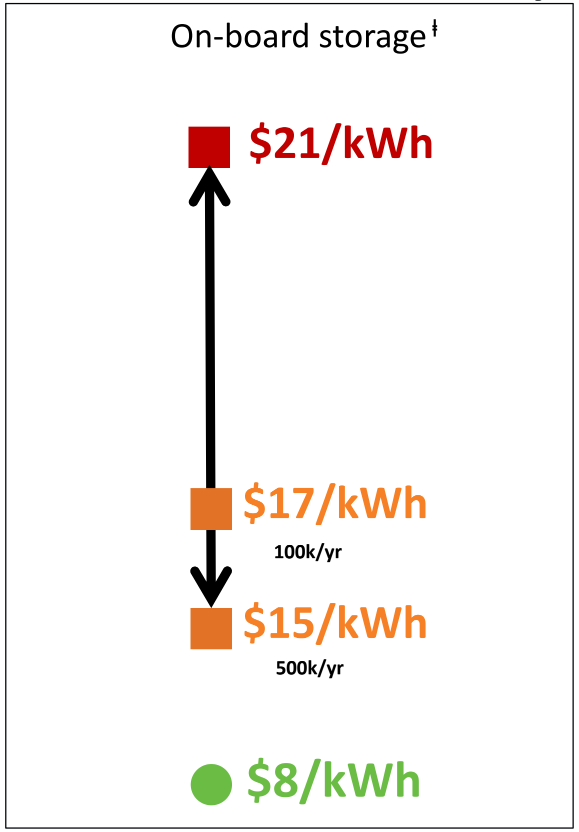
Key Goals: Reduce the cost of fuel cells and hydrogen production, delivery, storage, and meet performance and durability requirements – guided by applications specific targets

Fuel Cell R&D

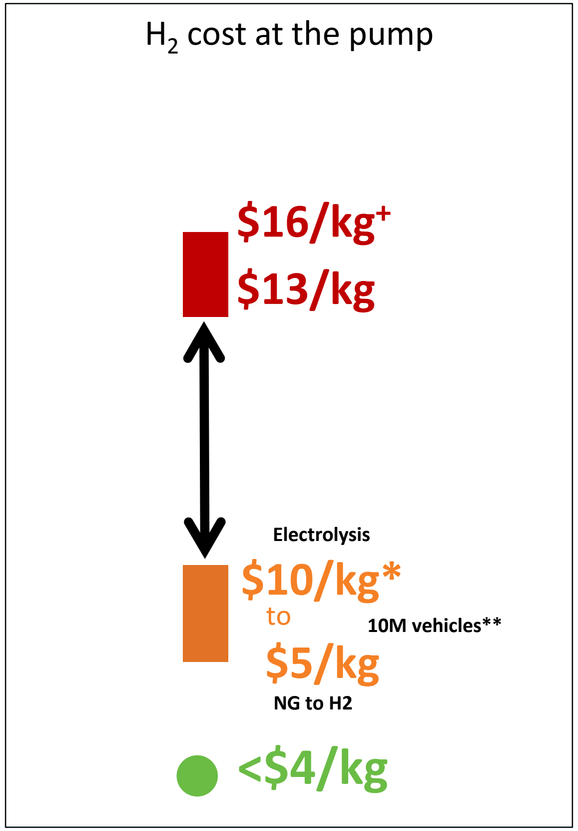


[†]Based on commercially available FCEVs
[*]Based on state of the art technology
[**]Based on commercial FCEV analysis at 3,000/yr

Hydrogen R&D



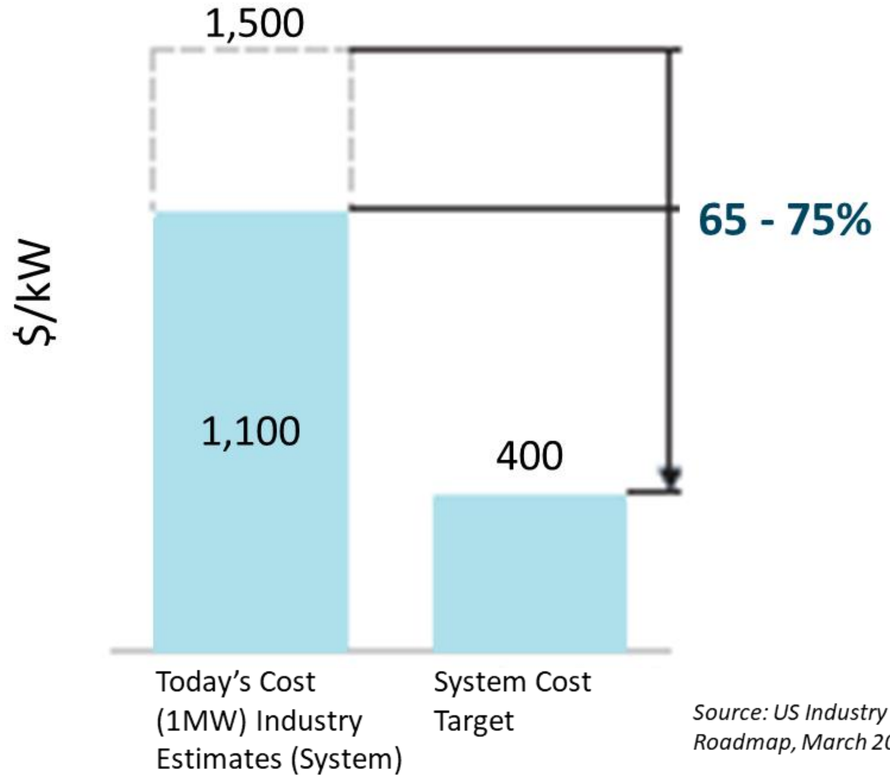
ⱡ Storage costs based on preliminary 2019 storage cost record



[†]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

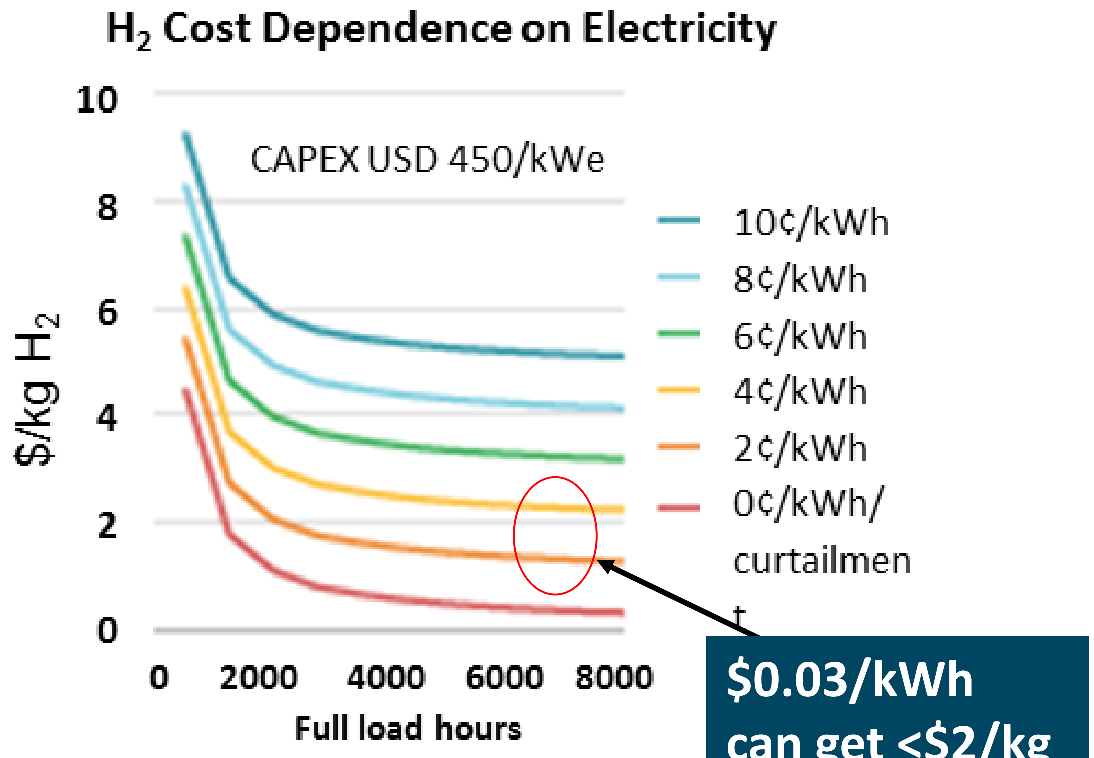
Electrolysis Cost – Recent Independent Analyses

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

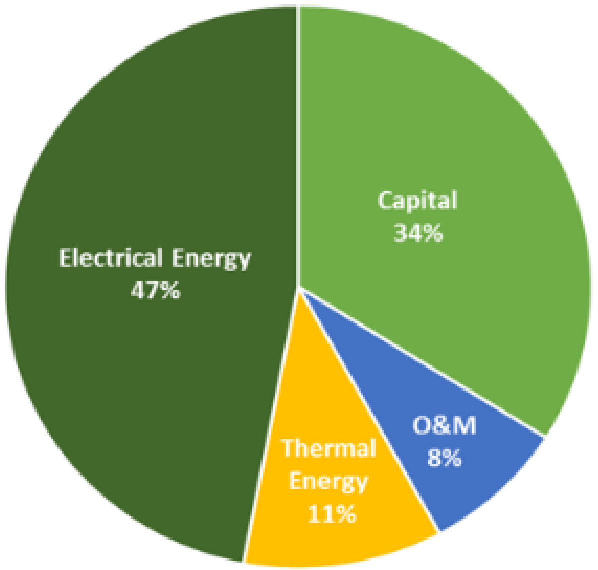


Source: IEA Hydrogen Future Report 2019

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

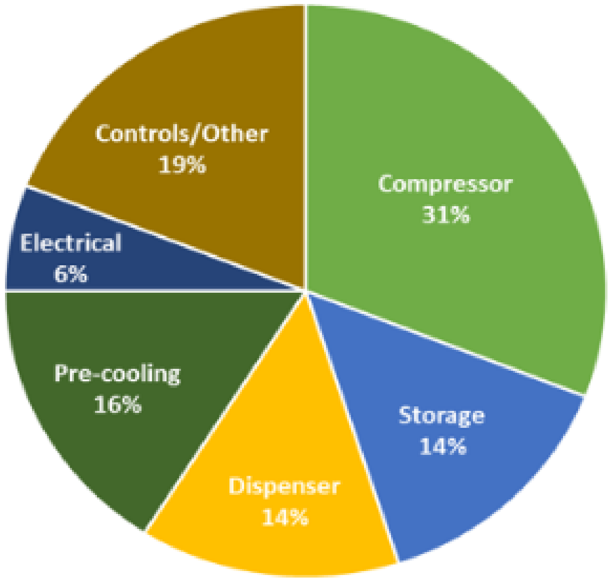
Identifying Hydrogen Cost Drivers is Key

Hydrogen Production Cost
(High Temperature Electrolysis)

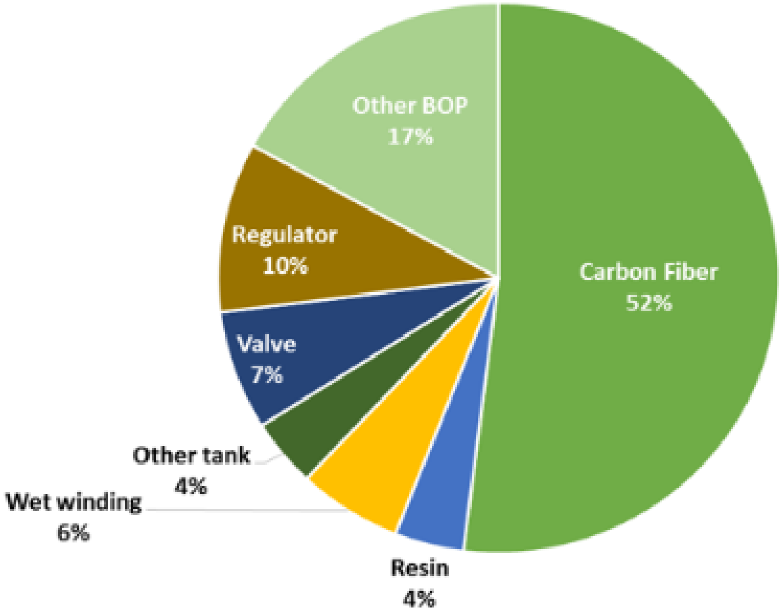


H_2 Onboard Storage Cost Drivers:
Carbon Fiber Precursors and Processing

Hydrogen Infrastructure Cost
(700 Bar Hydrogen Station)



Hydrogen Storage Cost
(Onboard 700 Bar Hydrogen Storage Vessel)



H_2 Production (Electrolysis) Cost Drivers: **Electrical energy and capital costs**

H_2 Infrastructure Cost Drivers: **Compressors and Storage**

Note: Updates to be published May, 2020

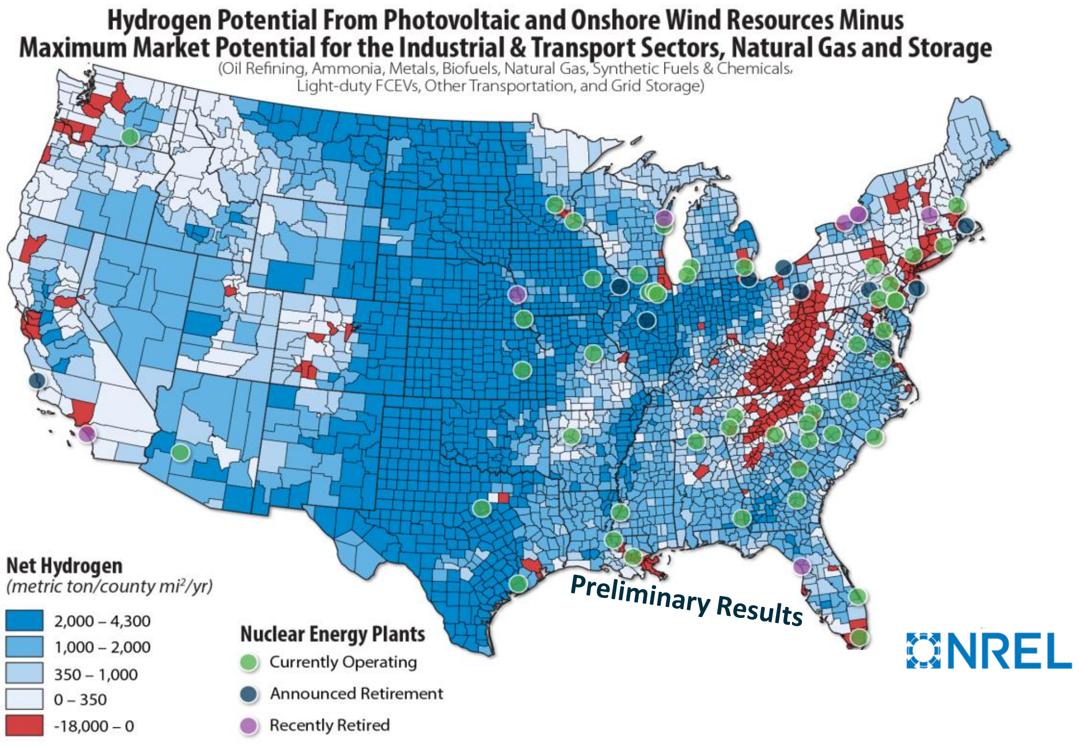
Examples of H2@Scale Analysis and Demonstration Projects

Assessing resource availability.
Most regions have sufficient resources.

New H2@Scale demonstration projects cover range of applications

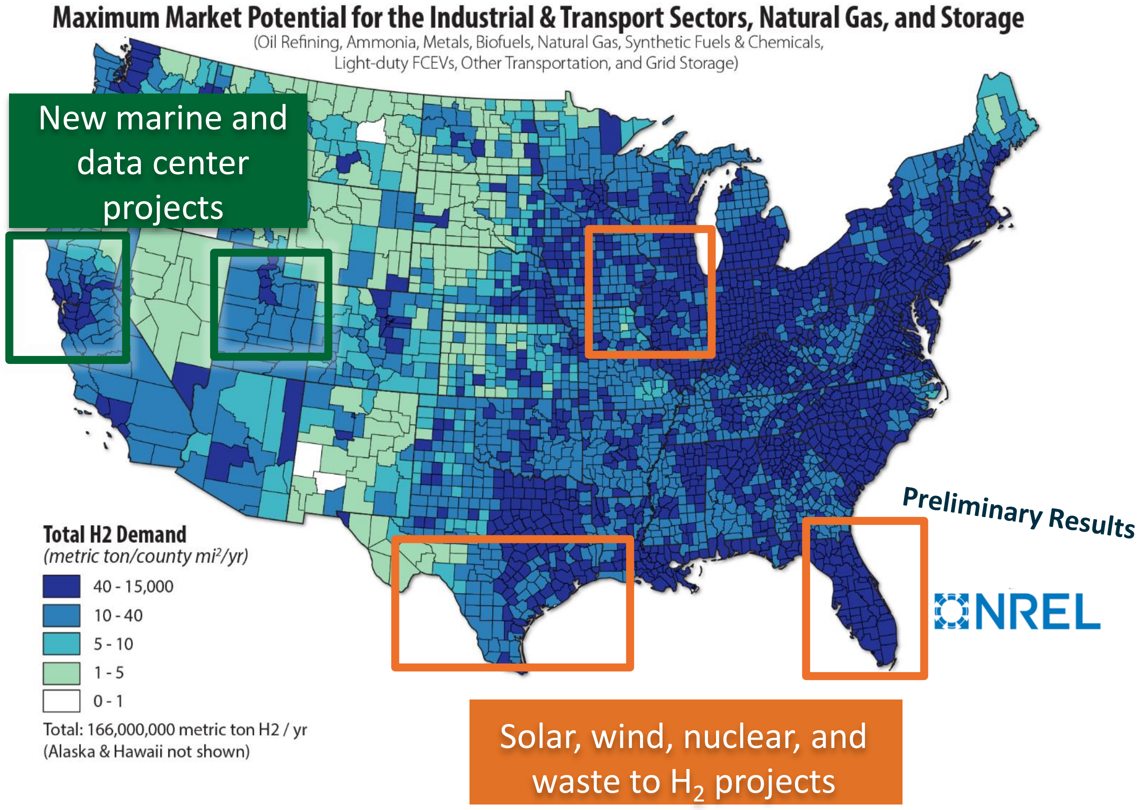
***Includes 1 project by Office of Nuclear Energy**

Hydrogen Availability



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

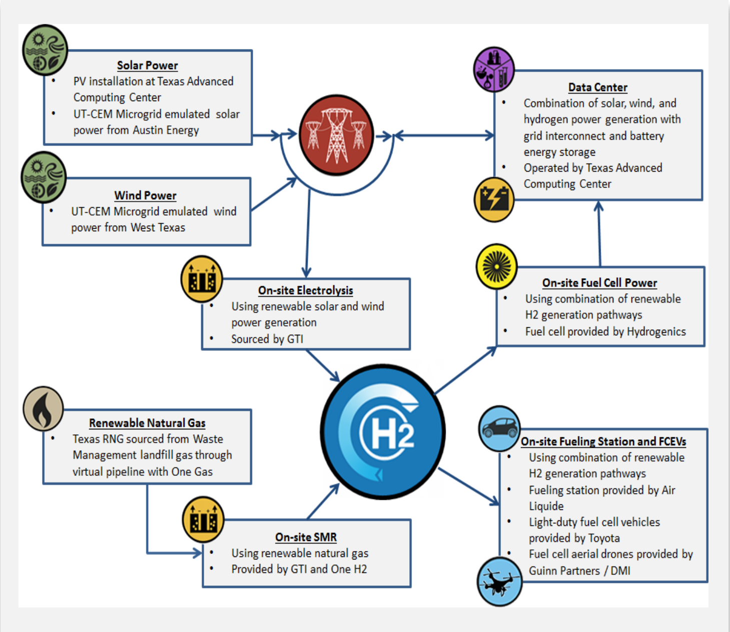
Hydrogen Demand Potential

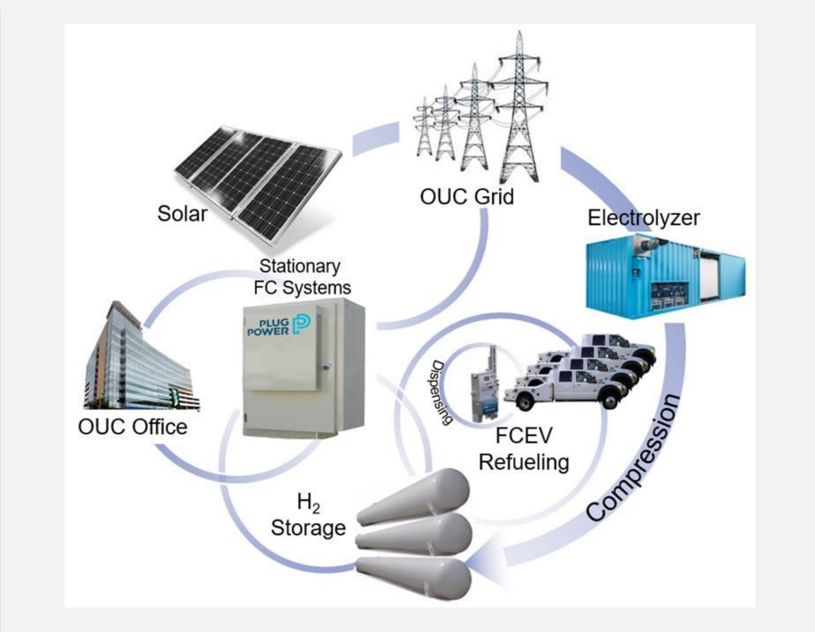


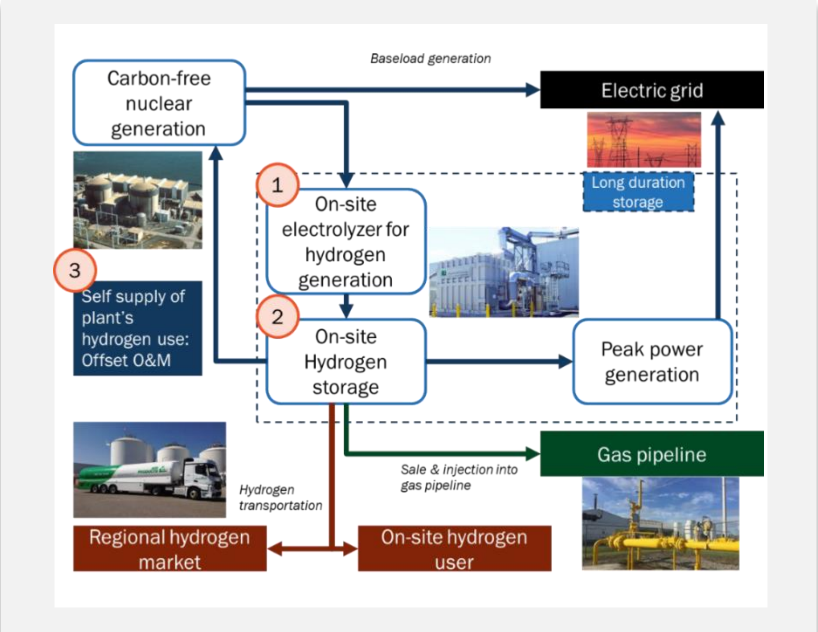
Example of H2@Scale Demonstration Projects

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

Texas		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







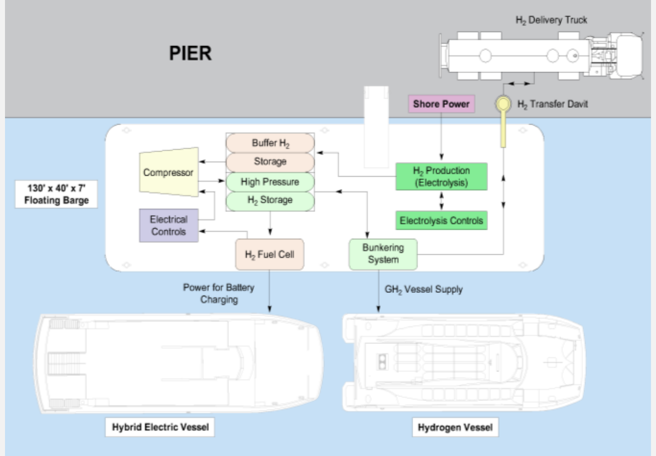
Examples of H2@Scale Demonstration Projects -2020

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

Marine Application

Total Budget $16M

Electrolyzer and fuel cell for marine application

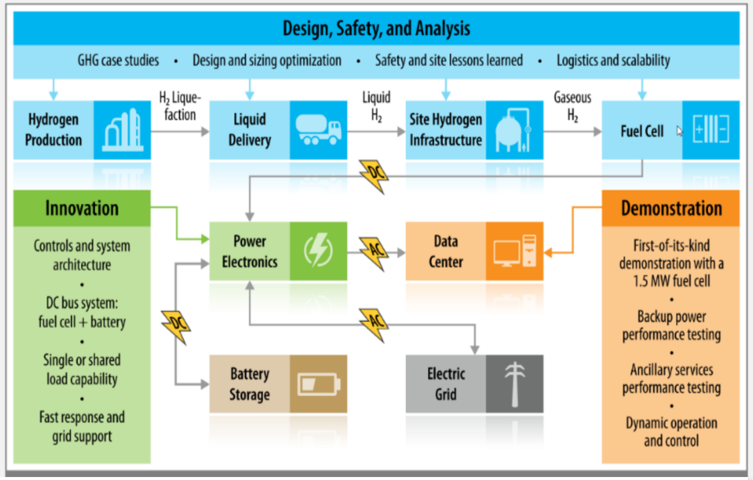


1st-of-its-kind maritime H_2 refueling on floating barge - up to 530 kg H_2 /day

H_2 for Data Center

Total Budget $13.7M

PEM fuel cell for data center power

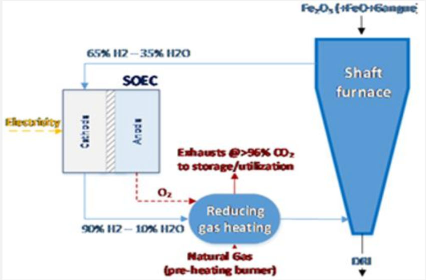


1.5MW fuel cell to meet data center requirements and future scale up

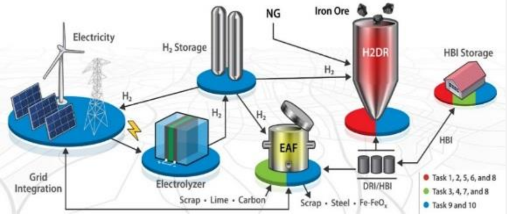
H_2 for Steel Production

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

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:

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

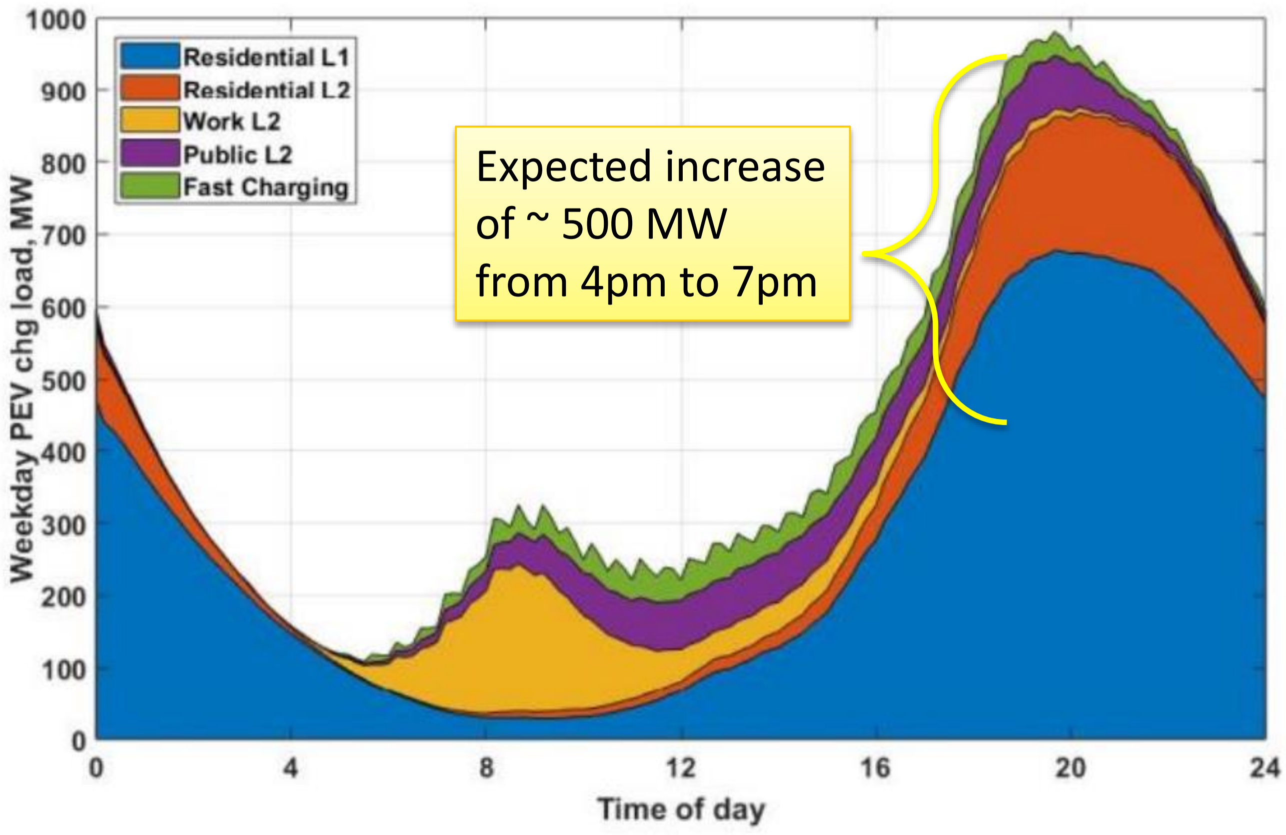
- **Industry and lab partners:** Southern California Gas Company, NREL and Electrochaea

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

H2@Scale activities include systems and grid integration

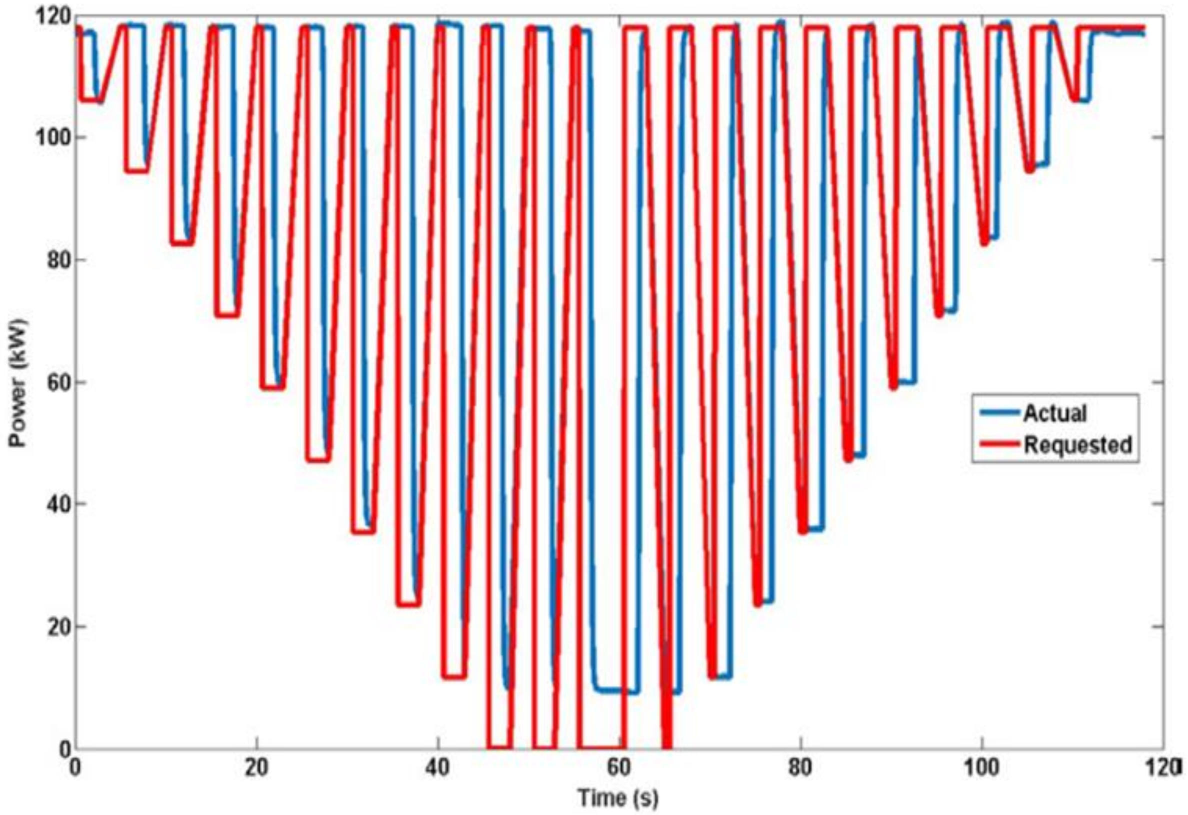
Flexibility will be needed to address grid challenges: high ramp rates and demand fluctuations

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

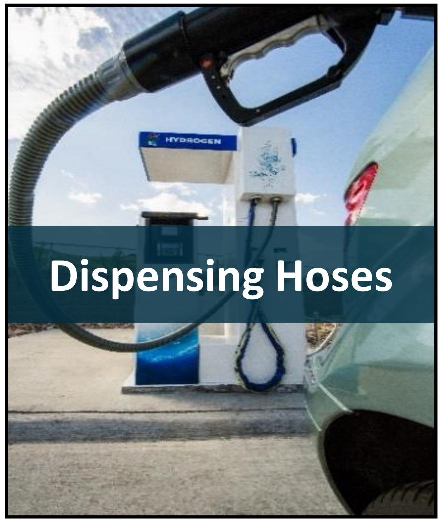


Idaho National Lab & National Renewable Energy Lab results. Direct fast charger impact project underway 2020-2021

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

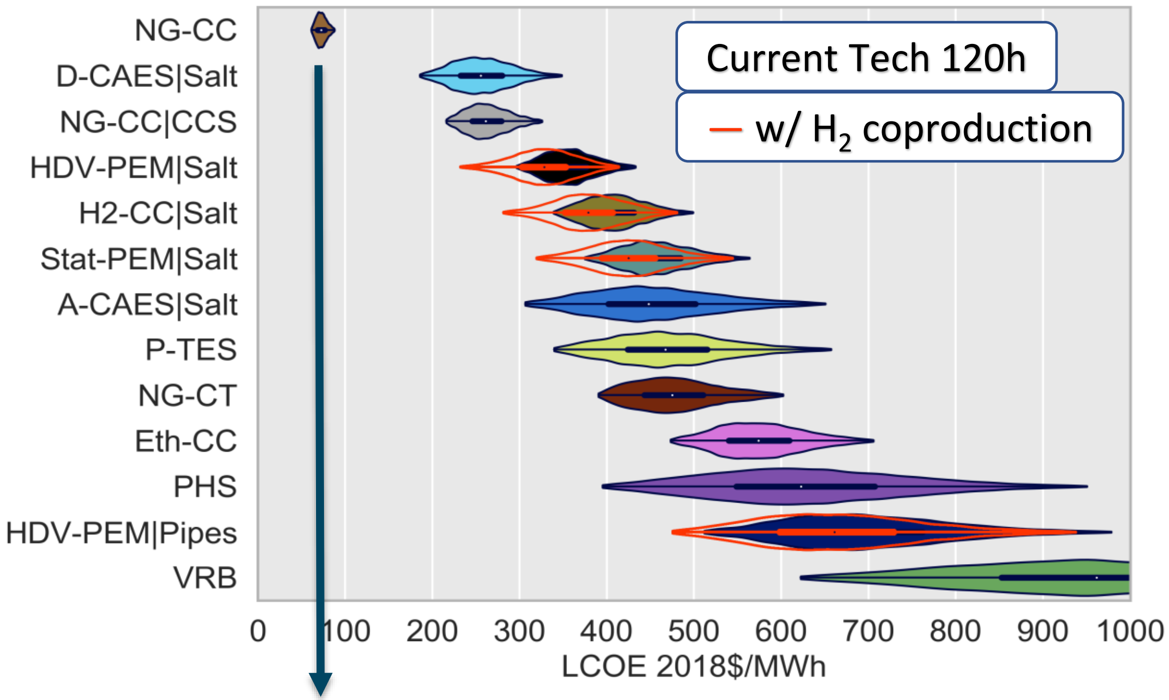
and can enable:

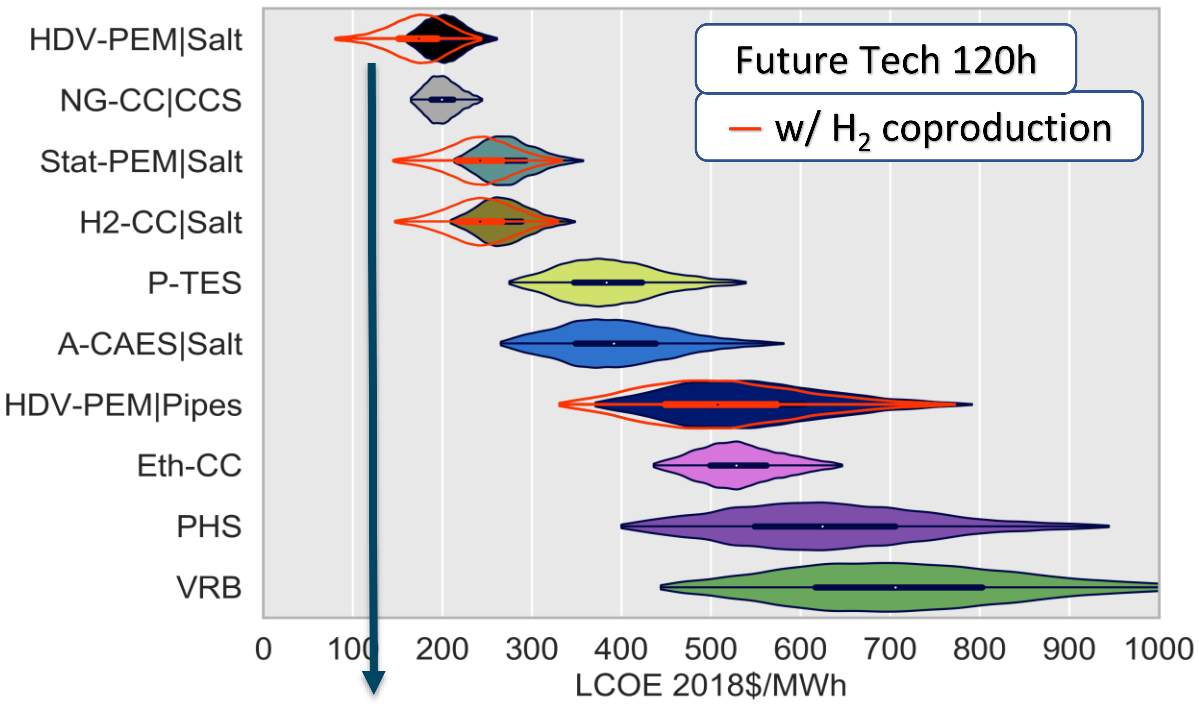
- Cross-sectoral emissions reductions
- Grid resiliency
- Terawatt hours of energy storage

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



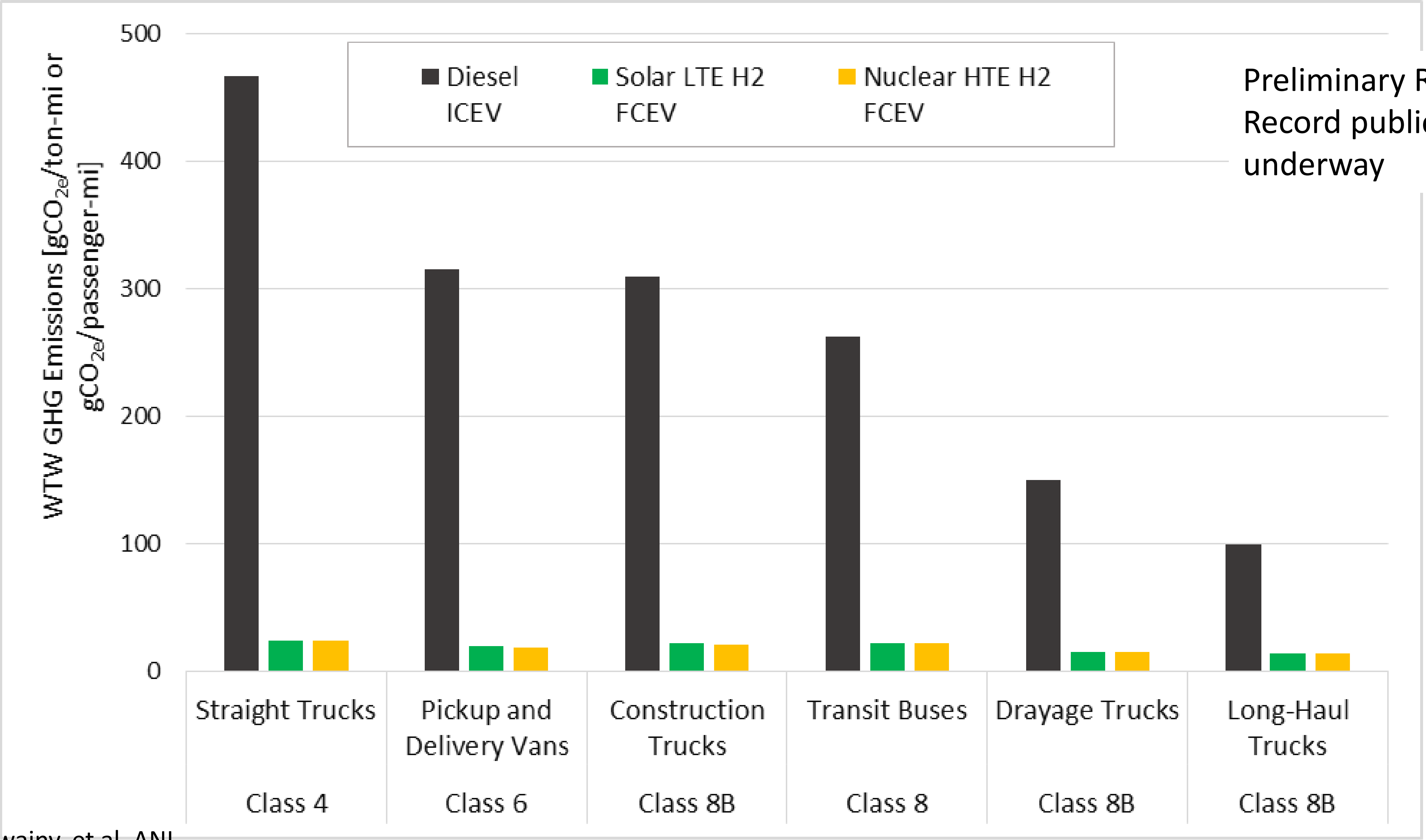


Natural gas combined cycle (NG-CC) is the lowest cost option today
Wide Range of Costs for Various Technologies $200 to >$1,000/MWh

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

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

IPHE

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

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

Formed 2003

19 Countries and EC

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

www.aiche.org/CHS

CENTER FOR Hydrogen SAFETY 水素安全センター

Connecting a Global Community

IPHE

Hydrogen Council

hySafe

AIChE

Pacific Northwest NATIONAL LABORATORY

Includes over 40 partners from industry, government and academia

CENTER FOR Hydrogen SAFETY

Connecting a Global Community

H2 HYDROGEN Safety Panel

H2 HYDROGEN Emergency Response Training Resources

Access to >110 countries, 60,000 members

Hydrogen Production Analysis Task Force (H2PA TF)

Addressing Priority from Industry and Governments

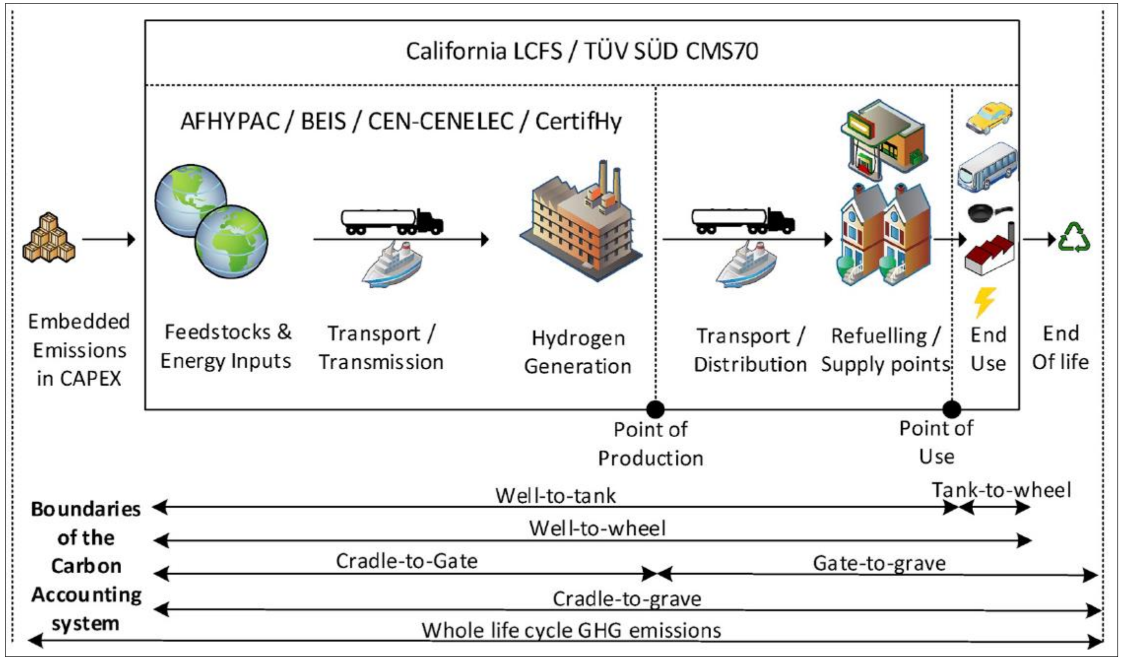
- Harmonize approach and develop framework to facilitate global trade of hydrogen

Scope

- Develop a mutually agreed upon analytical methodology for determining greenhouse gas (GHG) and other emissions associated with H2 production.

Next Steps and Engagement

- Continue to engage stakeholders, industry and experts to develop framework for methodology



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

Application of methodology will help facilitate market valuation and global trade in 'clean' hydrogen by recommending a common approach with adoption not mandatory and subject to each member's discretion and circumstance.

What can you do?

Get involved and help spread the word!

Follow @the_iphe

Introducing the 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

IPHE

#HydrogenNow

#FuelCellsNow

FOLLOW US

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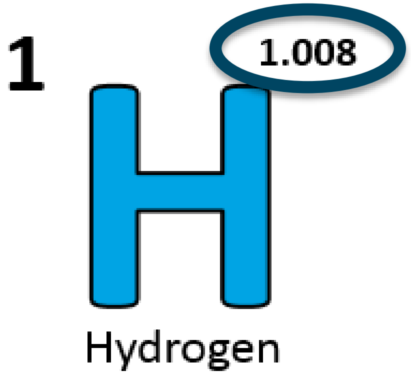
Resources and Events

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/

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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INCREASE YOUR H2IQ
www.hydrogen.energy.gov

Looking for more info?

#H2IQ

hydrogen.energy.gov