U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

DOE Hydrogen and Fuel Cell Perspectives and Overview of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

Dr. Sunita Satyapal, Director, U.S. Dept. of Energy Hydrogen and Fuel Cells Program

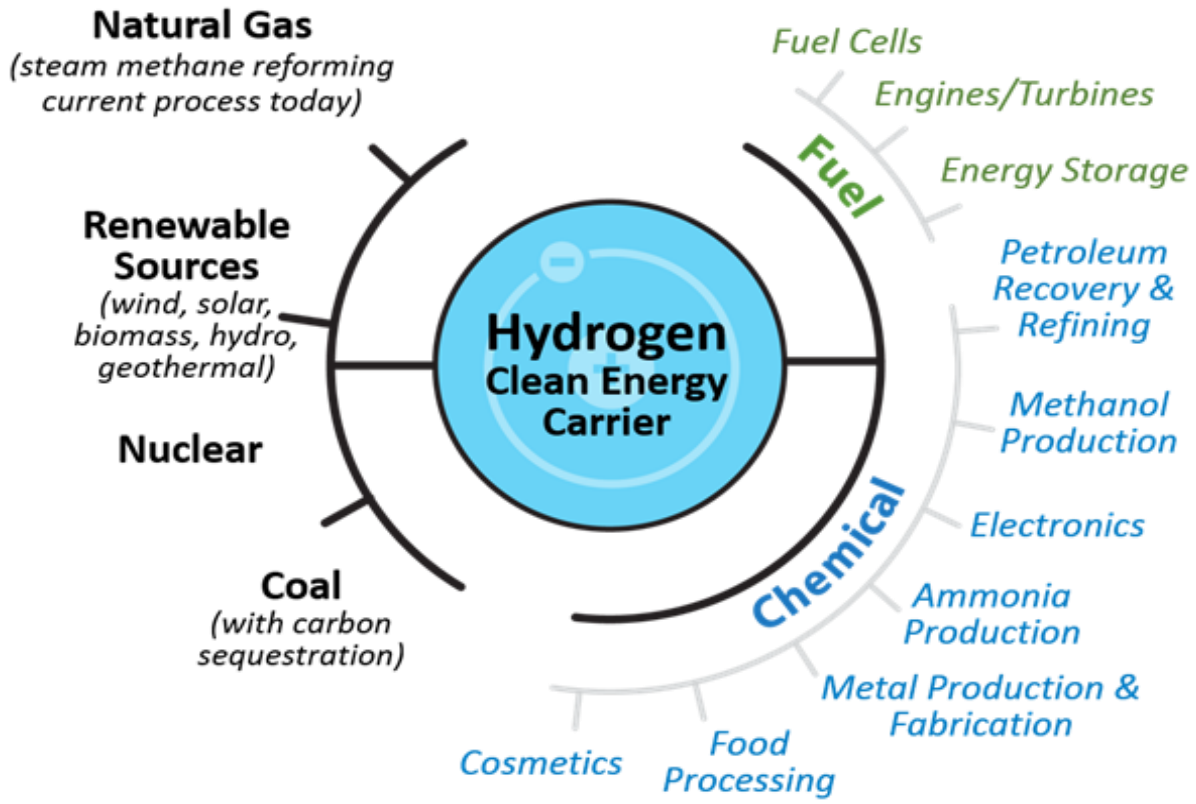
Global America Business Institute (GABI) Virtual Workshop

July 1, 2020

Hydrogen – Part of a Comprehensive Energy Strategy

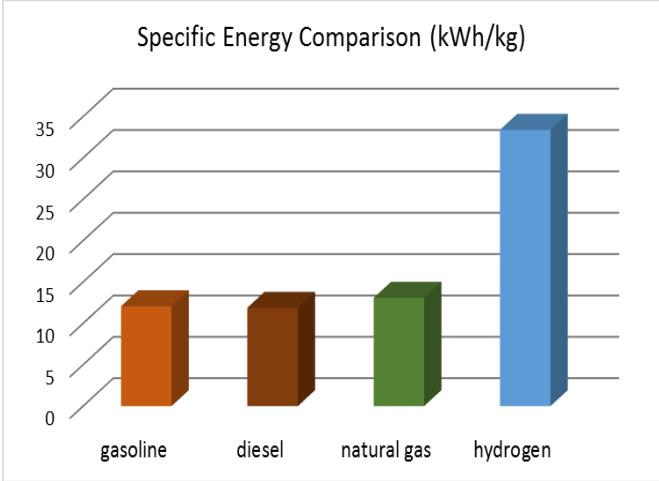
H_2 can be produced from diverse domestic sources

Many applications rely on or could benefit from H_2

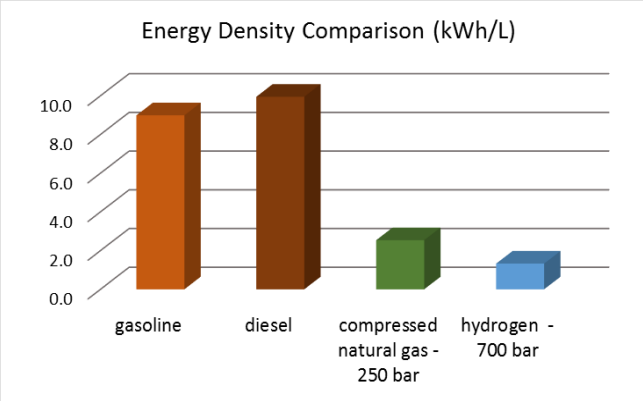


High energy content by mass

Nearly 3x more than conventional fuels



Low energy content by volume



Clean , sustainable, versatile, and efficient energy carrier

Guiding Legislation and Budget

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

- **$100M to $250M per year since ~2005**
- **>100 organizations & extensive collaborations including national lab-industry-university consortia**
- **Includes H_2 production, delivery, storage, fuel cells and cross cutting activities (e.g. codes, standards, tech acceleration)**

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

Hydrogen and Fuel Cell Technologies Office (HFTO) Subprograms	FY 2020 ($K)
Fuel Cell R&D	26,000
Hydrogen Fuel R&D	45,000
Hydrogen Infrastructure R&D	25,000
Technology Acceleration includes Systems Development & Integration	41,000
Safety, Codes, and Standards	10,000
Systems Analysis	3,000
Total	**$150,000**

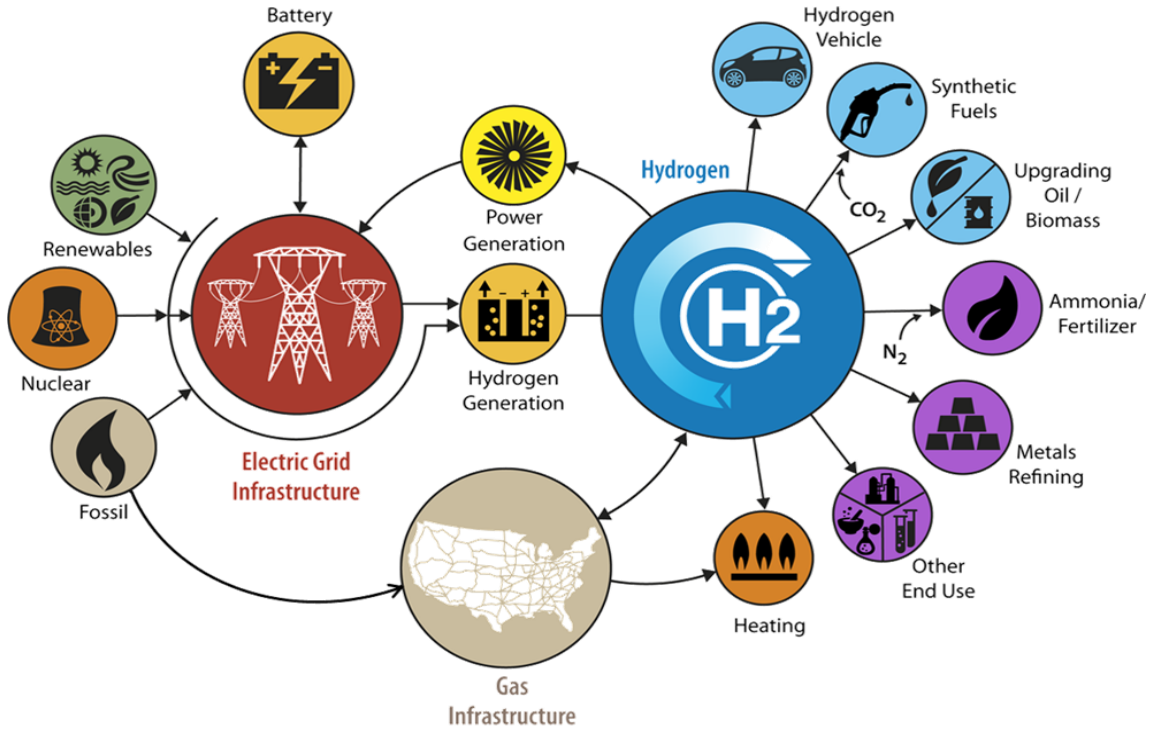
DOE Office	Appropriations ($K) FY20
EERE (HFTO) - Lead	$150,000
Fossil Energy (inc. SOFC)	$30,000
Nuclear Energy	$11,000*

- EERE: Energy Efficiency and Renewable Energy Office
- Collaboration with Office of Science, ARPA-E, Office of Electricity

* FY20 Appropriations for nuclear to H2 demonstration project with HFTO ($10M)

Key Programmatic Area: H2@Scale

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



And includes later stage RD&D:

Leverages private sector for large-scale demos

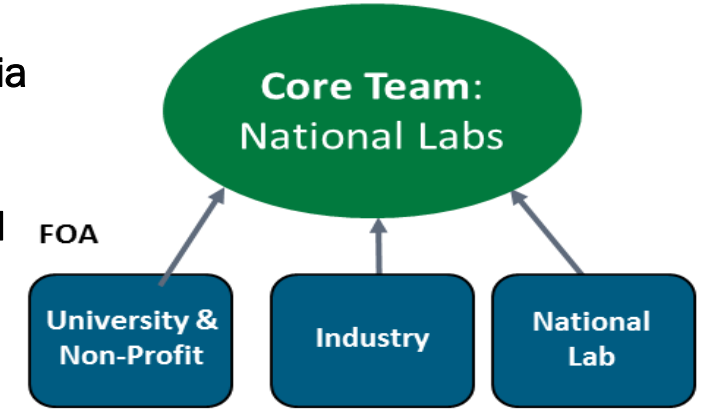
New H2@Scale demonstration projects announced

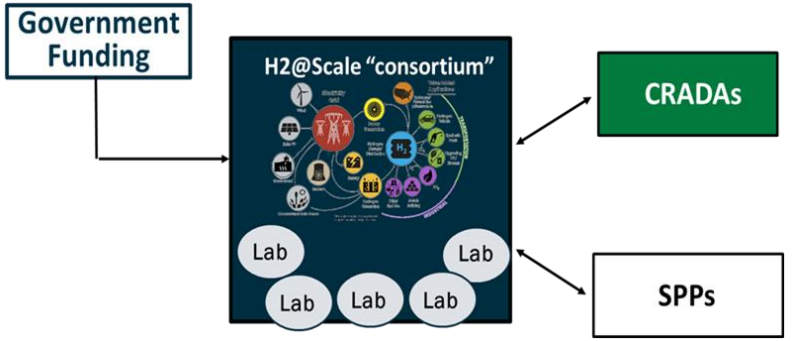
Texas, Florida, Midwest, complements California deployments

Includes Early stage R&D: Funding Opportunity Announcements (FOAs) for industry, universities and national labs, including consortia

2 New Lab Consortia Planned FY20:

- H2NEW
- Million Mile Fuel Cell Truck





CRADA = Cooperative Research and Development Agreement

SPP- Strategic Partnership Project ('Work for Others')

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

Examples of Applications

>500MW
Stationary Power

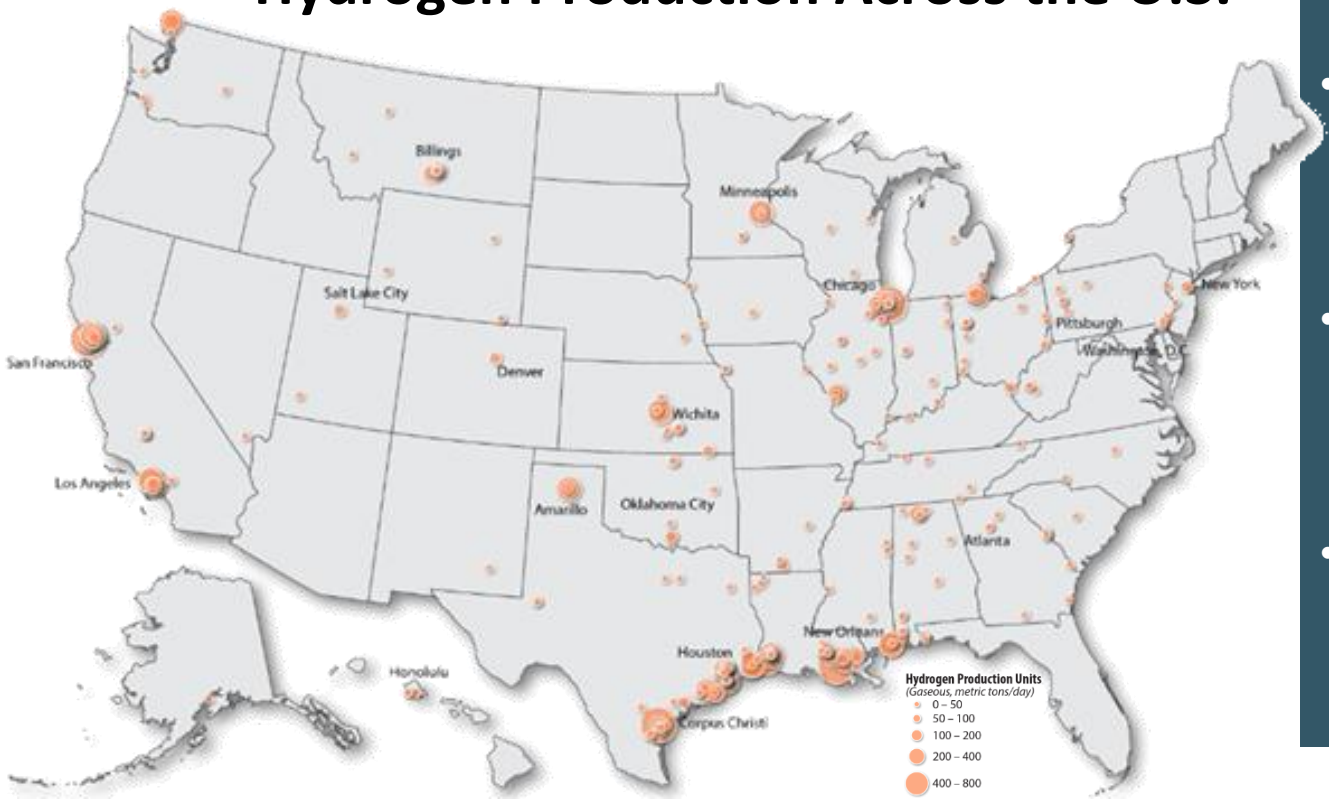
>33,000
Forklifts

>60
Fuel Cell Buses

>40
H_2 Retail Stations

>8,600
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

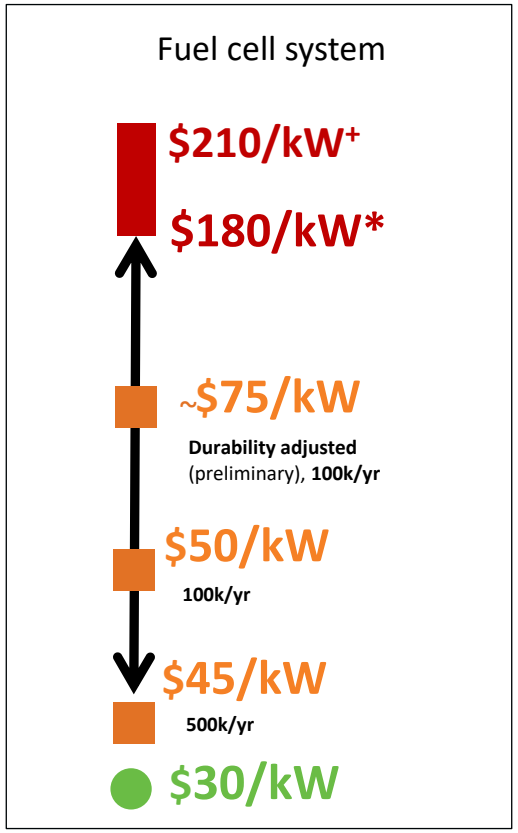
Northeast
12 – 20 stations planned

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

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

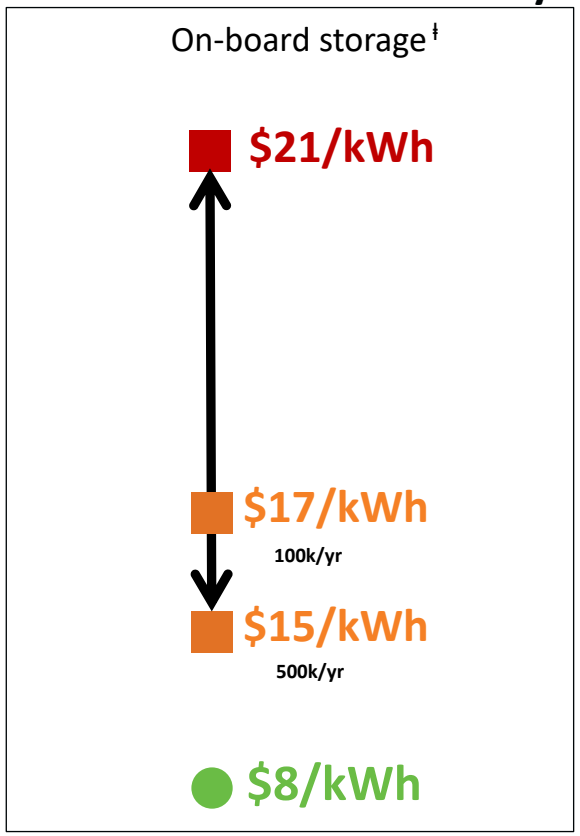
Key Goals: Reduce the cost of fuel cells and hydrogen production, delivery, storage, and meet performance and durability requirements – guided by applications specific targets

Fuel Cell R&D

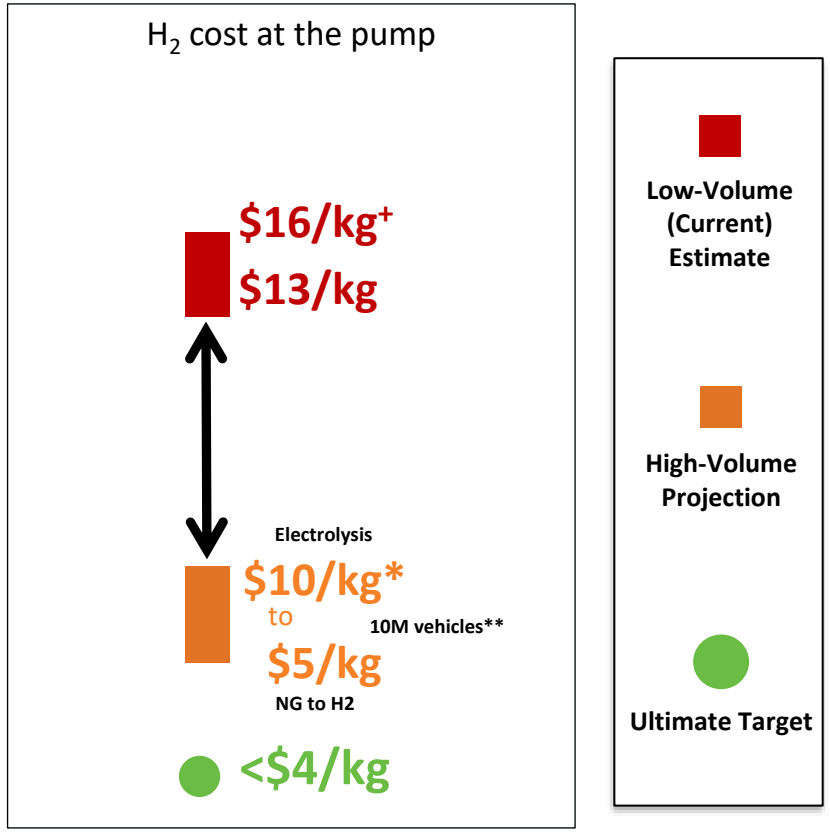


†Based on commercially available FCEVs
*Based on state of the art technology

Hydrogen R&D



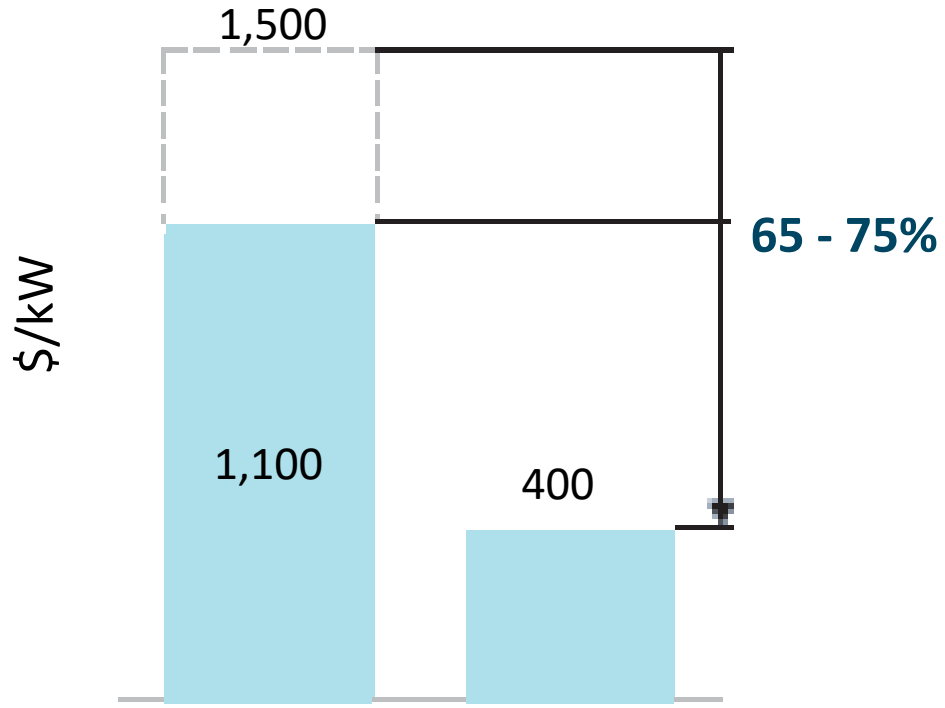
‡Storage costs based on preliminary 2019 storage cost record



†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

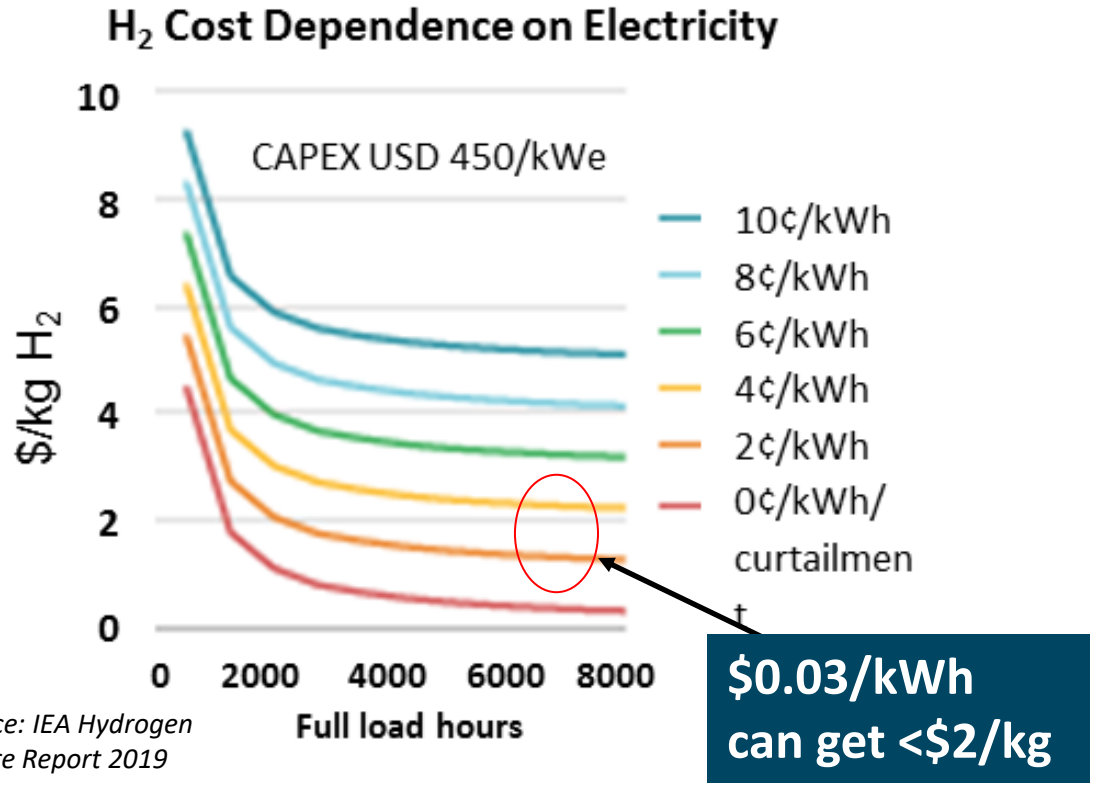
Electrolysis Cost Background – Recent Independent Analyses

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

Strategy

Near term: Focus on electrolyzer R&D to reduce cost, improve durability

Long term: Advanced options for H2 production (advanced water splitting)

Increased Activities on Hydrogen, Energy Storage, Hybrid Systems

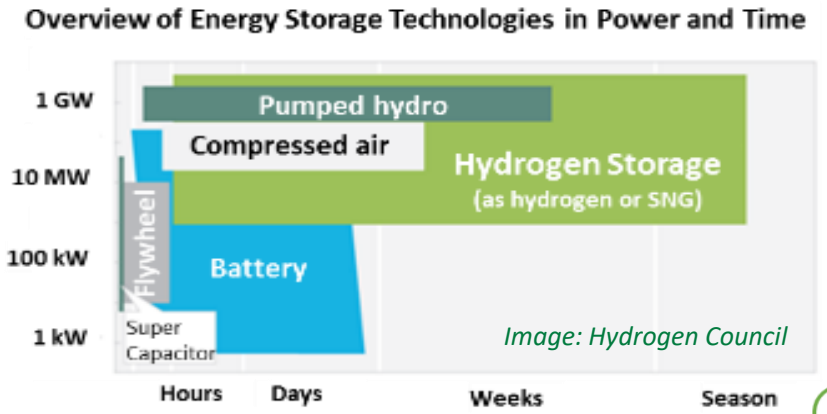
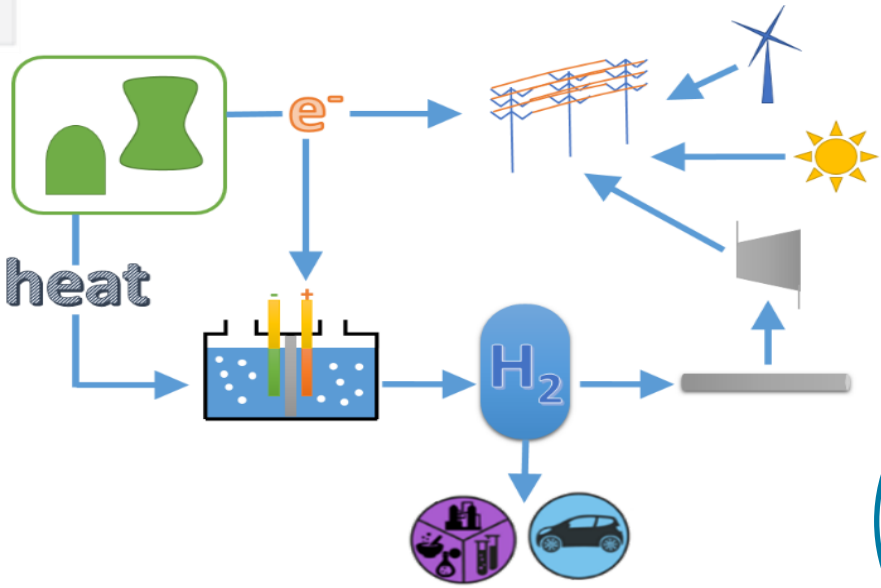


Image: Hydrogen Council

H_2 energy storage

Increased opportunities for nuclear and hydrogen

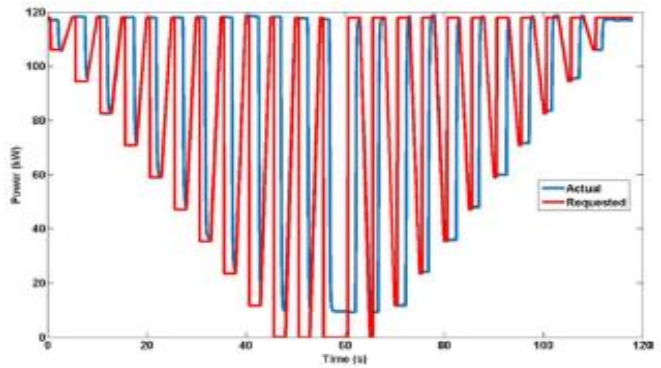


Multiple end use applications

25 kW high-temperature electrolysis @ INL Energy Systems Laboratory

Thermal Integration

Dynamic response



Dynamic electrolyzer response – INL & NREL

DOE Industry demos

Recently announced demonstrations

∗ Energy Harbor formerly known as FirstEnergy Solutions

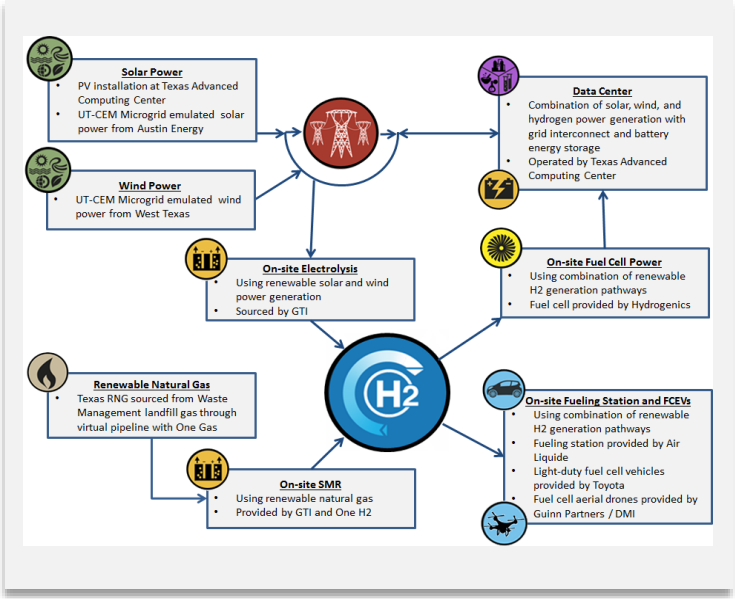
Example of H2@Scale Projects

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

Texas

Total Budget
$12.7M

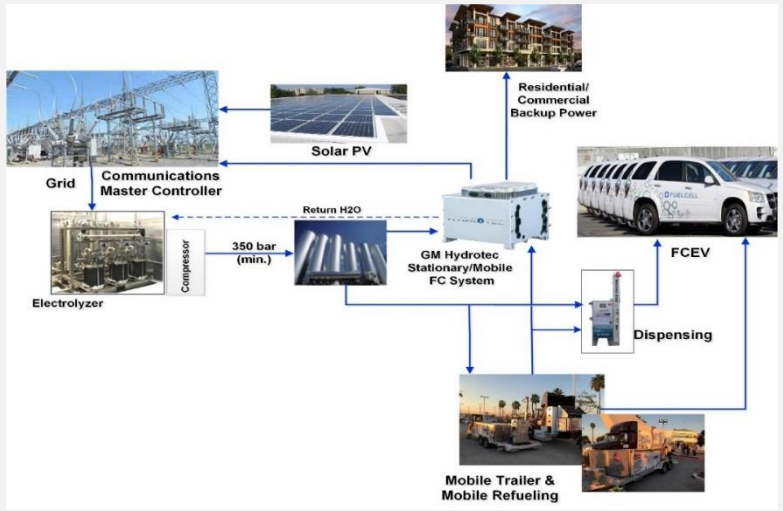
Wind, Solar, RNG/Waste



Florida

Total budget
$8.5M

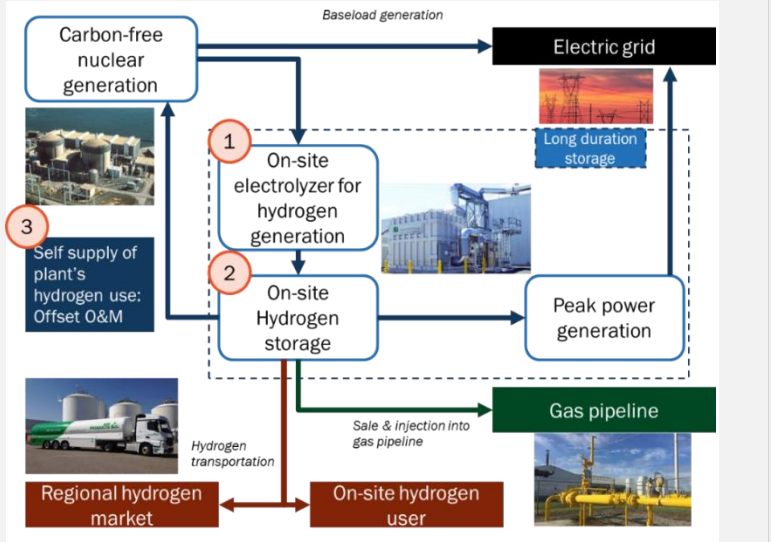
Solar-to-H2 with End Uses



Midwest/TBD

Total Budget
$7.2M

Nuclear To H2 For At-Plant Use



Note: Based on original submission. To be updated based on project finalization.

Two New Lab Consortia Just Announced at End of June

Department of Energy

DOE Announces New Lab Consortia to Advance Hydrogen and Fuel Cell R&D

JUNE 23, 2020

Home » DOE Announces New Lab Consortia to Advance Hydrogen and Fuel Cell R&D

WASHINGTON, D.C. – Today, the U.S. Department of Energy (DOE) announced the intention to invest up to $100 million over five years in two new DOE National Laboratory-led consortia to advance hydrogen and fuel cell technologies research and development (R&D). This funding is subject to appropriations.

Press Release
https://www.energy.gov/articles/doe-announces-new-lab-consortia-advance-hydrogen-and-fuel-cell-rd

1) R&D to achieve large-scale, affordable electrolyzers
- Can be powered by various energy sources, including natural gas, nuclear, and renewables
- Supports large industry deployment by enabling more durable, efficient, and low-cost electrolyzers

2) R&D to accelerate development of fuel cells for heavy-duty vehicle applications
- Includes long-haul trucks
- 5 year goal to develop fully competitive heavy-duty fuel cell truck that meets durability, cost, performance requirements of trucking industry.

Area	Total Funding Level	Anticipated # of Awards
Electrolyzer Manufacturing R&D	$15M	Up to 4
Advanced Carbon Fiber for Compressed Gas Storage Tanks	$15M	Up to 3
Fuel Cell R&D for Heavy-Duty Applications - Membranes for Heavy-Duty Applications	$4M	Up to 4
Fuel Cell R&D for Heavy-Duty Applications - Domestically Manufactured Fuel Cells for Heavy-Duty Applications	$6M	2 to 3
H2@Scale New Markets R&D-HySteel	$8M	1 to 2
H2@Scale New Markets Demonstrations - Maritime Demonstrations	$8M	1 to 2
H2@Scale New Markets Demonstrations - Data Center Demonstrations	$6M	1 to 2
Training and Workforce Development for Emerging Hydrogen Technologies	Up to $2M	1
Total:	**Up to $64M**	**Up to 21**


Collaboration

Announced February 2020: Industry and Government Collaboration Supporting American's Ingenuity and Enabling Technology Validation in Washington D.C.

The $1M H-Prize Challenge Incentivized Innovation in Community H_2 Fueling

The prize-winning SimpleFuel® team developed an electrolyzer-based appliance capable of refueling a 700 bar fuel cell vehicle at a rate of 1 kg-H_2 in less than 15 minutes

U.S. Department of Energy Joins Industry to Collaborate on Transportation Technology Validation and Assessment

FEBRUARY 10, 2020

Home » U.S. Department of Energy Joins Industry to Collaborate on Transportation Technology Validation and Assessment

Hyundai Motor Group Executive Vice Chairman Euisun Chung (left) and Under Secretary of Energy Mark W. Menezes (right)

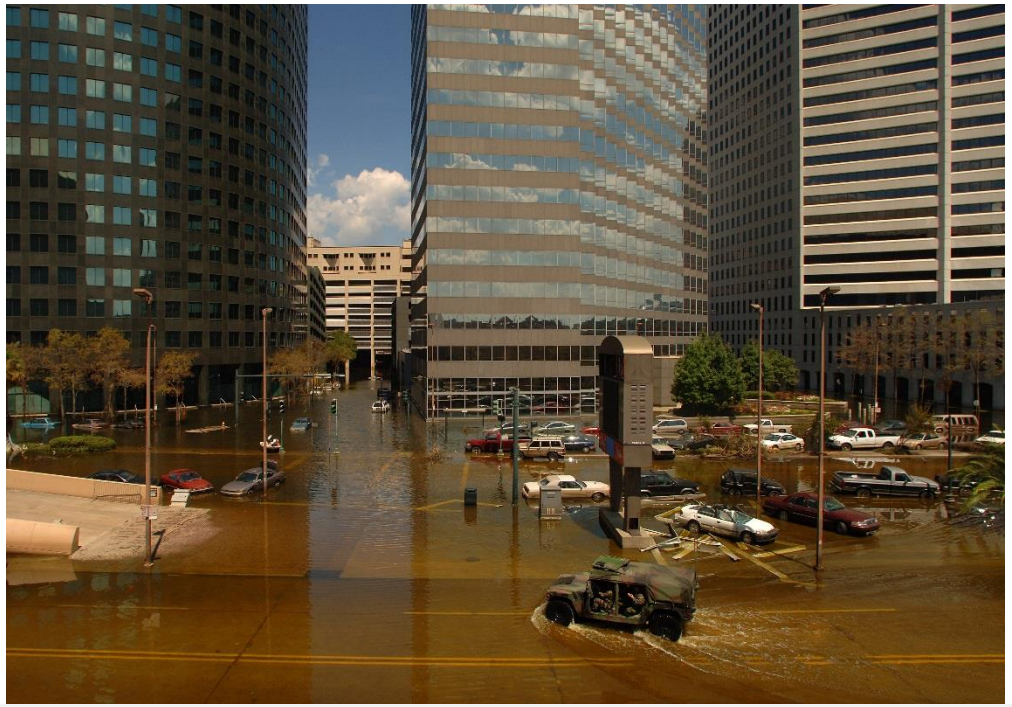
DOE, Hyundai and SimpleFuel collaboration will include:

- Data collection and validation on **five Hyundai Nexo fuel cell cars**
- Installation of **SimpleFuel unit to support refueling and identify infrastructure R&D gaps**

Interagency Collaboration to Enable Technology in Emergency Relief – Selection to Be Announced Later This Summer

U.S. Department of Energy and U.S. Army Issue Solicitation to Develop H2Rescue

FEBRUARY 3, 2020



Press Release
https://www.energy.gov/eere/fuelcells/articles/us-department-energy-and-us-army-issue-solicitation-develop-h2rescue

Opportunity Number and Due Date to Apply to Solicitation
W81EWF20FOA0001 - March 31, 2020

- Example of **interagency collaboration** (DoD and DOE)
- **Up to $1M** (requires equal match of industry contributions)
- Truck to **run on fuel cell/battery and hydrogen** and provide **power, heat and potable water**

International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

Formed in 2003

Elected Chair and Vice-Chair
2018

Chair Elect
2020

Past Chairs

Global Government Partnership to Accelerate Progress on Hydrogen and Fuel Cells

Enabling the adoption of hydrogen and fuel cells in the economy

- **Coordinates and shares information** among members and global and regional partnerships
- **Develops country updates** on initiatives, policies, status, shares best practices
- **Working Groups on** Regulations, Codes, Standards & Safety; Education & Outreach
- **Task Force on H_2 Production Analysis** methodology to facilitate international trade

❖ Coordinates with other partnerships including IEA, Hydrogen and Clean Energy Ministerials, Mission Innovation, Hydrogen Council, and others

Top Priorities	SHARE INFORMATION	INFORM FUTURE GOVERNMENT RD&D	FOSTER COLLABORATION

19 Countries and EC

www.iphe.net

Find IPHE on Facebook, Twitter and LinkedIn

Follow IPHE @The_IPHE

The International Partnership for Hydrogen and Fuel Cells in the Economy

Enabling the global adoption of hydrogen and fuel cells

19 Countries & European Commission

Canada
- 9 Fueling Stations
- 17 FC Vehicles
- >400 Forklifts

United States
- 500 MW Stationary Power
- >45 Fueling Stations + >8,400 FC Vehicles
- >33,000 Forklifts

Costa Rica
- 1 Bus
- 1 Fueling Station

Netherlands
- 7 Fueling Stations
- 162 FC Vehicles
- 1 MW Electrolyzer

United Kingdom
- 16 Fueling Stations
- 100 FC Vehicles
- 20 Buses

France
- 25 Fueling Stations
- 324 FC Vehicles
- 180 Forklifts

Germany
- 76 Fueling Stations
- 530 FC Vehicles
- 100 Forklifts

Japan
- 107 Fueling Stations
- 3,433 FC Vehicles
- 160 Forklifts

South Korea
- 34 Fueling Stations
- 5,068 FC Vehicles
- 15 Buses

China
- 35 Fueling Stations
- 2,800 Buses
- 1,200 Delivery Trucks

Brazil
- 11 Fueling Stations Under Construction
- 4 Buses
- 1 Hybrid FC Bus

South Africa
- 3 Scooters + Fueling Station
- 1 Forklift + Fueling Station
- 310 Stationary Fuel Cells

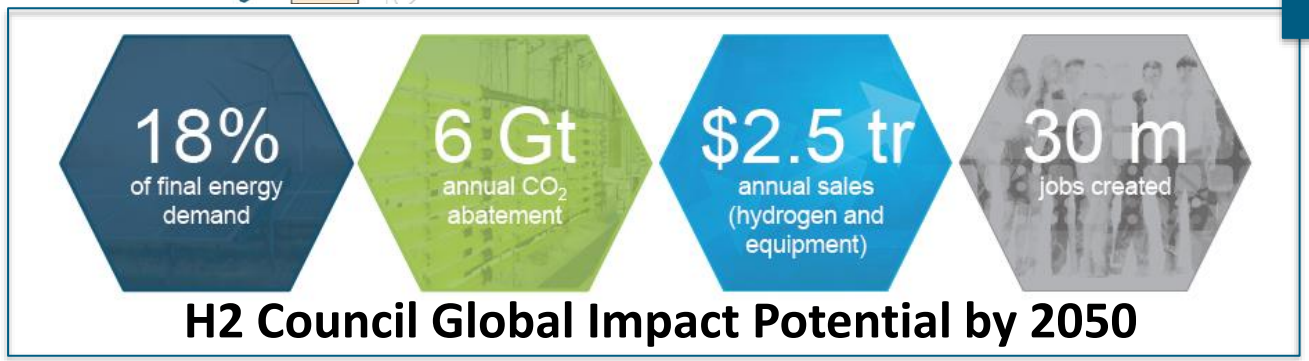
Around the world, there are over:

- 1/3 Million Stationary Fuel Cells
- 400 Fueling Stations
- 15,000 Fuel Cell Electric Vehicles
- 1 GW of Fuel Cells Shipped

Source: IPHE compiled through country updates and independent references and estimates.

Roadmaps and Plans Developing Globally

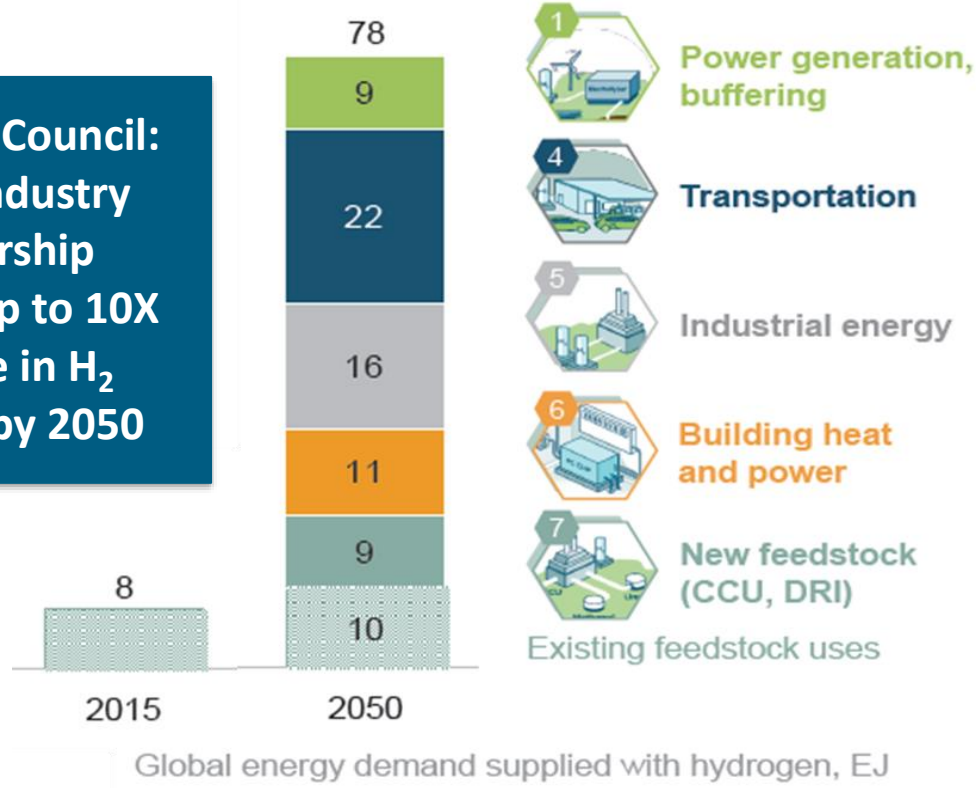
Drivers include: Energy security, energy efficiency & resiliency, economic growth, innovation & technology leadership, and environmental benefits



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



What can you do?
Get involved and help spread the word!

www.iphe.net

Follow @the_iphe

Example: Global Center for Hydrogen Safety Launched 2019

Promotes safe operation, handling and use of hydrogen across all applications.
Provides training and resources, includes industry, government, access to 110 countries

IPHE Hydrogen Council

AIChE

Pacific Northwest NATIONAL LABORATORY

Includes over 40 partners from industry, government and academia

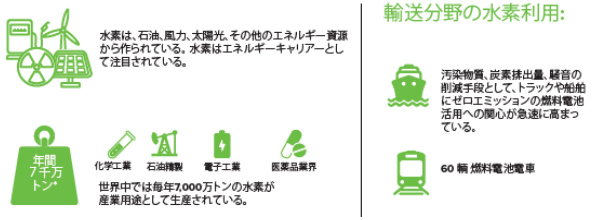
CENTER FOR Hydrogen SAFETY
Connecting a Global Community

HYDROGEN Safety Panel

HYDROGEN Emergency Response Training Resources

Access to >110 countries, 60,000 members

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



Language translations underway

www.aiche.org/CHS

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

Submit your entry by July 31
to **media@iphe.net**
Learn more **IPHE.net/challenge**

Two Chances to Submit

- Entries due **July 31, 2020 -** winners announced in late September
- **Entries due October 8, 2020** - winners announced in late November

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

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

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

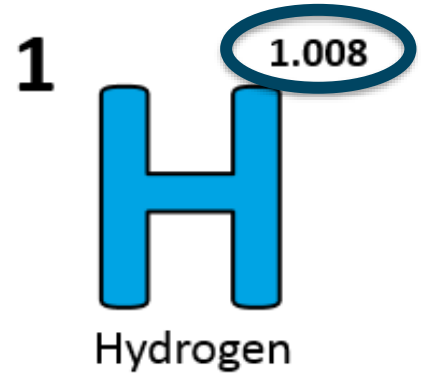
Resources and Announcements

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 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

Dr. Sunita Satyapal
Director, DOE Hydrogen and Fuel Cells Program
Sunita.Satyapal@ee.doe.gov

Looking for more info?

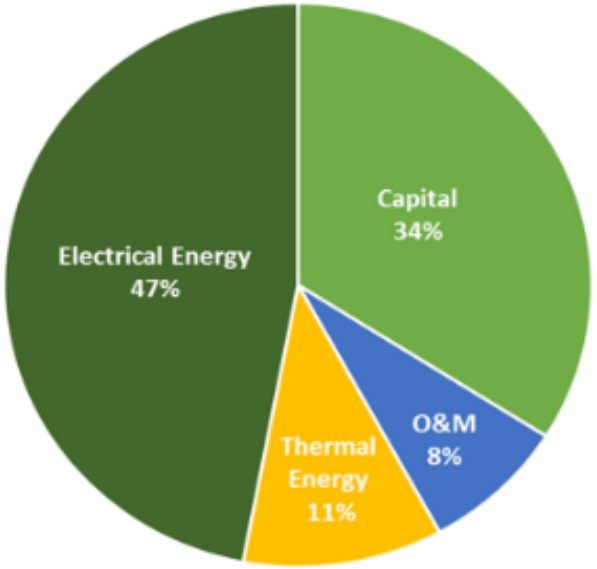
#H2IQ

hydrogen.energy.gov

Additional Information

Identifying Hydrogen Cost Drivers is Key

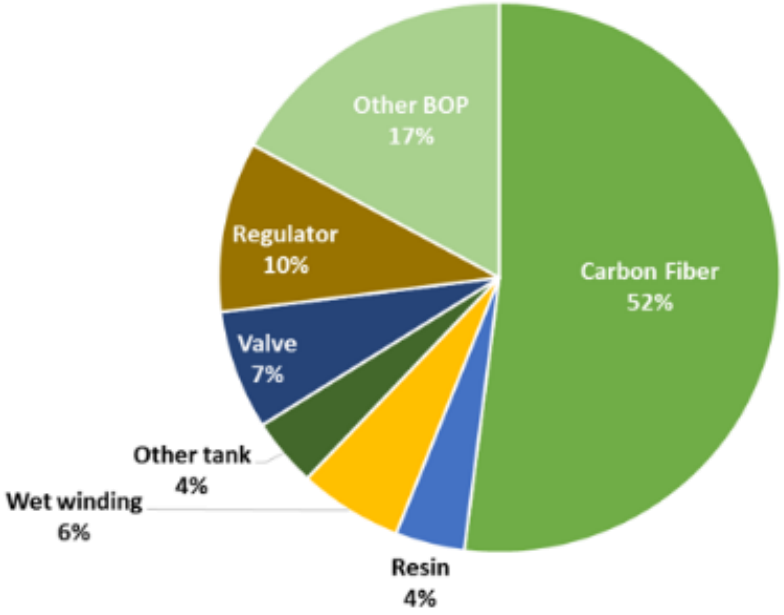
Hydrogen Production Cost
(High Temperature Electrolysis)



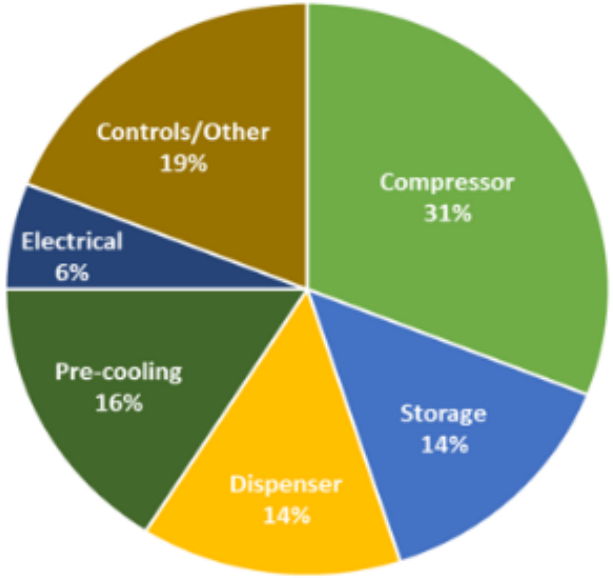
H_2 Production (Electrolysis) Cost Drivers: **Electrical energy and capital costs**

H_2 Onboard Storage Cost Drivers:
Carbon Fiber Precursors and Processing

Hydrogen Storage Cost
(Onboard 700 Bar Hydrogen Storage Vessel)



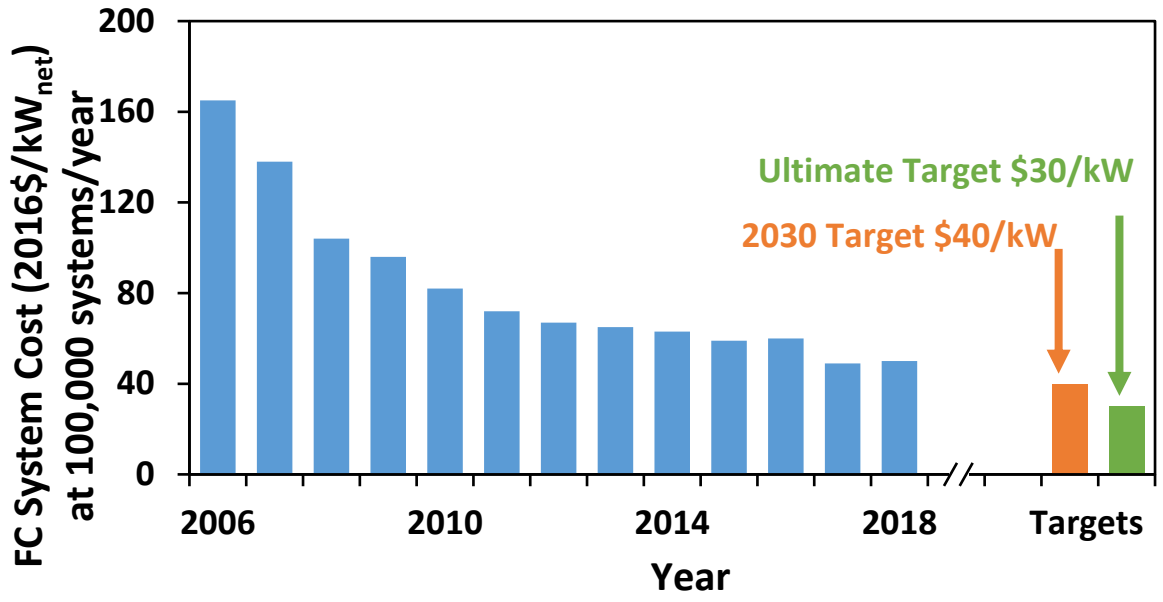
Hydrogen Infrastructure Cost
(700 Bar Hydrogen Station)

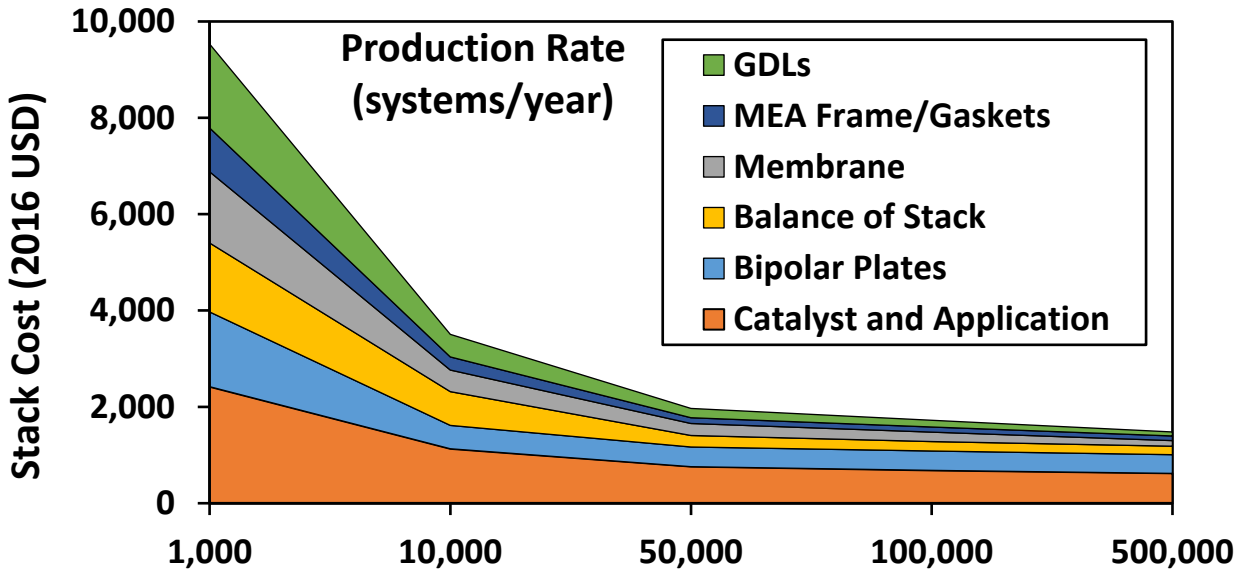


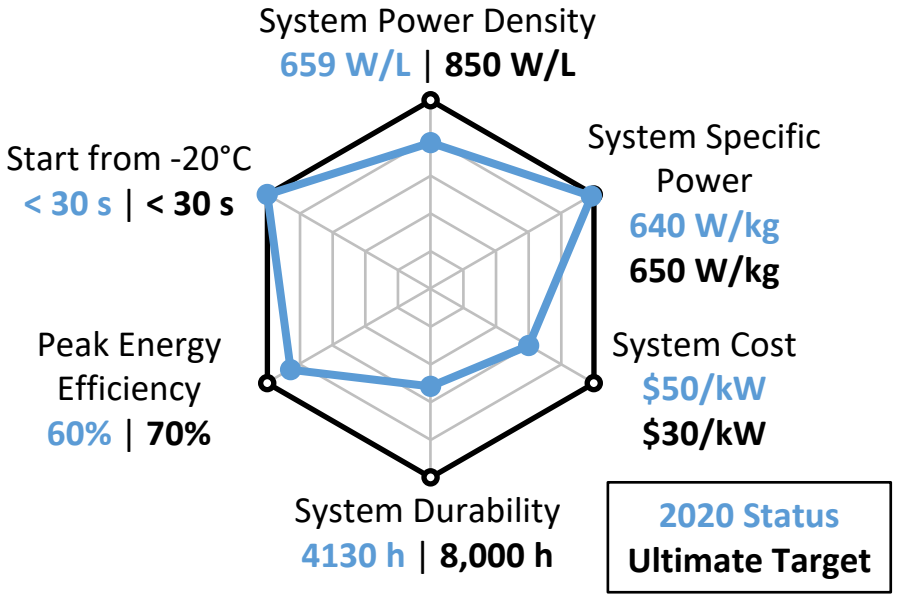
H_2 Infrastructure Cost Drivers:
Compressors and Storage

Note: Updates to be published May, 2020

Fuel Cell Status vs Targets





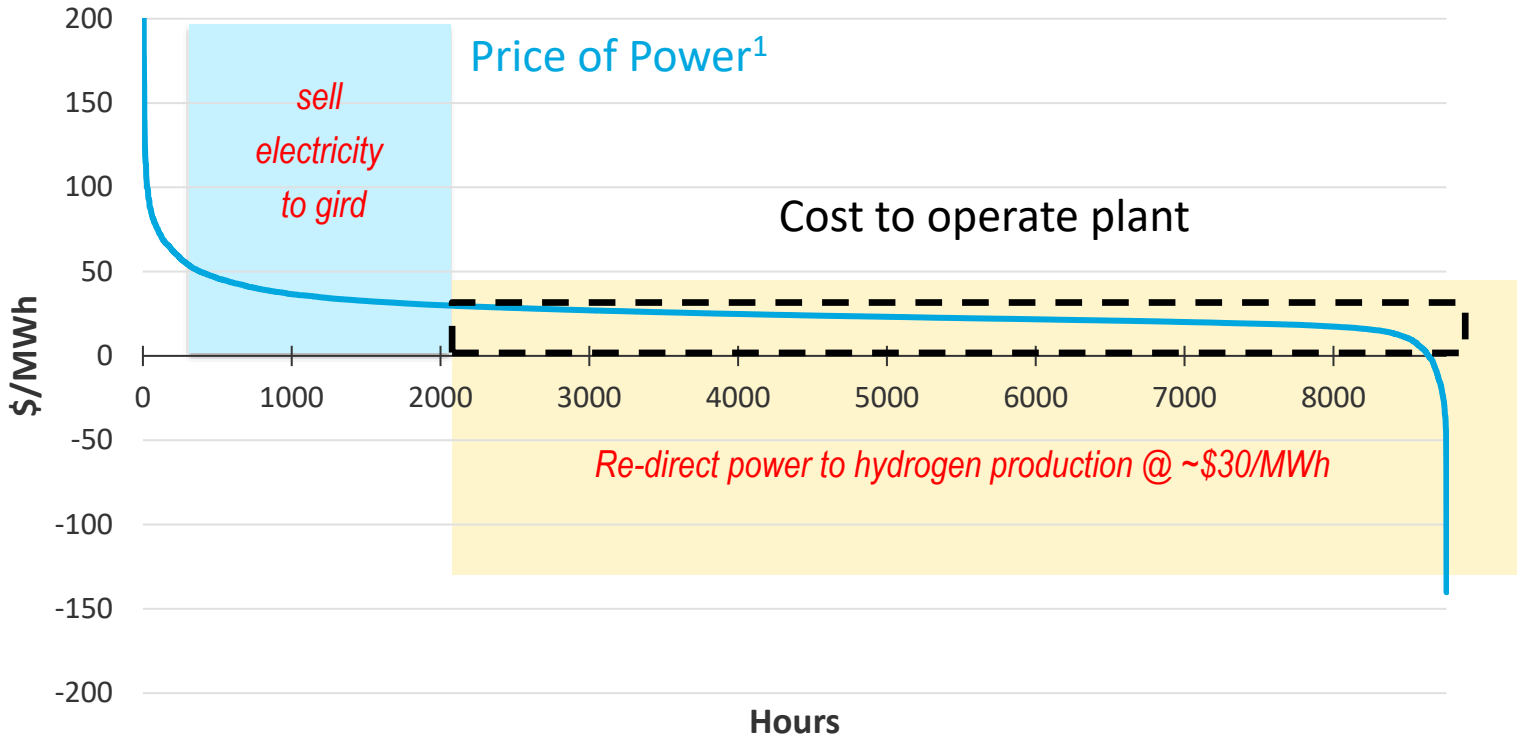


Program shifting to heavy duty vehicles:

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

Value Proposition for Nuclear Hybrid Systems

Low-cost electricity creates an opportunity to co-produce hydrogen. Direct power to hydrogen production creates a value stream for nuclear plants to supplement revenue from power generation.



The challenge in some regions:

Localized marginal price of electricity **<** Cost to generate electricity at nuclear plant

Up to 80% of the year, electricity price is lower than cost to operate nuclear

Sources:
1. 2017 data from PJM-NI Hub; R. Boardman, et. al. INL