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

Transport shows largest growth: includes buses, trucks, cars, rail, forklifts, etc.

Source: E4tech for DOE analysis project
Examples of Electrolyzer Deployments and Plans... by 2025

Increasing number of regions worldwide
Increasing in size

- 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, Engie)
- 100 MW Germany (Thyssengas, TenneT, Gasunie Deutschland)
- 100 MW Germany (Amprion, OGE)
- 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 H₂ 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 H₂ fueling stations worldwide
> 20% increase from 2018


European Commission
€750B economic recovery package, Green Deal; stimulus includes H₂ technologies

Germany
€9B for H₂, with €2B for international partnerships

Norway
€3.6B recovery package includes offshore wind to H₂, focus on maritime sector

France
€7.2B for H₂ and plans for 6.5 GW green H₂ 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 H₂ demand by 2050

18% of final energy demand
6 Gt annual CO₂ abatement
$2.5 tr annual sales (hydrogen and equipment)
30 m jobs created

H₂ Council Global Impact Potential by 2050

<table>
<thead>
<tr>
<th>Category</th>
<th>2015</th>
<th>2050</th>
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</thead>
<tbody>
<tr>
<td>Power generation, buffering</td>
<td>78</td>
<td>9</td>
</tr>
<tr>
<td>Transportation</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Industrial energy</td>
<td>16</td>
<td></td>
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<tr>
<td>Building heat and power</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>New feedstock (CCU, DRI)</td>
<td>10</td>
<td></td>
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<tr>
<td>Existing feedstock uses</td>
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Global Energy Related Carbon Emissions by Sector


Sectors today with no economically scalable option for deep emission reductions
U.S. Emissions by Sector

- **Electricity**: 28%
- **Industry**: 22%
- **Transportation**: 29%
- **Commercial & Residential**: 12%
- **Agriculture**: 9%

*Source: United States Environment Protection Agency*
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

• 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 H₂ 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 H₂ and fuel cell systems across applications
## Budget and Focus Areas in EERE H₂ and Fuel Cell Technologies Office

<table>
<thead>
<tr>
<th>EERE HFTO Activities</th>
<th>FY 2020 ($K)</th>
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<tbody>
<tr>
<td>Fuel Cell R&amp;D</td>
<td>26,000</td>
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<tr>
<td>Hydrogen Fuel R&amp;D</td>
<td>45,000</td>
</tr>
<tr>
<td>Hydrogen Infrastructure R&amp;D (included in Hydrogen Fuel in FY21)</td>
<td>25,000</td>
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<tr>
<td>Systems Development &amp; Integration (Technology Acceleration)</td>
<td>41,000</td>
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<tr>
<td>Safety, Codes, and Standards (included in Systems Development &amp; Integration in FY21)</td>
<td>10,000</td>
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<tr>
<td>Data, Modeling and Analysis</td>
<td>3,000</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$150,000</strong></td>
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### Hydrogen and Fuel Cells Breakdown FY 2020

- **Fuel Cell R&D**: $26M
- **Hydrogen Fuel R&D**: $45M
- **Hydrogen Infrastructure R&D**: $25M
- **Technology Acceleration**: $41M
- **Safety, Codes & Standards**: $10M

### Focus Areas
- **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

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

**Note:** Office of Fossil Energy covers fossil fuels to H₂
**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**
  - H₂ 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 H₂ pipeline**
- **World’s largest H₂ 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 Units**
- Gaseous Metric Tons/Day
  - 0 – 50
  - 50 – 100
  - 100 – 200
  - 200 – 400
  - 400 – 800

- 10 million metric tons produced annually
- More than 1,600 miles of H₂ pipeline
- World’s largest H₂ storage cavern
Key Programmatic Area: H2@Scale

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

Today: 10MMT H₂
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

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

- Coal Gasification with CCUS
- Biomass Conversion
- Waste to Energy
- Direct-Solar
- High Temp. Electrolysis
- Low Temp. Electrolysis
- Natural Gas Conversion with CCUS
- SMR
- PEC

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14
Key Programmatic Areas

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

And includes later stage RD&D: Leverages private sector for large-scale demonstrations and cost-shared RD&D. Demos in TX, FL, Midwest, CA and more

Core Team: National Labs
- University & Non-Profit
- Industry
- National Lab

2 New Lab Consortia
Just Announced:
H2NEW and Million Mile Fuel Cell Truck Consortium

Government Funding

H2@Scale "consortium"
H2@Scale Consortium
CRADAs

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

Expected increase of ~ 500 MW from 4pm to 7pm

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.

$2/kg H₂ is achievable at about $0.03/kWh electricity cost and high utilization.

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

$0.03/kWh can get <$2/kg.
Cross-cutting Materials Compatibility R&D

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

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


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)
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 + coproduction of H₂ 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
## 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-H₂ with End Uses**

### Site selection in process
- **Total Budget**: $7.2M
- **Nuclear-to-H₂ for at-Plant Use**

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### Example of H2@Scale Demonstration Projects

![Diagram](image-url)
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 H₂ refueling infrastructure for up to 530 kg H₂/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 H₂/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)

- Utilizes H₂ + CO₂ to generate pipeline quality natural gas (> 97% CH₄)

- Biocatalyst used in the process - Methanothermobacter thermautotrophicus

Biomethanation Process:

\[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \]

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

Press Release

Located at NREL, Golden, CO

- 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
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

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**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

Key Activities: Harmonization of codes & standards, Information sharing on safety, policies, regulations, analysis, education.
Task force on developing H₂ production analysis methodology to facilitate international trade, global RD&D monitoring

www.aiche.org/CHS
Online conference Sept 15-17
What can you do?

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


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

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

Submit your entry by Oct. 8 to media@iphe.net
Learn more IPHE.net/challenge

2020 IPHE Fellow
Theodore Onchan 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
- Synthesis of novel metal electrode materials cathode catalysts
- Polymer electrolyte membranes fuel cell electronic optimization
- Novel membranes for polymer electrolyte membranes fuel cell application
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

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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