Fuel Cell Technologies Office Update

Dr. Sunita Satyapal, Director, Fuel Cell Technologies Office

Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) Meeting

December 12, 2018 – Washington DC
Overview

• HTAC Scope
  – Membership
  – Energy Policy Act (EPACT) 2005 Title VIII

• Program History and Updates
  – H2@Scale
  – Budget and Progress

• Next Steps
  • Examples of outputs and recommendations
# 2018 HTAC Membership

<table>
<thead>
<tr>
<th>HTAC Member and Affiliation</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aszklar, Henry</td>
<td>Energy Project Development &amp; Financing</td>
</tr>
<tr>
<td>Ayers, Katherine</td>
<td>Hydrogen Production Companies</td>
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<tr>
<td>Azevedo, Inês</td>
<td>Behavioral/ Decision-Making Science</td>
</tr>
<tr>
<td>Ffolkes, Marie</td>
<td>Hydrogen Production and Delivery</td>
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<tr>
<td>Freese, Charles F. (Chair)</td>
<td>Automotive Companies</td>
</tr>
<tr>
<td>Irvin, Nick</td>
<td>Utilities/Advanced Energy Systems R&amp;D</td>
</tr>
<tr>
<td>Koyama, Harol</td>
<td>Stationary Power and Markets</td>
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<tr>
<td>Leggett, Paul</td>
<td>Venture Capital / Investment</td>
</tr>
<tr>
<td>Leo, Anthony</td>
<td>Stationary Fuel Cell and Hydrogen Production Technology Manufacturing</td>
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</table>

New members as of July 2018

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<thead>
<tr>
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<th>Expertise</th>
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<tbody>
<tr>
<td>Markowitz, Morry</td>
<td>Hydrogen and Fuel Cells Industry Association</td>
</tr>
<tr>
<td>Marsh, Andrew</td>
<td>Stationary and Transportation Fuel Cell Technology Manufacturing</td>
</tr>
<tr>
<td>Mizroch, John</td>
<td>Clean Energy Technology Exports and Investments</td>
</tr>
<tr>
<td>Novachek, Frank</td>
<td>Hydrogen Production R&amp;D</td>
</tr>
<tr>
<td>Nocera, Daniel</td>
<td>Utilities (Electricity and Natural Gas)</td>
</tr>
<tr>
<td>Powell, Joseph (Vice Chair)</td>
<td>Fuels Production and R&amp;D</td>
</tr>
<tr>
<td>Rogers, Paul</td>
<td>Department of Defense Hydrogen and Fuel Cell R&amp;D</td>
</tr>
<tr>
<td>Scott, Janea</td>
<td>State Energy Policies and Regulations</td>
</tr>
<tr>
<td>Thompson, Levi</td>
<td>Physical Sciences</td>
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</table>

U.S. DEPARTMENT OF ENERGY  OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY  FUEL CELL TECHNOLOGIES OFFICE
Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) Scope

To advise the Secretary of Energy on:

1. The implementation of programs and activities under Title VIII of EPACT

2. The safety, economical, and environmental consequences of technologies to produce, distribute, deliver, store or use hydrogen energy and fuel cells

3. The DOE Hydrogen & Fuel Cells Program Plan
Title VIII Sec. 802- Purposes

1. Enable and promote comprehensive development, demonstration, and commercialization of H₂ and fuel cells with industry.

2. Make critical public investments in building strong links to private industry, universities and National Labs to expand innovation and industrial growth.

3. Build a mature H₂ economy for fuel diversity in the U.S.

4. Decrease the dependency on foreign oil & emissions and enhance energy security.

5. Create, strengthen, and protect a sustainable national energy economy.
DOE-funded Innovation Driving Impact

Innovation and Progress

More than 730 Patents tracked to date

- 3.5X more patents tracked since 2005

- Reduced fuel cell and electrolyzer cost by >60%
- Quadrupled fuel cell durability
- Achieved world’s firsts: Tri-gen, PEC, liquefaction, etc.

Impact

More than 30 Technologies commercialized by private industry

and over 75 with potential to be commercial in the next 3-5 years

can be traced back to DOE R&D

Innovation to Market Technologies - Examples

- Electrolyzers - Giner
- Fuel cell systems - Plug Power
- Electrolyzers - Proton
- Hydrogen Tube Trailers – Hexagon Lincoln
Fuel Cell Shipments - Growth by Application

Fuel Cell Power Shipped (MW)

- **2014**: 100 MW
- **2015**: 250 MW
- **2016**: 500 MW
- **2017**: 650 MW

- **Stationary**
- **Portable**
- **Transportation**

**Source**: DOE and E4Tech

- **650 MW** fuel cell power shipped worldwide
- **70,000** fuel cell units shipped worldwide
- **$2 Billion** fuel cell revenue

Approximately
Electrolyzers

Global sales estimated at 100 MW/year*

Commercial status today
- Mature/established products available
- Technology in early commercial stage
- Technology in demonstration

Potential production capacity in 2020 by manufacturer (anonymised). Depending on corresponding growth in demand.

AEL  |  PEMEL  |  SOEC

Order of Magnitude:
- 5 MW/a
- 50 MW/a
- 500 MW/a

*Courtesy of NOW, E4tech and partners: A collaborative effort to assess electrolyzer market potential

© Fraunhofer ISE
Multiple H₂ and Fuel Cell Applications in the U.S.

U.S. Snapshot

- **>240MW** Backup Power
- **23,000** Forklifts
- **30** Fuel Cell Buses
- **36** H₂ Retail Stations
- **6,000** Fuel Cell Cars

States with Growing Interest

- **200 stations planned by 2025, 1,000 by 2030**
- **More than $180M**
  - The total amount states have invested in H₂ infrastructure in the past decade*

CA
- Nearly 1,000 stations by 2030
- Over 30 public stations open
- $150M invested
- $235M announced in 2018

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others with interest
- Over $27M invested
- 12-25 stations planned in the NE

*Excludes recent announcement from CA to invest $235M in electric vehicles
Fuel Cell Technologies Office (FCTO) Overview

Early R&D Focus

- Energy security
- Energy resiliency
- Strong domestic economy
- Applied research, development and innovation in emerging hydrogen and fuel cell technologies leading to:

Early R&D Areas

<table>
<thead>
<tr>
<th>Fuel Cells</th>
<th>Hydrogen</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>• PGM-free catalysts</td>
<td>• Production pathways</td>
<td>• Safety</td>
</tr>
<tr>
<td>• Durable MEAs</td>
<td>• Advanced materials for storage</td>
<td>• Manufacturing</td>
</tr>
<tr>
<td>• Electrode performance</td>
<td></td>
<td>• Delivery components</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Others</td>
</tr>
</tbody>
</table>

Impact

- 60% Lower Fuel Cell Cost
  - $124/KW at high-volume
  - $50/KW at low-volume
- Greater Fuel Cell Durability
  - 4X more hours of fuel cell durability since 2006
- 80% Lower Electrolyzer Cost
  - for H₂ production since 2002

PGM = Platinum group metals
MEA = Membrane Electrode Assembly

Leverage private sector

Enabling
### DOE Program Funding

#### DOE-wide Hydrogen and Fuel Cells Funding

<table>
<thead>
<tr>
<th>Office</th>
<th>FY 2018 ($ in thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EERE (FCTO)</td>
<td>115,000</td>
</tr>
<tr>
<td>Science (Basic/xcut)</td>
<td>19,000</td>
</tr>
<tr>
<td>Fossil Energy (SOFC)</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>~164,000</strong></td>
</tr>
</tbody>
</table>

Note: ARPA-E funding dependent on program selected each fiscal year

#### EERE – Fuel Cell Technologies Office

<table>
<thead>
<tr>
<th>Key Activity</th>
<th>FY 2017 ($ in thousands)</th>
<th>FY 2018 ($ in thousands)</th>
<th>FY 2019 ($ in thousands)</th>
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</thead>
<tbody>
<tr>
<td>Fuel Cell R&amp;D</td>
<td>32,000</td>
<td>32,000</td>
<td>30,000</td>
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<tr>
<td>Hydrogen Fuel R&amp;D</td>
<td>41,000</td>
<td>54,000</td>
<td>39,000</td>
</tr>
<tr>
<td>Hydrogen Infrastructure R&amp;D</td>
<td>-</td>
<td>-</td>
<td>21,000</td>
</tr>
<tr>
<td>Systems Analysis</td>
<td>3,000</td>
<td>3,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Technology Acceleration</td>
<td>18,000</td>
<td>19,000</td>
<td>21,000</td>
</tr>
<tr>
<td>Safety, Codes and Standards</td>
<td>7,000</td>
<td>7,000</td>
<td>7,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>101,000</strong></td>
<td><strong>115,000</strong></td>
<td><strong>120,000</strong></td>
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</table>

EERE: Office of Energy Efficiency and Renewable Energy
H₂@Scale: Enabling affordable, reliable, clean, and secure energy across sectors

More information at: [www.energy.gov/eere/fuelcells/h2-scale](http://www.energy.gov/eere/fuelcells/h2-scale)
Examples of Key Activities

Options to Scale up

- Opportunities to increase scale –
- Bundle supply & demand
- Rail, marine, heavy duty, industry (steel), etc.

H\textsubscript{2} Infrastructure

- DC H\textsubscript{2} Station
- Tri-Gen H\textsubscript{2} Station

Enablers

- HySTEP
- Mobile Fueler
- Tunnels
- Liquid Release
- Station footprints
- H-Prize

Recent Hydrogen and Fuel Cell Applications

- Lift Trucks
- Parcel Delivery Vans
- Ground Support Equip.
Cost remains a challenge: DOE fuel cell system cost vs. targets

<table>
<thead>
<tr>
<th></th>
<th>Light Duty</th>
<th>Truck (MD)</th>
<th>Forklifts (5-kW)</th>
<th>Backup Power (5-kW)</th>
<th>Stationary (25-kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$/kW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High-Volume</strong></td>
<td>$230†</td>
<td>$320</td>
<td>$6,100</td>
<td>$7,400</td>
<td>$3,000</td>
</tr>
<tr>
<td><strong>Low-Volume</strong></td>
<td>$180*</td>
<td>$100</td>
<td>$2,800</td>
<td>$3,200</td>
<td>$2,000</td>
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<tr>
<td><strong>Under Development</strong></td>
<td>$45</td>
<td>$100</td>
<td>$2,400</td>
<td>$2,800</td>
<td>$1,900</td>
</tr>
<tr>
<td><strong>N/A</strong></td>
<td>$40</td>
<td>$6,100</td>
<td>$1,900</td>
<td>$1,500</td>
<td></td>
</tr>
<tr>
<td><strong>$/yr</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High-Volume</strong></td>
<td>200</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Low-Volume</strong></td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td><strong>Note:</strong> Graphs not drawn to scale and are for illustration purposes only.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Based on commercially available FCEVs  †Based on state of the art technology
Fuel Cell Status vs. Targets

R&D has enabled > 60% cost reduction in the last decade

Some targets are met but fuel cell cost and durability must be addressed concurrently

1,000 Systems/Year

10,000 Systems/Year

50,000 Systems/Year

- Bipolar Plates
- Membranes
- Catalyst + Application
- GDLs
- MEA Frame/Gaskets
- Balance of Stack
Hydrogen fuel cost vs. targets

**Production, Delivery & Dispensing**
- $16/kg to $13/kg
- $10/kg to $5/kg
- <$4/kg

**On-board Storage**
- $24/kWh
- $17/kWh
- $15/kWh
- $8/kWh

Note: Graphs not drawn to scale and are for illustration purposes only.
Hydrogen Storage and Delivery Costs

Hydrogen is currently stored in Composite Overwrapped Pressure Vessels at 700 bar (~10,000 psig) for LDVs

Analysis for a single tank design

### Key Strategies and Focus Areas - Examples

#### Challenge
Reduce the cost of hydrogen production, storage, and delivery in support of H2@Scale

- Materials issues
- Feedstocks
- Capital costs
- O&M costs

#### Near-term Strategies
Applied R&D to enable 700 bar H₂ at refueling stations, reduce cost, address reliability

#### Longer-term Strategies
Improve performance and durability of materials & systems for production from sustainable sources

#### R&D Focus
- Techno-economics to guide applied R&D
- Advanced materials and systems for H₂ delivery
- Innovations in materials, devices and reactors for sustainable H₂ production
- Reliability and cost of compression, storage and dispensing
- Integrated/hybrid systems
- Improved balance of plant

#### Key Areas
- **Delivery & Storage**
  - Liquefaction technologies
  - Compression, materials R&D
  - H₂ carriers, dispensing R&D
- **Production**
  - Advanced electrolysis
  - Waste and bio-conversion
  - Nuclear/hybrid approaches
  - Solar water splitting: PEC & STCH

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#### R&D Support Framework:
- FCTO FOA & Lab Calls
- SBIR/STTR
- MOUs: NSF, DOD, etc
- Consortia (Seedlings)
- Crosscuts: Grid, etc.
- Prizes and Other
Program Management - Examples

FOA Topic Selection
- Stakeholders
  - e.g.: RFIs, industry, HTAC, etc.
- U.S. DRIVE
- Peer Reviews
  - NAS
  - GAO
  - Others

• Risk Analysis
• Technology Reviews

RD&D Plan and Solicitation Topics
• Targets
• “Critical Path” needs
• Technology Gaps

Technical Targets and Program Plans
Example Fuel Cell Membrane Targets

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>2011 Status</th>
<th>2017 Target</th>
<th>Nations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum oxygen crossover</td>
<td>mA/cm²</td>
<td>&lt;1</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>Maximum hydrogen crossover</td>
<td>mA/cm²</td>
<td>&lt;1.8</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>Area specific resistance at:</td>
<td>Ω cm²</td>
<td>0.033 (40 kPa)</td>
<td>0.012 (80 kPa)</td>
<td>0.02</td>
</tr>
<tr>
<td>80°C and water partial pressures from 25 - 45 kPa</td>
<td>Ω cm²</td>
<td>0.017 (25 kPa)</td>
<td>0.01</td>
<td>0.012</td>
</tr>
<tr>
<td>25°C and water partial pressures up to 4 kPa</td>
<td>Ω cm²</td>
<td>0.017 (25 kPa)</td>
<td>0.01</td>
<td>0.012</td>
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Operating temperature
Minimum electrical resistance
Cost
Durability
Mechanical
Chemical

Technical targets help guide go/no-go decisions.

Project & Program Review Processes
- Annual Merit Review & Peer Evaluation meetings
- Tech Team reviews (monthly)
- Other peer reviews- National Academies, GAO, etc.
- DOE quarterly reviews and progress reports

FOA Topic Selection

Project & Program Review Processes

Technical Targets and Program Plans

Example Fuel Cell Membrane Targets

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<td>0.012</td>
</tr>
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Operating temperature
Minimum electrical resistance
Cost
Durability
Mechanical
Chemical

Update of Multiyear RD&D Plan and Targets in process

$16M saved from Active Project Management & Downselects from FY 2014 to FY 2018

Project Number | Project Title PI Name & Organization | Final Score | Discontinue | Other | Summary Comment
--- | --- | --- | --- | --- | ---
123 | New Polymer/Inorganic Proton Conductive Composite Membranes for PEMFC | 2.1 | X | | The project was unable to meet conductivity targets or significantly improve upon Nafion®, and the membranes developed have poor chemical stability. The project will not be continued.

Reviewer comments for projects posted online annually. Projects discontinued/ work scope altered based on performance & likelihood of meeting goals.
Examples of Analysis Activities

- **H2.Terr.FC** (current status)
- **H2.Terr.CT** (current status)
- **H2.Terr.OT** (current status)
- **H2.Geo.FC** (current status)
- **H2.Geo.CT** (current status)
- **H2.Geo.OT** (current status)
- **Battery** (current status)
- **Battery** (tech potential)
- **H2.Terr.OT** (current status)
- **H2.Terr.FC** (current status)
- **H2.Terr.CT** (current status)
- **H2.Terr.OT** (tech potential)
- **H2.Geo.FC** (tech potential)
- **H2.Geo.CT** (tech potential)
- **H2.Geo.OT** (tech potential)
- **H2.Geo.FC** (tech potential)

### Cost of Hydrogen Delivery and Dispensing [$/kg_H2$]

- **Pipeline**
- **Liquid Tanker**
- **Tube Trailer**

### LCOE of peak power (2016$/kWh$)

<table>
<thead>
<tr>
<th>Days of energy storage</th>
<th>LCOE of peak power</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>$0.00</td>
</tr>
<tr>
<td>1</td>
<td>$0.20</td>
</tr>
<tr>
<td>2</td>
<td>$0.40</td>
</tr>
<tr>
<td>3</td>
<td>$0.60</td>
</tr>
<tr>
<td>4</td>
<td>$0.80</td>
</tr>
<tr>
<td>5</td>
<td>$1.00</td>
</tr>
<tr>
<td>6</td>
<td>$1.20</td>
</tr>
<tr>
<td>7</td>
<td>$1.40</td>
</tr>
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</table>

### Levelized Refueling Cost [$/kg_H2$]

- **Gaseous Station**
  - 1.8
  - 3.6
  - 7.2
- **Liquid Station**
  - 1.8
  - 3.6
  - 7.2

- **Controls/Other**
- **Electrical**
- **Refrigeration**
- **Compressor/Pump**
- **Storage**
- **Dispenser**

**Target:** $7/kg by 2025
## Compatibility of Delivery & Storage Options

<table>
<thead>
<tr>
<th>Delivery Options</th>
<th>Storage Options</th>
<th>Forecourt Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>700 Bar</td>
<td>Cold-compressed</td>
</tr>
<tr>
<td>Gaseous (Tube Trailer or Pipeline)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Liquid Trailer</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cold Gas tube Trailer</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>H₂ Carrier</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

### Forecourt Implications
- **Pre-cooling (-40 °C)**
- **Refrigeration (down to 150 K)**
- **Supercritical H₂ (<< 150 K); requires high utilization to prevent boil-off**
- **Liq H₂ or liq N₂ needed (down to 80 K) w/ recirculation**
- **Pre-cooling; Heat rejection at forecourt**
- **Heat rejection at forecourt**

**Decisions on H₂ delivery method and onboard storage technology can create limitations on the available choice for the other**

**Goal is to Optimize Both in Unison**
Issues Arising from \( \text{H}_2 \) Infrastructure Data Collection

Through NREL’s National Fuel Cell Technology Evaluation Center

Example: Sources of \( \text{H}_2 \) Infrastructure

Maintenance

- Most maintenance related to compressors and dispensers

To Participate

techval@nrel.gov

Need to address infrastructure component reliability

- Visit: energy.gov/eere/fuelcells/hydrogen-analysis-toolbox

Source: U.S. DOE Fuel Cell Technologies Office
Program Strategy

Use Energy Materials Network (EMN) National Lab capabilities to accelerate innovation and address key technical challenges

Bring in new industry and university players on an ongoing basis

Consortium Approach

Core Team:
National Labs

FOA
University & Non-Profit
Industry
National Lab

Launched and addressing R&D needs:

Part of:
Energy Materials Network (EMN)

Leverage Private Sector for Demonstrations & Late Stage R&D

Government Funding

CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project (‘Work for Others’)
Solicited Industry on Challenges and Needs

DOE held numerous workshops and issued requests on areas requiring assistance:

H2@Scale R&D Lab Capabilities—Examples

Over 20 new CRADA projects initiated between industry and national labs
Current $H_2@Scale$ CRADA Projects

**HYDROGEN QUANTITATIVE PERFORMANCE ANALYSIS AND OPERATION R&D**
- Air Liquide
- California Energy Commission
- Connecticut Center for Advanced Technology
- PDC Machines
- Quong & Associates, Inc.

**HYDROGEN DISTRIBUTION COMPONENT DEVELOPMENT R&D**
- California Go-Biz Office
- Frontier Energy
- HyET
- Honda
- NanoSonic
- RIX
- Tatsuno
- Shell

**ADVANCED HYDROGEN PRODUCTION CONCEPTS R&D**
- Honda
- C4-MCP, Inc.
- GinerELX
- GTA, Inc.

**HYDROGEN INTEGRATION WITH ENERGY GENERATION R&D**
- Electric Power Research Institute
- Exelon
- Southern Company / Terrestrial Energy
- Nikola Motor
- Pacific Gas & Electric
- TerraPower
Key focus areas to realize the H₂@Scale vision

MAKE
Increased Low Cost Hydrogen Production

MOVE
More Efficient Hydrogen Transmission

USE
Low Cost Value-added Applications

STORE
Flexible, Low-cost Bulk Storage Technologies

CRADA Project Distribution
Make working group kick-off meeting December 2018
H₂@Scale: Nationwide Resource Assessment

Assessing resource availability.
Most regions have sufficient resources.

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

Assessing cost of H₂ vs electricity transmission
(in process)
Refineries: Where is the H₂ demand today?

H₂ Demand

2017

5.9 MMT

Refineries

H₂ demand (1000 MT/yr)

- 100
- 300
- 500

Source: Elgowainy, et al, ANL
Ammonia: Where is the H₂ demand today?

2017

H₂ Demand
2.9 MMT

Source: Elgowainy, et al, ANL
Ammonia & Refineries and Potential H₂ Demand

2030

H₂ Demand

11.2 MMT

Refineries

Ammonia

Source: Elgowainy, et al, ANL
Plus demand from synthetic fuel production...

Source: Elgowainy, et al, ANL
Nearly 30 million metric tons of potential hydrogen demand in the U.S.
Source: Elgowainy, et al, ANL
IPHE: International Partnership for Hydrogen and Fuel Cells in the Economy

- **Increase** international **collaboration to accelerate progress**

- **Working Groups:**
  - Regulations, Codes and Standards, Safety
  - Education & Outreach

Launched 2003 and includes 18 countries and the European Commission

Coordination with IEA, Mission Innovation, and Energy Ministerials

U.S. elected Chair May 2018
Japan Vice Chair
EC, Germany, France, Canada support
Commitment from Ministers on H₂ and Fuel Cells

The U.S. Deputy Secretary of U.S. Dept. of Energy attended the Hydrogen Ministerial Meeting in Tokyo on Oct 23

Tokyo Statement
4 areas for collaboration

• Harmonization of regulation, codes and standards
• Information sharing on safety and infrastructure
• Technical studies
• Communication, education and outreach
Action from Oct 23, 2018 Hydrogen Ministerial: Develop concrete actions that Agencies can undertake to address four priorities

<table>
<thead>
<tr>
<th>Harmonization of Codes and Standards</th>
<th>Information Sharing, Safety, Infr. Supply Chain</th>
<th>Studies and Evaluations of Impact Potential</th>
<th>Communication and Outreach</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Coordinate with industry to enable harmonization of relevant regulations, codes and standards such as those for: • refueling stations, • heavy duty transportation, • energy storage • technologies supporting sectoral integration, • maritime • other</td>
<td>• Collaborate on relevant infrastructure R&amp;D • Share safety lessons learned, best practices on hydrogen safety • Collaborate on R&amp;D of risk assessment and mitigation to enable the safe and sustainable use of hydrogen technologies across applications.</td>
<td>• Collect, analyze and share data and conduct studies • Assess impact potential for sustainable production of H2 across pathways • Develop business cases and models across value chain and integrated systems analysis across scenarios</td>
<td>• Work together to promote appropriate outreach and awareness programs and initiatives to educate a broad range of stakeholder groups on H2 and fuel cell technologies • Develop ‘train the trainer’ programs, to build awareness of hydrogen solutions, especially on safety</td>
</tr>
</tbody>
</table>
## HTAC Recommendations Being Addressed

### Recently Published: Sixth Biennial Report to Congress
responding to HTAC Findings and Recommendations from FY16 – FY17

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Actions Taken Since Last Meeting (Examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensuring positive retail hydrogen fueling experience</td>
<td>• Issued RFIs on regulatory barriers to $H_2$ infrastructure and $H2@scale$</td>
</tr>
</tbody>
</table>
| Continue efforts in material and process integration and technology acceleration in order to meet the 2020 EPACT Title VIII goals | • Launched H-Mat consortium to focus on materials compatibility with hydrogen  
• **Funded over 20 projects** to enable H2@scale ($11M total including cost share)**                                                                                   |
| Maximize the role of the Hydrogen Safety Panel (HSP)                          | • **Spearheaded formation of the Center for Hydrogen Safety (CHS)** to provide the hydrogen and fuel cell industries and its stakeholders with hydrogen safety guidance (Direct HTAC output).** |
| Leverage the capabilities of public-private partnerships                      | • **Participated in hydrogen fuel R&D workshop with Industry and National Labs** to foster collaboration and identify R&D gaps                                                                                     |
| Identify and support other federal and state agencies                        | • **Signed DOD TARDEC MOU** to $H_2$ and fuel cell applications for military and civilian use                                                                                                                                 |
HTAC Impact – Examples

• HTAC Annual Reports and Letters to DOE Secretary
  – 2007 to 2017

• Subcommittee Outputs
  – Hydrogen Safety & Event Response (2017)
  – Communication & Outreach (2017)
  – Manufacturing (2014)

• Other Examples
  – Input on Hydrogen Safety Panel and affiliation with AIChE
  – Input on H-Prize – 1st commercial system exported to Japan, manufactured in the US
  – Peer review of H₂ cost target – published
  – Input on R&D Plan
  – H2@Scale
Potential Areas of Input by HTAC

• Plans and Roadmaps
  – Program Plan (see next slide for brief update)
  – 2020 infrastructure goals in EPACT and Program Plan

• Collaboration - Examples
  – Tokyo Statement areas of collaboration and IPHE role
  – MOUs and concrete collaboration opportunities (e.g. TARDEC-FCTO MOU)
  – Center for Hydrogen Safety (see next slide and tomorrow’s presentation at HTAC)
  – Prize concepts
Example of HTAC Impact: Expanding Safety Collaborations

Direct result of HTAC input and recommendations:

- Leverages private sector
- Expands impact of safety panel
- Transitions key areas to industry for sustainable business model
- Supports IPHE, Hydrogen Ministerial, etc.

Leverages new partnership to promote collaboration on H₂ safety

Modeled after Center on industrial Chemical Process Safety
200 industry members- access to 110 countries & 60,000 members
Hydrogen and Fuel Cell Technologies Program Plan

Completed outline. Preliminary draft underway. Tentative complete date: End of 2018

1. Introduction
   - DOE Objectives
   - Program Overview
     - Mission
     - Vision
   - H2@Scale Goals
     - Key targets
   - Program structure
   - Program Accomplishments
   - Program Impact
     - Tracking Innovation
     - Tracking R&D Impact (e.g. patents)

2. Program Activities, Plans, and Milestones
   - H2@Scale concept (benefits of hydrogen/impacts of widespread utilization)
   - Barriers
   - Make
   - Move
   - Use
   - Store
   - Overarching activities

3. Program Implementation
   - Organizations and Partnerships
   - Federal, State, and International Collaboration and Coordination
   - Active Project Management
   - Peer Review
   - Stakeholder Input
Stakeholder Engagement to support early stage R&D

Celebrate Hydrogen & Fuel Cell Day
October 8 or 10/8

Use Safety Information and Training Resources

Attend the 2019 Annual Merit Review

Sign up to receive hydrogen and fuel cell updates

Learn more at: energy.gov/eere/fuelcells
Examples of Recent DOE Engagement

Driving a fuel cell car blog by Under Secretary of Energy Menezes

Sent to 20,000 people in distribution list

Reached 3,000 people through various outreach events

Reached over 30 different DOE offices
Thank You

&

Additional Information

Dr. Sunita Satyapal
Director
Fuel Cell Technologies Office
Sunita.Satyapal@ee.doe.gov

energy.gov/eere/fuelcells
DOE activities cover many states across the U.S.

EERE Fuel Cell Technologies Office Funding¹
FY 2013 – FY 2017

From 2013 to 2017
$429M

Covering H₂ and Fuel Cell Activities in
30 states and DC

With FCTO funding
¹Prime recipients only
## FY 2019 Congressional Language

<table>
<thead>
<tr>
<th>House</th>
<th>Senate</th>
<th>Conference</th>
</tr>
</thead>
<tbody>
<tr>
<td>[No direction.]</td>
<td>The Committee recommends <strong>$19,000,000</strong> for Technology Acceleration activities, including <strong>$3,000,000</strong> for manufacturing R&amp;D, and <strong>$7,000,000</strong> for industry-led efforts to demonstrate a hydrogen-focused integrated renewable energy production, storage, and transportation fuel distribution/retailing system. Regular consultation with industry is encouraged to avoid duplication of private-sector activities. The Committee encourages the Secretary to work with the Secretary of Transportation and industry on coordinating efforts to deploy hydrogen fueling infrastructure.</td>
<td>Within available funds, the agreement provides <strong>$21,000,000</strong> for Technology Acceleration activities, including <strong>$3,000,000</strong> for manufacturing research and development and <strong>$7,000,000</strong> for industry-led efforts to demonstrate a hydrogen-focused integrated renewable energy production, storage, and transportation fuel distribution/retailing system. [Senate language stands.]</td>
</tr>
</tbody>
</table>
### FY 2019 Congressional Language

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<td>Within available funds, $2,000,000 is for the EERE share of the integrated hybrid energy systems work with the Office of Nuclear Energy.</td>
<td>$39,000,000 for Hydrogen Fuel R&amp;D for efforts to reduce the cost and improve the performance of hydrogen generation and storage systems, hydrogen measurement devices for fueling stations, hydrogen compressor components, and hydrogen station dispensing components.</td>
<td>$39,000,000 for Hydrogen Fuel Research and Development</td>
</tr>
</tbody>
</table>
| $7,000,000 is to enable integrated energy systems using high and low temperature electrolyzers with the intent of advancing the H2@Scale concept. | The Department shall continue to research novel onboard hydrogen tank systems, as well as trailer delivery systems to reduce cost of delivered hydrogen. | [Senate language stands.]
|                                                                      | ... directed to support R&D activities that reduce the use of platinum group metals, provide improvements in electrodes and membranes and balance-of-plant components and systems. | Within available funds, the agreement provides $4,000,000 for the EERE share of the integrated energy systems work with the Office of Nuclear Energy |
|                                                                      | .... is directed to continue the H2@Scale Initiative, which couples current research efforts within the program with new opportunities for using hydrogen to provide grid resiliency and advance a wide range of industrial processes for the production of fuels, chemicals, and materials. | $7,000,000 to enable integrated energy systems using high and low temperature electrolyzers with the intent of advancing the H2@Scale concept. |
### FY 2019 Congressional Language

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<tbody>
<tr>
<td>The Committee recognizes the need to support the development of alternative fueling infrastructure for U.S. consumers. Accordingly, the Department is encouraged to collaborate with the National Institute of Standards and Technology to allow accurate measurement of hydrogen at fueling stations.</td>
<td>The Committee further recommends $7,000,000 for Safety, Codes, and Standards to maintain a robust program and engage regulatory and code officials to support their technical needs relative to infrastructure and vehicle safety.</td>
<td>$7,000,000 for Safety, Codes, and Standards. [House language stands. “Encouraged” is not considered congressional direction.]</td>
</tr>
<tr>
<td>The Department is encouraged to work with the Department of Transportation on coordinating supporting hydrogen fueling infrastructure.</td>
<td>Within the amounts recommended, <strong>$19,000,000</strong> is recommended for Hydrogen Infrastructure R&amp;D.</td>
<td>[Senate &amp; House language stands. In both cases, ‘encouraged’ and ‘recommended’ are not considered congressional direction]</td>
</tr>
</tbody>
</table>
### FY 2019 Congressional Language

<table>
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<tbody>
<tr>
<td>The Committee recognizes the progress of the program and continues support for stationary, vehicle, motive, and portable power applications of this technology.</td>
<td>[No direction.]</td>
<td>[House language stands. “Recognizes” is not considered congressional direction.]</td>
</tr>
<tr>
<td>[No direction.]</td>
<td>The Committee recommends $1,000,000 for Systems Analysis, including research on in-situ metrology for process control systems for manufacturing of key hydrogen system components.</td>
<td>[Senate language stands. “recommends” is not considered congressional direction.]</td>
</tr>
</tbody>
</table>
## Example of HTAC “Dashboard” Recommendation

<table>
<thead>
<tr>
<th>Technology Areas</th>
<th>EPACT 2005, Title VIII – HTAC Review Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DOE Hydrogen &amp; Fuel Cell Programs</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>Fossil Fuels, Hydrogen Carrier Fuels Renewables, Nuclear</td>
</tr>
<tr>
<td>Delivery</td>
<td>Transmission by Pipelines, Surface Transport; Fueling (Central Refueling Stations, Distributed Onsite)</td>
</tr>
<tr>
<td>Uses</td>
<td>Commercial, Industrial &amp; Residential Power Generation</td>
</tr>
<tr>
<td>Storage</td>
<td>Hydrogen &amp; Hydrogen Carrier Fuels, Development of Materials for Storage in Gas, Liquid or Solid Form at Refueling Facilities and On-Board Vehicles</td>
</tr>
<tr>
<td>Fuel Cells</td>
<td>Safe, Durable, Affordable, Efficient, Fuel Flexible</td>
</tr>
<tr>
<td>Power Systems</td>
<td>U.S. Produced, Commercially Available, Competitive</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>High Temperature Membranes, Cost Effective Stack &amp; System Reliability,</td>
</tr>
</tbody>
</table>
“The DOE’s contribution and support of the EERE and FCTO’s testing and development of ASME B31.12 code gives operators and engineers the basis for employing FRP in spools, or in our case, site manufactured FRP in very long lengths. We appreciate all the hard work and dedication from the DOE team that has brought this project to such a successful conclusion.”

- Gary Littlestar, CEO of Smart-Pipe Technologies

**Pipeline Delivery**

- Inclusion of FRP in ASME B31.12 Hydrogen Piping and Pipelines code, lowering cost of high-pressure transmission pipelines by ~25%. (SRNL)

**Vehicular Transport**

- Reduction of material performance factors for X70 steel in ASME B31.12 code, lowering cost of hydrogen pipelines construction by up to 30%. (SNL)

**Continued Applied R&D Needs**

- New materials for H₂ service
- Non-mechanical FRP joints
- Weld performance for higher strength (X100) pipeline steel in H₂
- Advanced liquid transport technologies

**Reduction of cost of hydrogen tube trailers by > 20% from 2011 baseline, while increasing capacity by > 40%.** (Hexagon Lincoln)
Well-to-Wheels Analysis: Petroleum Use and Emissions

Petroleum Use, BTUs/Mile

GHG Emissions, gCO₂/Mile

Program Record #13005: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf
Cross-Office Updates
The $\text{H}_2$ and Fuel Cells Program spans other DOE offices

Funded over:
110 companies
100 universities
& institutes
13 national labs

Hydrogen and Fuel Cells Program Coordination Group

- **EERE: Fuel Cell Technologies Program**
  - $\text{H}_2$ and fuel cells R&D
  - Cross cutting activities
  - Infrastructure R&D

- **FE Hydrogen Activities**
  - $\text{H}_2$ from coal R&D
  - SOFC

- **NE Hydrogen Activities**
  - $\text{H}_2$ from Nuclear Energy RD&D

- **SC Hydrogen and Fuel Cell Activities**
  - Basic Energy Sciences

ARPA-E

Secretary

Under Secretary of Energy

Energy Efficiency & Renewable Energy (EERE)
- Fossil Energy (FE)
- Nuclear Energy (NE)

Under Secretary for Science

Office of Science (SC)

DOE Hydrogen & Fuel Cells Program Management (EERE)

Interagency Task Force

Interagency Working Group

Systems Integrator
DOE-BES Overview

• FY 2018 Hydrogen and Fuel Cell crosscut spending level was approximately $19M

• Current solicitations are our “open” core FOA, Computational Materials Science and EPSCoR (https://science.energy.gov/bes/funding-opportunities/)

• BES coordinates with other DOE Offices through the internal working group, and with other Government Agencies through participation in the Interagency Working Group

• 2017 Basic Research Needs workshop on Catalysis Science report is available online. No upcoming workshops directly related to hydrogen or fuel cells.
ARPA-E Programs in Fuel Cells/Electrolyzers for Energy Conversion and Storage

**Mission**
Develop new disruptive technologies for efficient, cost-effective electrical storage and generation systems using renewable energy and natural gas with applications for transportation, commercial and industrial power customers across the economy, resulting in increased energy efficiency and security, significant fuel and energy savings, and emissions reduction.

**Drivers**
- Growth of intermittent renewable energy, cheap and abundant natural gas
- Need for increased efficiency throughout the whole economy
- Increased demand for clean/electrified transportation
- Growth of microgrids and distributed energy generation

**Coordination and cooperation with other DOE offices (FCTO, FE)**
- Program development (workshops, common technical targets)
- Project evaluation (proposal reviewing, annual program reviews)
- Constant coordination via Fuel Cell and Hydrogen working group
ARPA-E Programs in Fuel Cells/Electrolyzers for Energy Conversion and Storage

Power-to-Fuels
- AEM water electrolysis
- Ammonia synthesis
- NG and CO₂ conversion

Fuels-to-Power
- Intermediate temperature fuel cells
- Integrated SOFC/engine systems
- Regenerative fuel cells
- H₂ generation

- OPEN $17.5
- IONICS $6.6*
- REFUEL $33M
- REBELS $33M
- IDEAS $1.7M*
- INTEGRATE $18M

* - related to FC/electrolyzers/H₂

OPEN 2018 TBD
SOFC Program
Funding History

- FY19 Appropriation: $30M
- Cumulative Funding (FY00 – FY18)
  - DOE ~$712M
  - Participant Cost Share ~$265M

- Total Number of Awards >290
- Total Number of Participants 116
  - Industry 66
  - Academia 40
  - National Labs/Agencies 10
SOFC Program
How the technology has evolved

**Cell Development**
- Increased power
- Established material set
- Improved reliability
- Reduced cost

**Stacks**
- Increased cell area by 5x
- Increased cell power by 10x
- Degradation reduced to 0.2 - 0.5%/1,000 hrs

**Technology Validation**

**Proof-of-Concept Systems**
- Two POC systems, 50kW & 200 kW
- Efficiency improvements to >55%

**200 kWe Prototype Field Test**
(two in-progress)

**10 MWe Pilot**
(planned)

**200 kWe POC**
(courtesy LG Fuel Cell Systems)

**10 kWe-Class Stack Tests**
- Improved efficiency, 35 – 41%
- Reduced degradation, <2%/1000 hr
- Cost target at high volume achieved (extrapolated)

**50 kWe POC**
(courtesy FuelCell Energy)

**50 MWe Utility-Scale Demo**
(planned)

**MWe-Class Pilot**

<table>
<thead>
<tr>
<th>Technology Validation</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell and Stack Performance Improvements</td>
<td>- Increased cell area by 5x</td>
<td>- Increased cell power by 10x</td>
<td>- Degradation reduced to 0.2 - 0.5%/1,000 hrs</td>
<td></td>
</tr>
<tr>
<td>10 kWe-Class Stack Tests</td>
<td>Improved efficiency, 35 – 41%</td>
<td>Reduced degradation, &lt;2%/1000 hr</td>
<td>Cost target at high volume achieved (extrapolated)</td>
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<td>Proof-of-Concept Systems</td>
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<th>CELLS</th>
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</tbody>
</table>
Cross-Office Activities Update

• Solar Fuels Research Initiative Strategic Plan
  – Addressed in FY 2019 congressional language

“The Committee directs the Department of Energy to submit a solar fuels research initiative strategic plan within 120 days after enactment of this act. The 10-year plan shall include research challenges and opportunities, program goals and milestones to overcome scientific and technological impediments, a description of coordination between the Office of Science, EERE, and ARPA-E to leverage basic research and early-stage translational research in solar fuels to accelerate the pace of innovation, an assessment of U.S. leadership in solar fuels research relative to international competition and the extent to which the Department's investments are sufficient to maintain U.S. leadership.”

– Basic Energy Sciences leading

– Solar, ARPA-E and Fuel Cell Tech Offices contributing