More than 60,000 Fuel Cells Shipped in 2015

Fuel Cell Systems Shipped Worldwide by Application

Capacity shipped in 2015
300 MW
Approximately 2X the capacity shipped in 2014
Consistent 30% annual growth since 2010


Published DOE 2016 Market Report
Agenda

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

• Program Updates

• Next Steps
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
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
### 2016 HTAC Members

<table>
<thead>
<tr>
<th>HTAC Member and Affiliation</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ayers, Katherine</td>
<td>Hydrogen Production R&amp;D</td>
</tr>
<tr>
<td>Proton OnSite</td>
<td></td>
</tr>
<tr>
<td>Azevedo, Ines</td>
<td>Academia/Behavioral Science</td>
</tr>
<tr>
<td>Co-Director of the Climate and Energy Decision Making Center, Carnegie Mellon University</td>
<td></td>
</tr>
<tr>
<td>Clay, Kathryn</td>
<td>Associations/Non-profits</td>
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<tr>
<td>American Gas Association</td>
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<td>Dunwoody, Catherine</td>
<td>Government</td>
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<td>California Air Resources Board</td>
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<td>Eggert, Anthony</td>
<td>Program Director, Climateworks</td>
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<tr>
<td>Freese, Charles F.</td>
<td>Transportation</td>
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<td>General Motors Company</td>
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<td>Gobin, Anne</td>
<td>Government</td>
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<tr>
<td>Bureau of Air Management, Connecticut</td>
<td>Department of Energy &amp; Environmental Protection</td>
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<tr>
<td>Kaya, Maurice</td>
<td>Government</td>
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<tr>
<td>Pacific International Center for High Technology; Chief Technology Officer (retired), Hawaii Dept. of Business, Economic Development, and Tourism</td>
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<td>Kodjak, Drew</td>
<td>Transportation</td>
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<td>International Council on Clean Transportation (ICCT)</td>
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<td>Koyama, Harol</td>
<td>Stationary Power</td>
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<td>H2 PowerTech</td>
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<table>
<thead>
<tr>
<th>HTAC Member Name and Affiliation</th>
<th>Expertise</th>
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<tbody>
<tr>
<td>Leggett, Paul</td>
<td>Venture Capital / Investment</td>
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<td>Morgan Stanley, Investment Banking Division</td>
<td></td>
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<tr>
<td>Lipman, Timothy</td>
<td>Academia</td>
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<tr>
<td>Transportation Sustainability Research Center, UC Berkeley; Director, DOE Pacific Region Clean Energy Application Center</td>
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<td>Markowitz, Morry</td>
<td>Associations / Non-profits</td>
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<td>Fuel Cell and Hydrogen Energy Association (FCHEA)</td>
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<td>Novachek, Frank (Chair)</td>
<td>Utilities (Electricity and Natural Gas)</td>
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<td>Professor, Dept. of Environmental Science and Policy, UC Davis</td>
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<td>Office of Transportation and Air Quality, Environmental Protection Agency</td>
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<td>Powell, Joseph</td>
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<td>Chief Scientist, Shell Global Solutions</td>
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<td>Director, Manufacturing Technology Office of the Deputy Assistant Secretary of Defense</td>
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<td>University of Michigan</td>
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*Indicates new members as of Dec. 2016*
## 2015 Recommendations and Responses (Examples)

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Committee recommends that <strong>the federal tax credit for fuel cell electric vehicles be extended beyond 2016</strong> to continue to enable fuel cell commercialization and help achieve Title VIII goals for 2020.</td>
<td>We agree that extension of the vehicle and state tax credits beyond December 31, 2016 would encourage continued fuel cell vehicle deployments. Tax policies set by Legislative branch but <strong>Information related to such policies publicized.</strong></td>
</tr>
</tbody>
</table>
| Provide **additional funding** to achieve 2020 Title XIII goals.               | **FY 2017 FCTO Budget request:** $105.5M (higher than past few years)  
Launched 3 new consortia in support of DOE’s **Energy Materials Network and advanced manufacturing priorities:** **HydroGEN, ElectroCat, and HyMARC** |
| Clean Cities program emphasis must actively **promote and educate consumers on FCEV technology.** | The revised **Clean Cities strategic vision plan will include additional focus on zero emission technologies including hydrogen and fuel cells, such as funding opportunity announcements and station locations on DOE online maps. |
Mission

To enable the widespread commercialization of hydrogen and fuel cell technologies, which will reduce petroleum use, greenhouse gas (GHG) emissions, and criteria air pollutants, and will contribute to a more diverse energy supply and more efficient use of energy.

2020 Targets by Application

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
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<tbody>
<tr>
<td>Fuel Cell Cost</td>
<td>$40/kW</td>
</tr>
<tr>
<td></td>
<td>$1,000/kW**</td>
</tr>
<tr>
<td></td>
<td>$1,500/kW**</td>
</tr>
<tr>
<td>Durability</td>
<td>5,000 hrs</td>
</tr>
<tr>
<td></td>
<td>80,000 hrs</td>
</tr>
<tr>
<td>H₂ Storage Cost (On-Board)</td>
<td>$10/kWh</td>
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<tr>
<td></td>
<td>1.8 kWh/L, 1.3 kWh/kg</td>
</tr>
<tr>
<td>H₂ Cost at Pump</td>
<td>&lt;$4/gge</td>
</tr>
<tr>
<td></td>
<td>&lt;$7/gge (early market)</td>
</tr>
</tbody>
</table>

*For Natural Gas
**For Biogas

Integrated approach to widespread commercialization of H₂ and fuel cells
DOE Activities Span from R&D to Deployment

1. **Research & Development**

**Fuel Cells**
- **80% lower cost** since 2002
- **5X less platinum** since 2005
- **4X increase in durability** since 2006

<table>
<thead>
<tr>
<th>Cost Year</th>
<th>Cost/kW</th>
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<tbody>
<tr>
<td>2002</td>
<td>$275</td>
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<tr>
<td>2007</td>
<td>$106</td>
</tr>
<tr>
<td>2016</td>
<td>$53</td>
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</tbody>
</table>

2. **Demonstration**

- Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APU's, buses, mobile lighting, refuse trucks
- >220 FCEVs, >30 stations, >6M miles traveled
- **World’s first tri-gen station**
- **H₂ technology station in Washington D.C.**

3. **Deployment**

- ~18,000 units
- >11X additional purchases
- ~1,600 units

**Examples of consortia supporting R&D**
- FC PAD: Fuel Cell Performance & Durability
- MARC: Advanced H₂ Storage Materials
- ElectroCat: PGM-Free Catalysts for Fuel Cells
- HydroGEN: Advanced Water Splitting Materials
- Renewable H₂ Production

**Supporting Deployment**

- H₂ USA: Collaboration to address H₂ Infrastructure Barriers
## Hydrogen & Fuel Cells Budget

### Key Activity

<table>
<thead>
<tr>
<th>Key Activity</th>
<th>FY 15 ($ in thousands)</th>
<th>FY 16 ($ in thousands)</th>
<th>FY 17 Request ($ in thousands)</th>
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<tr>
<td>Fuel Cell R&amp;D</td>
<td>33,000</td>
<td>35,000</td>
<td>35,000</td>
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<td>Hydrogen Fuel R&amp;D</td>
<td>35,200</td>
<td>41,050</td>
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<td>Manufacturing R&amp;D</td>
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<td>Technology Validation</td>
<td>11,000</td>
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<td>Safety, Codes and Standards</td>
<td>7,000</td>
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<td>10,000</td>
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<td>Market Transformation</td>
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<td>Technology Acceleration</td>
<td>0</td>
<td>0</td>
<td>13,000</td>
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<tr>
<td>NREL Site-wide Facilities Support</td>
<td>1,800</td>
<td>1,900</td>
<td>N/A</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>97,000</strong></td>
<td><strong>100,950</strong></td>
<td><strong>105,500</strong></td>
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### Office FY 2016*

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<th>Office</th>
<th>FY 2016*</th>
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<tbody>
<tr>
<td>EERE</td>
<td>$101.0M</td>
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<tr>
<td>Basic Science</td>
<td>$18.5M</td>
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<tr>
<td>Fossil Energy, SOFC</td>
<td>$30.0M</td>
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</tbody>
</table>

### FY 2016 DOE Total: ~$150M

*Estimated for BES funding (based on FY15)

1. Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

---

**Sustained, stable funding requests and appropriations**
DOE Impact- H₂ and Fuel Cells

Innovation

Cumulative Number of Patents

- By 2007: 249 patents
- By 2015: More than 2X
- More than 589 patents

Commercialization

Cumulative Number of Commercial Technologies Entering the Market

- By 2007: 17 Technologies
- By 2015: More than 2X
- 46 Technologies

Examples of Commercial Technologies

- Catalysts
- Fuel Cell System Components
- Tanks
- Electrolyzers

Impact of DOE Investment on Industry

- Revenues: More than 7X the DOE Investment
- Additional Investment: More than 5X the DOE Investment

Jobs

- From DOE-supported Commercial Technologies: 450 jobs average per year
- From ARRA-supported Technology Deployments: 1,400 jobs created or sustained

ARRA: American Recovery and Reinvestment Act

*for selected companies
## DOE-Enabled Commercial Technologies by State

![Map of DOE-Enabled Commercial Technologies by State](image)

<table>
<thead>
<tr>
<th>State</th>
<th>Total</th>
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<tbody>
<tr>
<td>MA</td>
<td>9</td>
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<tr>
<td>CT</td>
<td>5</td>
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<tr>
<td>OH</td>
<td>5</td>
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<td>NY</td>
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<tr>
<td>TX</td>
<td>1</td>
</tr>
<tr>
<td>VA</td>
<td>1</td>
</tr>
</tbody>
</table>

### Commercial Technologies Enabled by DOE funding by 2016

More than 45

Source: 2016 Pathways to Commercialization Report
Emerging Technologies by State

More than 75 Emerging Technologies anticipated to be commercial in 3 to 5 years

Source: 2016 Pathways to Commercialization Report
Henry Ford’s Quadricycle in 1896 to Model T in 1908
DOE Cost Targets and Status

**Fuel Cell System**
- $230/kW<sup>+</sup>
- $59/kW 100K/yr
- $53/kW 500K/yr
- $40/kW

**H<sub>2</sub> Production, Delivery & Dispensing**
- $16/gge to $13/gge
- $7.5*/gge to $5**/gge
- <$4/gge

**Onboard H<sub>2</sub> Storage** (700-bar compressed system)
- $33/kWh
- $17/kWh 100K/yr
- $15/kWh 500K/yr
- $10/kWh

- **2020 Targets**
- **High-Volume Projection**
- **Low-Volume Estimate**

**Key Challenges- Examples**
- PGM loading
- Catalyst and membrane durability
- Electrode performance and durability
- Efficiency and Reliability
- Feedstock and Capital Costs
- Compression, Storage and Dispensing (CSD) Costs
- Carbon fiber precursors and conversion
- Composite/resin materials
- BOP and assembly costs

*Based on Electrolysis ** Based on NG SMR * Based on 2016 Program Cost Record (preliminary)
DOE H₂ Infrastructure Roadmap Development

Purpose

Align RD&D across sub-programs to enable H₂ fueling station deployment in the near-term

Feedback guiding process

- June 2016: Infrastructure Review Meeting
  - Industry (27), national labs (13), government (5)
- July 2016: Infrastructure Request for Information
  - Industry (14), academia/labs (8), government (2)
- October 2016: 2-Day H2FIRST Gap Analysis
  - DOE-funded projects, Infrastructure priorities, and National Laboratory R&D Capabilities
- Early 2017: Development of Technology-Specific Targets to Address R&D Critical Barriers
  - Led by H2FIRST national laboratory team

Barriers

- Reliability
- Cost
- Financing
- Workforce
- Fuel Quality
- Footprint

Planned to complete by late 2017
DOE H₂ Infrastructure Strategy

KEY CHALLENGES

1. Station Cost
2. Station Reliability
3. Station Rollout

DOE ACTIVITIES

- Components R&D
- Systems R&D
- Contaminant Detection
- Sensors Testing
- Safety Awareness
- Codes and Standards Harmonization
- Training & Education

EXAMPLES

- HySTEP
- Reference Station Design
- Contaminant Report

SHOWCASE STATION
(HyTEST)

TOOLS
(HyRAM- Hydrogen Risk Assessment Models)

DOE efforts support public-private partnership:
Gasoline History: Many diverse options

Cans, barrels, home models, mobile refuelers

Source: M. Melaina 2008.

Source: Vieyra, 1979

Source: Milkues, 1978
Refueling Methods Evolved Over Time

History shows phased introduction of different refueling methods

Source: Turn of the Century Refueling: A Review of Innovations in Early Gasoline Refueling Methods and Analogies for Hydrogen (Melaina 2007)
U.S. Hydrogen Infrastructure

- **California**: 25 retail stations now, 100 planned
- **U.S. Northeast**: 12 to 25 stations planned
- Approx. **10M metric tons of H₂ produced** annually
- **1,600 miles of H₂ pipeline** already in place

**A variety of H₂ stations demonstrated to date:**

- Delivered Compressed Steam Methane Reforming
- On-Site Electrolysis
- Delivered Liquid SMR
- On-Site SMR
- Other:
  - Delivered Pipeline
  - Delivered Liquid By-Product
  - Delivered Compressed By-Product
  - On-Site Tri-Gen
  - Mobile Fueler
  - Trailers

*Includes current (21), future (38) and retired (2) stations*
Complementing Retail Stations: \( \text{H}_2 \) Refuel H-Prize

$1\text{M} \text{ Competition: On-site H}_2 \text{ fueling}

Finalist Team
More at hydrogenprize.org

- Launched October 2014
- Finalist selected January 2016
- Testing phase in progress
- Finalist must meet technical & cost criteria to win $1M prize
- Outcome announcement expected early 2017

Ribbon Cutting at H-Prize Open House on November 2016
Team: Ivys, PDC, McPhy
Technology Data, Models and Resources Available

Data Validation of Real World Applications through the NREL’s NFCTEC

- Data products provide insights on technology improvements, issues and gaps

To Participate

technval@nrel.gov

Models “Toolbox” Online

- Financial, technical and economic models covering H₂ infrastructure, jobs, and more.
- Visit: energy.gov/eere/fuelcells/hydrogen-analysis-toolbox

Example: Sources of H₂ Infrastructure Maintenance

- Total Events: 3,140

- Most maintenance related to compressors and dispensers
H₂Tools: One-stop for H₂ safety knowledge

- Includes resources on safety best practices, first responder training, and H₂ codes & standards
- 36,000 code officials and first responders trained
- Tracked downloads from Europe and Japan
- Resource translated in Japanese
- 50% of visits are international!

h2tools.org

Enabling dissemination of safety information around the world
New DOE Efforts to enable robust supply chain

Integrated Network of Regional Technical Centers

Locations
- East Coast (CCAT)
- Midwest (OFCC)
- Central States (NREL)
- West Coast (UC Irvine)

Activities (Examples)
- Hold supply chain exchanges
- Promote cooperation between suppliers & developers, and standardization of component specifications

Global Competitiveness Analysis including:
- Global Cost Breakdown
- Design for Manufacturing & Assembly
- Value Stream Mapping

Fuel Cell and H₂ Opportunity Center
- Comprehensive online database
- Project activities include:
  - Encourage supplier engagement
  - Release and maintain public directory
  - Conduct outreach campaign (social media, etc.)

Recent Workshops
- Ohio Fuel Cell Symposium- Sept 2016
- Connecticut- CCAT- Nov 2016


Objectives
- Identify gaps, needs and opportunities
- Enhance interaction between supply chain stakeholders
Diverse Energy Sources

- Natural Gas
- Renewable Sources (wind, solar, biomass, hydro, geothermal)
- Nuclear
- Coal (with carbon sequestration)

Diverse Applications

- Fuel Cells
- Engines / Turbines
- Energy Storage
- Petroleum Recovery & Refining (~47%)
- Methanol Production (4%)
- Electronics
- Ammonia Production (~45%)
- Metal Production & Fabrication (2%)
- Cosmetics
- Food Processing

Services all energy sectors AND improves

Energy Security and Domestic Economy

Source: DOE, NREL, Hydrogen and Fuel Cell Program
How much H₂ is needed?

### How much hydrogen for 1 car?

<table>
<thead>
<tr>
<th>12,000 miles per year</th>
<th>60 miles per kilogram</th>
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</thead>
<tbody>
<tr>
<td>200 kg or 0.2 tonnes per year</td>
<td></td>
</tr>
</tbody>
</table>

### How much hydrogen for many cars?

| 100 M cars | 200 M kg H₂ per year |
| 20 M tons H₂ per year |
| = 10M cars |

| 1 M cars | 0.2 M tonnes H₂ per year |
| = 100,000 cars |
How much H₂ is needed?

How to get hydrogen for 100M FCEVs?

Quads of Annual U.S. Energy Consumption

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>2015 Consumption</th>
<th>To Produce H₂ for 100 Million FCEVs</th>
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</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>28.3</td>
<td>3.4 x</td>
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<tr>
<td>Coal</td>
<td>15.5</td>
<td>1.3 x</td>
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<td>Nuclear/Uranium</td>
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<td>1.7 x</td>
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<td>Biomass</td>
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<td>Wind</td>
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<tr>
<td>Solar</td>
<td>0.5</td>
<td>18.2 x</td>
</tr>
</tbody>
</table>

Solar Sources: Opportunity for Renewable H₂

Resource analysis underway
Bio-feedstock reforming is a near term option
Next Steps...

H2@Scale RD&D Roadmap that addresses issues including:

- Hydrogen production from diverse domestic sources
- Hydrogen for grid stability and energy storage
- Development of industrial scale hydrogen delivery and storage infrastructure
- Penetration of clean/sustainable (including renewable) hydrogen in current and future end-use markets—e.g. industrial applications

H2@Scale requires collaboration across stakeholders!
A Week of Hydrogen and Fuel Cells Celebration

EnergyGov Blogs

Hydrogen Fuel Cell Car Ride & Drives

National Hydrogen & Fuel Cell Day | 10-08

Reached Half a Million

Informational Events

Announcements

Direct Outreach
Going Forward

• Continue to strengthen R&D activities
  • H₂, fuel cells, safety, manufacturing, etc.
  • Cost, performance, durability need to be addressed

• Develop Infrastructure and H₂@Scale strategies & roadmaps

• Continue to conduct key analyses to guide RD&D and path forward
  • Life cycle cost; infrastructure, economic & environmental analyses, etc. (e.g. Medium/heavy duty vehicle target setting underway)

• Address HTAC comments on safety & event response

• Leverage activities to maximize impact
  • U.S. and global partnerships, H₂USA, States

Save the date: Annual Merit Review (AMR)
Week of June 5, 2017- Washington DC
Thank You

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

hydrogenandfuelcells.energy.gov
Additional Information
Senate Report

- The Committee recommends $92,000,000 for Hydrogen and Fuel Cell Technologies.
- Within available funds, the committee recommends not less than $7,000,000 to demonstrate an integrated hydrogen renewable energy production, storage, and transportation fuel distribution and retailing system.
- Within Hydrogen Fuel research and development, the Committee recommends $3,000,000 for carbon-free production of hydrogen using new chemical synthesis methods that break apart natural gas to solid carbon and hydrogen.
- The Committee recommends $7,000,000 for Safety, Codes, and Standards.

House Report

- The Committee recommends $97,000,000 for Hydrogen and Fuel Cell Technologies.
- Within available funds, the recommendation includes $13,000,000 for Technology Validation, of which $2,000,000 is for the EERE share of the integrated energy systems work with the Office of Nuclear Energy and $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 Committee recognizes the progress of the program and expresses continued support for stationary, vehicle, motive, and portable power applications of this technology. The Department is encouraged to explore technologies that advance the storage and transportation fuel distribution and retailing systems.
- 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.
- The Department is encouraged to engage the appropriate national laboratories to pursue novel advanced demonstrations that validate how integrated, renewable hydrogen production and storage infrastructure supports transportation and non-transportation applications. The Department is directed to submit not later than 180 days after the enactment of this Act a report on its efforts a report on its efforts to deploy hydrogen infrastructure.
### DOE H₂ and Fuel Cells Strategy

#### BARRIERS

<table>
<thead>
<tr>
<th>R&amp;D</th>
<th>Infrastructure Development</th>
<th>Manufacturing and Supply Chain</th>
<th>Safety, Codes and Standards (SCS)</th>
<th>Public Acceptance and Awareness</th>
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<tr>
<td></td>
<td>Fuel Cell Cost and Durability</td>
<td>Hydrogen Storage</td>
<td>Hydrogen Production and Delivery</td>
<td></td>
</tr>
</tbody>
</table>

#### NEAR TO MID-TERM

<table>
<thead>
<tr>
<th>Low PGM catalysts, MEAs, durability, components</th>
<th>700 bar tanks, composites</th>
<th>H₂ from NG/electrolysis; delivered H₂, high P, compression</th>
</tr>
</thead>
</table>

#### LONG-TERM

<table>
<thead>
<tr>
<th>PGM-free catalysts, advanced membranes, AEMs, MEAs</th>
<th>Materials R&amp;D for low P storage, cold/cryo-compressed</th>
<th>H₂ from renewables (PEC, biological, etc.), pipelines, low P option</th>
</tr>
</thead>
</table>

#### ADDITIONAL

<table>
<thead>
<tr>
<th>Enablers: H₂FIRST-station validation, metering, sensors, etc.</th>
<th>Materials compatibility, station innovation, cost reduction- H-Prize</th>
<th>Mfg. processes and scale up; strong supply base- H₂ and fuel cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalyst, MEA and tank manufacturing; QC; cost &amp; reliability; supply chain</td>
<td>Set back distances, fueling protocols; safety dissemination</td>
<td>Risk mitigation; National and International harmonization of SCS</td>
</tr>
<tr>
<td>H₂Tools, code officials, responders; early markets; H₂USA</td>
<td>Widespread Outreach, Education &amp; Social Acceptance</td>
<td></td>
</tr>
</tbody>
</table>

**Level of Difficulty**
- High
- Medium
- Low to Medium
Funding Announcements for 2017

$30 million in funding to

- Leverage hydrogen and fuel cell lab consortia under DOE’s Energy Materials Network (EMN)
  - **ElectroCat**: PGM-free catalysts (Topic 1)
  - **HydroGEN**: Advanced water splitting materials (Topic 2)
  - **HyMARC**: Solid-state materials for H₂ storage (Topic 3)
- Develop precursors for low cost, high strength carbon fiber for high pressure H₂ storage vessels (Topic 4)

**Deadlines**
- **Concept papers**: Dec. 20, 2016 5:00 PM ET
- **Full application**: Feb. 21, 2017 5:00 PM ET

**More Information**
Visit EERE Exchange website at eere-exchange.energy.gov

DE-FOA-0001647
Highlights: Renewable H₂ Production

Cost* Renewable H₂ Production Pathways

World Record

Solar-to-hydrogen Efficiency

16.4%

Benchmarked under outdoor sunlight at NREL

H₂ Cost* Targets

Less than $4/gge by 2020

Less than $7/gge Early Market

*at the pump

*high volume cost projections. See DOE Record for details.
Highlights: H₂ Delivery

Cost of Delivering and Dispensing H₂ from Central Production

- First ever liquefaction of a gas from room temperature with magnetocaloric cooling
- Record breaking 100°C temperature span

- Projected to **high volume with economies of scale**
- **Delivery/dispensing** apportionment of the <$4/kg P&D target

Source: PNNL, Emerald Energy, Ames Laboratory
Highlights: H$_2$ Storage

Cost* of High Pressure H$_2$ Storage System

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2015</th>
<th>2020</th>
<th>Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost ($/kWh)</td>
<td>17</td>
<td>15</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

- Composite Materials & Processing
- BOP & Assembly
- Other Manufacturing Processes

*Assumes high volume (500K/yr.), 2007$, 700-bar type IV single tank system. Based on program record 15013

12% Net Cost Reduction since 2013 for H$_2$ storage systems


World’s First

- Two H$_2$ molecules adsorbed at a single metal site
- Synthetic path to materials with higher densities of adsorbed H$_2$
Highlights: Fuel Cells

Modeled Cost* of Fuel Cell System Over Time

* 80-kW_{net} PEM fuel cell system projected to high-volume* manufacturing

8,000 Hrs. Ultimate Durability Target Established

World Record

- Alkaline exchange Membrane
- Record breaking durability
- Opportunities in flow batteries/electrolysis

Source: SNL
“Toolbox” online:

- HyRAM
- HDSAM
- H2FAST
- H2A
- JOBS and more

Available now at:
http://energy.gov/eere/fuelcells/hydrogen-analysis-toolbox

H2Tools.org

September/October 2016: Supply Chain Exchange and Partnership Development Regional Forum- North Canton, OH
Organized by Ohio Fuel Cell Coalition (OFCC) and Partners

Supplier engagement & collaboration & information readily and publicly accessible
Update: Fuel Cell Buses Status

AC TRANSIT FLEET

Largest in North America

AC Transit Fuel Cell Electric Bus

RECORDS

Record Durability:
More than 23,000 hours

Driven for approximately 1.8M miles

More than 15 million passengers

FTA Funding and Collaboration with DOE- NREL Data collection

Reliability and durability demonstrated in fuel cell electric buses

As of November, 2016
First Lady’s and Dr. Jill Biden’s Initiative: Joining Forces

Supporting veterans and their families in 3 areas:

- Wellness
- Employment
- Education

Strong Commitment by the H₂ and Fuel Cells Community

Air Liquide and PDC committed to hiring veterans for 10% of their workforce

Photo credit: philly.com
Outreach & Education

• San Diego Military Community Transition Summit: April 21, California

• Camp Pendleton Military Summit: Sep. 28-29, California

• Joint Base Lewis McChord Military Summit: Oct. 12-13, Tacoma, WA

• Hawaii Transition Summit, October 18, 19, Honolulu, Hawaii

Resources & Models

• JOBS Models
  • JOBS and economic impacts of Fuel Cells (JOBS FC)
  • JOBS and economic impacts of Hydrogen infrastructure (JOBS H2)
  • http://JOBSmodels.es.anl.gov

• Employment Report Update Underway
  • Planned release late 2017/early 2018
Key Tasks:

1. Economic criteria that must be met for H2@Scale.
2. Forecast hydrogen supply curves.
3. Forecast hydrogen demand curves.
5. Develop Sankey diagrams, and down-select scenarios.
6. Analysis of down-selected scenarios.
7. Analyze spatial issues of H2@Scale (e.g. proximity of supply and demand).
8. Comparison of H2@Scale impact with base case business as usual.

Techno-economic analysis will forecast the resource requirements and impact of H2@Scale.
Demonstration of Electrolyzer Grid Integration

FCTO is validating electrolyzer potential in energy storage.
H2@Scale RFI Key Themes – Interest in:

1. Innovative $H_2$ production technologies
   - Electrolyzer cost reduction
   - Alternative feedstocks (e.g. solid and liquid waste, process gases)
   - Integrate $H_2$ production with waste heat (e.g. from nuclear or steelmaking)

2. Integrated $H_2$ systems (e.g., reversible fuel cells,)

3. Innovative $H_2$ storage and delivery technologies
   - Liquid organic carriers, metal organic frameworks; bulk storage

4. Use of $H_2$ to enable grid stability and energy storage

5. Data collection & sharing on the value proposition and feasibility of H2@Scale
   - Demonstration of electrolyzer integration with the grid; RD&D on power-to-gas

6. Deployments of $H_2$ in near-term markets, including for buses, ammonia, & steel

*RFI & workshop will guide cross-cutting H2@Scale RD&D Roadmap*
Life-Cycle GHG Emissions- Today’s Cars

Almost 50% reduction in GHG can be achieved with today’s FCEVs.

Source: Program Record 16004 (https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf)
Well to Wheels Emissions and Petroleum Use*

Electric Drive With Low Carbon Fuels - Pathway with lowest GHG emissions and petroleum use

Program Record #13005: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

*2035 Technology except for 2012 gasoline
Collaborations and Partnerships

R&D
- Pre-Competitive R&D
- USCAR, energy companies, EPRI and utilities
- Implementing Agreements
- 25 countries

Demonstration & Deployment
- State Partnerships and Collaborations

Accelerated Commercialization
- International Government Coordination
- 18 countries and European Commission
- Public-Private Partnership
- More than 50 partners
- FCHEA (trade association)

Hydrogen and Fuel Cells Technical Advisory Committee (HTAC)

Industry, academia and state & federal stakeholders working together