Fuel Cell Technologies Overview

HTAC
Washington, DC
5/10/2012

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Fuel Cell Technologies Program
Program Manager
• Fuel Cell Industry Overview
  – Clean Energy Patents
  – Global OEM Update
• Update on Progress
  – RD&D
  – Recovery Act
• Budget Update
  – Funding Announcements
• Additional Information
Overview
Fuel Cells - An Emerging Industry

Fuel Cell Patents Geographic Distribution 2002-2011

Top 10 companies: GM, Honda, Samsung, Toyota, UTC Power, Nissan, Ballard, Plug Power, Panasonic, Delphi Technologies

Clean Energy Patent Growth Index\(^1\) shows that fuel cell patents lead in the clean energy field with over 950 fuel cell patents issued in 2011.

* Nearly double the second place holder, solar, which has ~540 patents.

\(^1\) http://cepgi.typepad.com/files/cepgi-4th-quarter-2011-1.pdf
Worldwide Commitment to FCEVs

The world’s leading automakers have committed to develop FCEVs. Germany and Japan have announced plans to expand the hydrogen infrastructure.

Major Auto Manufacturers’ Activities and Plans for FCEVs

**Toyota**
- 2010-2013: U.S. demo fleet of 100 vehicles
- 2015: Target for large-scale commercialization
- “FCHV-adv” can achieve 431-mile range and 68 mpgge

**Honda**
- Clarity FCX named “World Green Car of the Year”; EPA certified 72mpgge; leasing up to 200 vehicles
- 2015: Target for large-scale commercialization

**Daimler**
- Small-series production of FCEVs began in 2009
- Plans for tens of thousands of FCEVs per year in 2015 – 2017 and hundreds of thousands a few years after
- In partnership with Linde to develop fueling stations.
  - Recently moved up commercialization plans to 2014

**General Motors**
- 115 vehicles in demonstration fleet
- 2012: Technology readiness goal for FC powertrain
- 2015: Target for commercialization

**Hyundai-Kia**
- 2012-2013: 2000 FCEVs/year
- 2015: 10,000 FCEVs/year
  - “Borrego” FCEV has achieved >340-mile range.

**Volkswagen**
- Expanded demo fleet to 24 FCEVs in CA
- Recently reconfirmed commitment to FCEVs

**SAIC (China)**
- Partnering with GM to build 10 fuel cell vehicles in 2010

**Ford**
- Alan Mulally, CEO, sees 2015 as the date that fuel cell cars will go on sale.

**BMW**
- BMW and GM plan to collaborate on the development of fuel cell technology

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**H₂Mobility** - evaluate the commercialization of H₂ infrastructure and FCEVs
- **Public-private partnership between NOW and 9 industry stakeholders including:**
  - Daimler, Linde, OMV, Shell, Total, Vattenfall, EnBW, Air Liquide, Air Products
- **FCEV commercialization by 2015.**

**UKH₂Mobility** will evaluate anticipated FCEV roll-out in 2014/2015
- **13 industry partners including:**
  - Air Liquide, Air Products, Daimler, Hyundai, ITM Power, Johnson Matthew, Nissan, Scottish & Southern Energy, Tata Motors, The BOC Group, Toyota, Vauxhall Motors
- **3 UK government departments**
- **Government investment of £400 million to support development, demonstration, and deployment.**

13 companies and Ministry of Transport announce plan to commercialize FCEVs by 2015
- **100 refueling stations in 4 metropolitan areas and connecting highways planned, 1,000 station in 2020, and 5,000 stations in 2030.**
The Program is an integrated effort, structured to address all the key challenges and obstacles facing widespread commercialization.

Nearly 300 projects currently funded at companies, national labs, and universities/institutes

More than $1B DOE funds spent from FY 2007 to FY 2011
Federal Role in Fuel Cells:
RD&D to Deployments

**DOE R&D**
- Reduces cost and improves performance

**Examples:**
- Reduced cost of fuel cells 30% since 2008, 80% since 2001
- Reduced cost of electrolyzer stacks 60% since 2007

**Transportation Fuel Cell System Cost**
- Projected to high-volume (500,000 units per year)
  - Status: $49/kW (high vol)
  - Target: $30/kW

**DOE Demonstrations & Technology Validation**
- Validate advanced technologies under real-world conditions
- Feedback guides R&D
- Examples—validated:
  - 59% efficiency
  - 254 mile range (independently validated 430-mile range)
  - 75,000-mi durability
- Program also includes enabling activities such as codes & standards, analysis, and education.

**Deployments**
- Market Transformation
- DOE Recovery Act Projects
- Government Early Adoption (DoD, FAA, California, etc.)
  - IDIQ*
- Tax Credits: 1603, 48C

Recovery Act & Market Transformation Deployments
- 1,000 fuel cell deployments in ~ 2 years
- 1 million hours of operation

*IDIQ = indefinite delivery/indefinite quality
Assessing the Impact of DOE Funding

DOE funding has led to 313 patents, ~33 commercial technologies and >60 emerging technologies.

DOE’s Impact: ~$70M in funding for specific projects was tracked – and found to have led to nearly $200M in industry investment and revenues.

>310 PATENTS resulting from EERE-funded R&D:
- Includes technologies for hydrogen production and delivery, hydrogen storage, and fuel cells

Examples

- 3M
- BASF Catalysts LLC
- Proton Energy Systems
- DuPont
- Quantum Technologies
- BASF
- Catalysts LLC
- Dynalene, Inc.

Source: Pacific Northwest National Laboratory


*Partial data for 2012
The mission of the Hydrogen and Fuel Cells Program is to enable the widespread commercialization of hydrogen and fuel cell technologies through:

- basic and applied research
- technology development and demonstration
- Addressing institutional and market challenges

Key Goals: Develop hydrogen and fuel cell technologies for:

1. Early markets (e.g., stationary power, forklifts, portable power)
2. Mid-term markets (e.g., residential CHP, auxiliary power, buses and fleet vehicles)
3. Longer-term markets, 2015-2020 (including mainstream transportation, with focus on passenger cars)
The Program addresses the key challenges facing the widespread commercialization of fuel cells.

**Key Challenges**

**Technology Barriers**

<table>
<thead>
<tr>
<th>Fuel Cell Cost &amp; Durability</th>
<th>Technology Validation:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targets:</strong></td>
<td>Technologies must be demonstrated under real-world conditions.</td>
</tr>
<tr>
<td><em>Stationary Systems:</em> $1,000 to $1,500 per kW, 60,000-80,000 hr durability</td>
<td></td>
</tr>
<tr>
<td><em>Vehicles:</em> $30 per kW, 5,000-hr durability</td>
<td></td>
</tr>
</tbody>
</table>

**Hydrogen Cost**

Target: $2 – 4 $/gge, (dispensed and untaxed)

**Hydrogen Storage Capacity**

Target: > 300-mile range for vehicles—without compromising interior space or performance

**Economic & Institutional Barriers**

<table>
<thead>
<tr>
<th>Safety, Codes &amp; Standards Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Manufacturing &amp; Supplier Base</td>
</tr>
<tr>
<td>Public Awareness &amp; Acceptance</td>
</tr>
<tr>
<td>Hydrogen Supply &amp; Delivery Infrastructure</td>
</tr>
</tbody>
</table>

**Market Transformation**

Assisting the growth of early markets will help to overcome many barriers, including achieving significant cost reductions through economies of scale.
Strategic technical analysis guides focus areas and priorities for budget.

Need to reduce high volume cost from $49/kW to $30/kW and increase durability from 2,500-hr to 5,000-hr.

Key Focus Areas for R&D

Sensitivity Analysis helps guide R&D

Strategies to Address Challenges – Catalyst Examples

- Lower PGM Content
- Pt Alloys
- Novel Support Structures
- Non-PGM catalysts

Targeted 80 kW PEM fuel cell system cost: $30/kW at 500,000 units/yr
**Projected High-Volume Cost of Hydrogen Production**¹ (Delivered²) — Status

<table>
<thead>
<tr>
<th>Distributed Production (near term)</th>
<th>Central Production (longer term)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrolysis</strong></td>
<td><strong>Electrolysis</strong></td>
</tr>
<tr>
<td>Feedstock variability: $0.03 - $0.08 per kWh</td>
<td>Feedstock variability: $0.03 - $0.08 per kWh</td>
</tr>
<tr>
<td><strong>Bio-Derived Liquids</strong></td>
<td><strong>Biomass Gasification</strong></td>
</tr>
<tr>
<td>Feedstock variability: $1.00 - $3.00 per gallon ethanol</td>
<td>Feedstock variability: $40- $120 per dry short ton</td>
</tr>
<tr>
<td><strong>Natural Gas Reforming</strong></td>
<td></td>
</tr>
<tr>
<td>Feedstock variability: $4.00 - $10.00 per MMBtu</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

[1] Cost ranges for each pathway are shown in 2007$ based on high-volume projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates.

[2] Costs include total cost of production and delivery (dispensed, untaxed). Forecourt compression, storage and dispensing added an additional $1.82 for distributed technologies, $2.61 was added as the price of delivery to central technologies. All delivery costs were based on the Hydrogen Pathways Technical Report (NREL, 2009).
Develop technologies to produce hydrogen from clean, domestic resources at a delivered and dispensed cost of $2-$4/gge H₂ by 2020.
Significance of Results

- Wind incentives amounting to $0.02/kWh result in a $~1/kg H₂ cost reduction.
- These incentives allow some sites to meet DOE targets.
- Interactive tool allows users to provide input to the analysis and see updated results immediately.

Users can:
- Explore the effects of the four different balance scenarios; cost or power with & without the purchase of peak summer electricity.
- Compare H₂ costs with DOE targets.
- See the effects of wind power incentives on H₂ costs.
- Add compression, storage, and dispensing costs.
- See the effects of local topography.
- See what’s at the site with Google Street View™.

International Collaboration: Resource Analysis

Objectives*

- Through collaboration with IEA analysts and IPHE, perform comprehensive technical and market analysis of
  - Hydrogen technologies and resources
  - Resource supply and demand related to projected hydrogen use
  - Global hydrogen infrastructure
  - GHG emissions and petroleum reduction
- Identify international flows of:
  - Energy
  - Hydrogen
  - Natural gas, LNG, coal
  - Platinum and other materials

*Objectives for IEA Hydrogen Implementing Agreement Task 30
Recently Released States Reports

Northeast Hydrogen Fuel Cell Industry Status and Direction

Report by Joel M. Rinebold, Alexander C. Barton, and Adam J. Brzozwski
Connecticut Center for Advanced Technology, Inc.

Highlights potential for fuel cell industry in northeast US detailing relevant information on products and markets, employment, and system efficiency and cost. 1.85 GW opportunity identified.


State by state plans identifying fuel cell opportunities and potential implementation strategies (drafts in process)

Targets: Geographic Information System (GIS) Mapping

Food Sales
Food Services
Inpatient Healthcare

Education
Airports (Military)
Alternative Fueling Stations

Lodging

Energy Intensive Industry

## Preliminary Analysis - Economic Impact Summary

<table>
<thead>
<tr>
<th></th>
<th>CT</th>
<th>NY</th>
<th>MA</th>
<th>ME</th>
<th>NH</th>
<th>RI</th>
<th>VT</th>
<th>NJ</th>
<th>Regional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Employment</td>
<td>2,529</td>
<td>1,728</td>
<td>964</td>
<td>18</td>
<td>45</td>
<td>32</td>
<td>16</td>
<td>111</td>
<td>5,443</td>
</tr>
<tr>
<td>Total Revenue / Investment in 2010 ($ million)</td>
<td>$496</td>
<td>$292</td>
<td>$171</td>
<td>$2.9</td>
<td>$8.7</td>
<td>$6.9</td>
<td>$3.3</td>
<td>$26.5</td>
<td>$1,009</td>
</tr>
<tr>
<td>Total Supply Chain Companies</td>
<td>599</td>
<td>183</td>
<td>322</td>
<td>28</td>
<td>25</td>
<td>19</td>
<td>5</td>
<td>8</td>
<td>1189</td>
</tr>
</tbody>
</table>

The Connecticut Center for Advance Technology, Inc. www.ccat.us

Source: US DOE 5/11/2012 eere.energy.gov
Spark spread determines regions for favorable use of natural gas
Red/orange regions: High electricity cost, low natural gas cost- favorable for DG

Lower natural gas prices offer increased opportunities for CHP and distributed generation- current vs. 2007

Source: NREL
Aggregated results provide a benchmark in time of state-of-the-art fuel cell durability

NREL is aggregating and analyzing durability results by application that protect proprietary data, providing a benchmark in time of state-of-the-art fuel cell durability. Results include 82 data sets from 10 fuel cell developers.

<table>
<thead>
<tr>
<th>Application</th>
<th>Avg Projected Time to 10% Voltage Drop</th>
<th>Avg Operation Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backup power</td>
<td>2,400</td>
<td>1,100</td>
</tr>
<tr>
<td>Automotive</td>
<td>4,000</td>
<td>2,700</td>
</tr>
<tr>
<td>Forklift</td>
<td>14,600</td>
<td>4,400</td>
</tr>
<tr>
<td>Prime</td>
<td>11,200</td>
<td>7,000</td>
</tr>
</tbody>
</table>

PEM & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing.

Please send inquiries to Fuelcelldatacentre@ee.doe.gov
DOE FCT Program adjusted FY 2012 budget based on Senate Mark language.

Excerpts from Senate Mark Language in the FY 2012 Appropriation
“The Committee recognizes the progress and achievements of the Fuel Cell Technologies program. The program has met or exceeded all benchmarks, and has made significant progress in decreasing costs and increasing efficiency and durability of fuel cell and hydrogen energy systems.”

“Within the available funds, the Committee recommends funding is provided for Technology Validation focused on passenger vehicle and hydrogen infrastructure applications, hydrogen fuels R&D, and for Market Transformation in early markets.”

IMPACT
FY 2012 Request: $100.5 M
FY 2012 Appropriation: $104 M
Following guidance from the Senate mark language:
• $1 M was added to the original request for Technology Validation (total $9M)
• $3 M was added for Market Transformation (total $3M)
($33.8 M already planned for Hydrogen Fuels R&D)
### Funding ($ in thousands)

<table>
<thead>
<tr>
<th>Key Activity</th>
<th>FY 2010 Appropriation</th>
<th>FY 2011 Allocation</th>
<th>FY 2012 Appropriation</th>
<th>FY 2013 Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell Systems R&amp;D</td>
<td>75,609</td>
<td>41,916</td>
<td>44,812</td>
<td>38,000</td>
</tr>
<tr>
<td>Hydrogen Fuel R&amp;D</td>
<td>45,750</td>
<td>32,122</td>
<td>34,812</td>
<td>27,000</td>
</tr>
<tr>
<td>Technology Validation</td>
<td>13,005</td>
<td>8,988</td>
<td>9,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Market Transformation</td>
<td>15,005</td>
<td>0</td>
<td>3,000</td>
<td>0</td>
</tr>
<tr>
<td>Safety, Codes &amp; Standards</td>
<td>8,653</td>
<td>6,901</td>
<td>7,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Education</td>
<td>2,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Systems Analysis</td>
<td>5,408</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Manufacturing R&amp;D</td>
<td>4,867</td>
<td>2,920</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$170,297</strong></td>
<td><strong>$95,847</strong></td>
<td><strong>$103,624</strong></td>
<td><strong>$80,000</strong></td>
</tr>
</tbody>
</table>

**Notes:** Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D. FY11, FY12 include SBIR/STTR funds to be transferred to the Science Appropriation; prior years exclude this funding.

FY 13 House Mark $82 M
FY 13 Senate Mark $104 M
### Fuel Cell Technologies Budget ($ Million)

<table>
<thead>
<tr>
<th>Year</th>
<th>Request</th>
<th>Actual</th>
<th>House Mark</th>
<th>Senate Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY 2010</td>
<td>$174</td>
<td>$137</td>
<td>$98</td>
<td>$104</td>
</tr>
<tr>
<td>FY 2011</td>
<td>$68</td>
<td>$100</td>
<td>$104</td>
<td></td>
</tr>
<tr>
<td>FY 2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY 2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: US DOE 5/11/2012 eere.energy.gov*
The conference committee appropriation language changes how new R&D awards could be funded.

Excerpts from Language

“The conferees are concerned the Department is over-committing future budgets by announcing multi-year awards subject to future appropriations for a substantial portion of activities within Energy Programs.”

“The Department is directed to transition to a model in which it fully funds multi-year awards with appropriated funds, except in the cases of major capital projects, management and operating contracts, and large research centers which require multi-year awards subject to appropriations.”

<table>
<thead>
<tr>
<th>POTENTIAL FUNDING CHANGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>CURRENT SYSTEM</td>
</tr>
<tr>
<td>Fund projects on a fiscal year basis</td>
</tr>
<tr>
<td>Number of awards based on projected spending pattern</td>
</tr>
<tr>
<td>Quantitative Go/No Go milestones</td>
</tr>
</tbody>
</table>
**Methodology** - Includes competitive review processes, peer reviews & risk analyses

**Project & Program Review Processes**
- Annual Merit Review & Peer Evaluation meetings (EE, NE, FE, SC)
- FreedomCAR & Fuel Partnership Tech Team reviews (monthly)
- Other peer reviews- National Academies, GAO, etc.
- DOE quarterly reviews and progress reports

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

### Risk Analysis & Technology Reviews
- **Targets**
- “Critical Path” needs
- Technology Gaps

#### RD&D Plan and Solicitation Topics

**Example Fuel Cell Membrane Targets**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>2011</th>
<th>2017</th>
<th>Nafion®</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>ohm cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max operating temp and 40 – 80 kPa water partial pressure</td>
<td>0.023 (40 kPa)</td>
<td>0.012 (80 kPa)</td>
<td>0.02</td>
<td>0.186</td>
</tr>
<tr>
<td>80°C and water partial pressures from 25 - 45 kPa</td>
<td>ohm cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30°C and water partial pressures up to 4 kPa</td>
<td>ohm cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-20°C</td>
<td>ohm cm²</td>
<td>0.1</td>
<td>0.2</td>
<td>0.179</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>°C</td>
<td></td>
<td>&lt;120</td>
<td>±120</td>
</tr>
<tr>
<td>Minimum electrical resistance</td>
<td>ohm cm²</td>
<td>1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>$/m²</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycles w/10 sccm crossover</td>
<td>&gt;20,000</td>
<td>20,000</td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Technical targets help guide go/no-go decisions.**

<table>
<thead>
<tr>
<th>Project Number</th>
<th>Project Title</th>
<th>PI Name &amp; Organization</th>
<th>Final Score</th>
<th>Continue</th>
<th>Discontinued</th>
<th>Other</th>
<th>Summary Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>Fluoroalkyl-Phosphonic-Acid-Based Proton Conductors</td>
<td>Xxx University</td>
<td>2.7</td>
<td>X</td>
<td></td>
<td></td>
<td>Progress was made in molecular dynamics modeling of model compounds, but the membranes synthesized failed in testing and did not meet the conductivity targets. The project will not be continued.</td>
</tr>
</tbody>
</table>

Over $19M saved in the last 3 years through go/no-go decisions

Reviewer comments for projects posted online annually. Projects discontinued/ work scope altered based on performance & likelihood of meeting goals.
Example - Target Table for Electrocatalysts

<table>
<thead>
<tr>
<th>Electrocatalysts for Transportation Applications</th>
<th>Statusa</th>
<th>Targetsb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platinum group metal (PGM) total content (both electrodes)</td>
<td>0.19 g/kW</td>
<td>0.125 g/kW</td>
</tr>
<tr>
<td>PGM Total Loading</td>
<td>0.15 mg/cm²</td>
<td>0.125 mg/cm²</td>
</tr>
<tr>
<td>Loss in catalytic (mass) activityc</td>
<td>&lt;40%</td>
<td>&lt;40% loss of initial</td>
</tr>
<tr>
<td>Catalyst support lossc</td>
<td>&lt;10% mass loss</td>
<td>&lt;10% mass loss</td>
</tr>
<tr>
<td>Mass activitye</td>
<td>0.24 A/mg Pt in MEA</td>
<td>&gt;0.44 A/mg Pt new alloy in RDE</td>
</tr>
<tr>
<td>Activity per volume of supported catalyst (non-PGM)f</td>
<td>60 A/cm³ (measured) 160 A/cm³ (extrapolated)</td>
<td>&gt;300 A/cm³</td>
</tr>
</tbody>
</table>

- a single cell status — will require scale-up
- b preliminary targets — approval pending
- c after 30,000 cycles from 0.6 – 1.0 V; after 400 hours at 1.2 V
- d after 400 hours at 1.2 V
- e baseline @ 900mV_RH=free
- f baseline @ 800mV_RH=free

H = High (significant challenge)  M = Medium  M/H = Medium/High  L = Low (minimal challenge)
“Go / No-go” decisions are used in downselecting certain research pathways to focus on the most promising areas. They are defined by performance-based technical milestones and quantitative metrics. Expert Panels are convened for independent assessments.

A “no-go” decision
- May indicate that further advances in basic science are needed
- May eliminate an entire technology pathway

Key examples
- Single-walled Carbon Nanotubes — “no-go”
- Thermochemical Hydrogen Production — three cycles selected out of 350
- Sodium Borohydride for On-Board Vehicular Hydrogen Storage — “no-go”
- On-board Fuel Processing — “no-go”

The decision tree used by the Program in the process of down-selecting pure carbon single-walled nanotubes (SWNTs) for hydrogen storage.

As a result of the first no-go decision shown on the left side of the figure, funding was redirected to the areas shown on the right side of the figure.

Funding Opportunity Announcements & Request for Information

<table>
<thead>
<tr>
<th>FY 2012 FOAs</th>
<th>$M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect Performance Data on Fuel Cell Electric Vehicles</td>
<td>$6.0</td>
</tr>
<tr>
<td>Hydrogen Fueling Stations and Innovations in Hydrogen Infrastructure Technologies</td>
<td>$2.0</td>
</tr>
<tr>
<td>Fuel Cell Powered Baggage Vehicles at Commercial Airports</td>
<td>$2.5</td>
</tr>
<tr>
<td>Zero-Emission Cargo Transport Vehicles (VTP)</td>
<td>$10.0</td>
</tr>
</tbody>
</table>

Request for Information

- Fuel Cell RFI on Preliminary Cost, Performance, and Durability Targets for Class I, II, and III Lift Trucks.
- Storage RFI on Early Market Targets
- Hydrogen Production RFI on Potential Topics for H-Prize
Examples of Key Activities: HTAC and Program Impact

• Annual Report
• Input on Program Requests
  – Feedback on H₂ Threshold Cost
  – H₂ Enabling Renewables Working Group (subcommittee)
  – H₂ Production Expert Panel
    • Comprised of experts from industry, academia and the national labs
    • Goals:
      – Evaluate current status of hydrogen production technologies
      – Identify remaining challenges
      – Prioritize R&D needs
      – Strategize how to best leverage R&D among DOE Offices and with other agencies

Tasked with establishing paths forward for the widespread production of affordable renewable hydrogen for current markets and future energy scenarios
Published more than 70 news articles in FY 2011 (including blogs, progress alerts, and DOE FCT news alerts)

Communication and Outreach Activities include:

• Webinar Series
  • Continuing series of informational webinars led by FCT and partners on various topics.

• News Items
  • Energy Department Awards More Than $7 Million for Innovative Hydrogen Storage Technologies in Fuel Cell Electric Vehicles

• Monthly Newsletter

• Blogs

"These technologies are part of a broad portfolio that will create new American jobs, reduce carbon pollution, and increase our competitiveness in today's global clean energy economy."
The DOE Fuel Cell Technologies Program also funds the development and publication of key reports:

**The Business Case for Fuel Cells: Why Top Companies are Purchasing Fuel Cells Today**

**State of the States: Fuel Cells in America**

**2010 Fuel Cell Market Report**
By Breakthrough Technologies Institute, Inc. [http://www.btionline.org/](http://www.btionline.org/)

**Annual Merit Review & Peer Evaluation Proceedings**
Includes downloadable versions of all presentations at the Annual Merit Review
[http://www.hydrogen.energy.gov/annual_review11_proceedings.html](http://www.hydrogen.energy.gov/annual_review11_proceedings.html)

**Annual Merit Review & Peer Evaluation Report**
Summarizes the comments of the Peer Review Panel at the Annual Merit Review and Peer Evaluation Meeting

**Annual Progress Report**
Summarizes activities and accomplishments within the Program over the preceding year, with reports on individual projects
[www.hydrogen.energy.gov/annual_progress.html](http://www.hydrogen.energy.gov/annual_progress.html)

**Next Annual Review:** May 14 & 18, 2012 Arlington, VA
Partnerships & Collaboration

Federal Agencies
- DOC
- DOD
- DOE
- DOT
- EPA
- GSA
- DOI
- DHS
- NASA
- NSF
- USDA
- USPS
- Interagency coordination through staff-level Interagency Working Group (meets monthly)
- Assistant Secretary-level Interagency Task Force mandated by EPACT 2005.

DOE Hydrogen & Fuel Cells Program

External Input
- Annual Merit Review & Peer Evaluation
- H2 & Fuel Cell Technical Advisory Committee
- National Academies, GAO, etc.

Industry Partnerships & Stakeholder Assn’s.
- Tech Teams (USCAR, energy companies- U.S. DRIVE)
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- Hydrogen Utility Group
- ~ 65 projects with 50 companies

Universities
- ~ 50 projects with 40 universities

International
- IEA Implementing agreements – 25 countries
- International Partnership for Hydrogen & Fuel Cells in the Economy – 17 countries & EC, 30 projects

State & Regional Partnerships
- California Fuel Cell Partnership
- California Stationary Fuel Cell Collaborative
- SC H2 & Fuel Cell Alliance
- Upper Midwest Hydrogen Initiative
- Ohio Fuel Coalition
- Connecticut Center for Advanced Technology

National Laboratories
- National Renewable Energy Laboratory
  P&D, S, FC, A, SC&S, TV, MN
- Argonne
  A, FC, P&D, SC&S
- Los Alamos
  S, FC, SC&S
- Sandia
  P&D, S, SC&S
- Pacific Northwest
  P&D, S, FC, SC&S, A
- Oak Ridge
  P&D, S, FC, A, SC&S
- Lawrence Berkeley
  FC, A
- Lawrence Livermore
  P&D, S, SC&S
- Savannah River
  S, P&D
- Brookhaven
  S, FC
- Idaho National Lab
  P&D

Other Federal Labs:
- Jet Propulsion Lab
- National Institute of Standards & Technology
- National Energy Technology Lab (NETL)

P&D = Production & Delivery; S = Storage; FC = Fuel Cells; A = Analysis; SC&S = Safety, Codes & Standards; TV = Technology Validation; MN = Manufacturing
Adam Weber (LBNL) honored as Energy Technology Division Supramaniam Srinivasan Young Investigator Award from The Electrochemical Society in Seattle.

Scott Samuelsen (UC Irvine) named a White House Champion of Change for his work as Director of the Advanced Power and Energy Program and the National Fuel Cell Research Center.

Dr. Fernando Garzon (LANL) was elected President of the National Electrochemical Society (ECS).

3 Presidential Awardees:

- **Professor Susan Kauzlarich** – UC Davis, a 2009 recipient of the *Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring*—and a partner of the Chemical Hydrogen Storage Center of Excellence

- **Dr. Jason Graetz** – Brookhaven National Laboratory, a 2009 recipient of the *Presidential Early Career Award for Scientists and Engineers*—and a partner of the Metal Hydride Center of Excellence

- **Dr. Craig Brown** – NIST, a 2009 recipient of the *Presidential Early Career Award for Scientists and Engineers*—and a Partner of the Hydrogen Sorption Center of Excellence
Additional Information
Projected high-volume cost of fuel cells has been reduced to $49/kW (2011)*

• More than 30% reduction since 2008

• More than 80% reduction since 2002

*Based on projection to high-volume manufacturing (500,000 units/year). The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the DOE Program at the laboratory scale. Additional efforts would be needed for integration of components into a complete automotive system that meets durability requirements in real-world conditions.
Demonstrations are essential for validating technologies in integrated systems.

Real-world Validation

Vehicles & Infrastructure

- >180 fuel cell vehicles and 25 hydrogen fueling stations
- 3.6 million miles traveled
- 152,000 kg of hydrogen produced or dispensed
- 2,500 hours (nearly 75K miles) durability
- 5 minute refueling time (4 kg of hydrogen)
- Vehicle Range: ~196 – 254 miles (430 miles on separate FCEV)

Buses (with DOT)

- H₂ fuel cell buses have a 42% to 139% better fuel economy when compared to diesel & CNG buses

Forklifts

- Over 150,000 total refuelings since 2009

CHHP (Combined Heat, Hydrogen and Power)

- Demonstrated the world’s first facility for co-producing hydrogen and power (with 54% efficiency)
The Business Case for Fuel Cells: Why Top Companies are Purchasing Fuel Cells Today
34 companies profiled in the report, cumulatively, have ordered, installed or deployed:
- more than 1,000 fuel cell forklifts;
- >250 fuel cells totaling 30+ MWs of stationary power;
- more than 240 fuel cell units at telecom sites.

State of the States: Fuel Cells in America
Report analyzing the seven regions of the United States, compiling state activities supporting fuel cell and hydrogen policy, as well as installations and demonstrations in each state.

Emerging Market Opportunities for States

Hydrogen and fuel cell technologies can be utilized across a wide spectrum of industries for several different applications including:
- Material Handling Equipment
- Backup power
- Combined-heat-and-power

Major companies including FedEx, Coca-Cola, AT&T, Wegmans, and Whole Foods (among others) are utilizing fuel cell technology today.

Additional States to Watch

Hawaii - hydrogen station at Hickam Air Force Base, recently launched the Hawaii Hydrogen Initiative (H2I) with GM, starting a renewable hydrogen generation and refueling station with the Navy
Texas - Fuel cell forklift deployments by several major food distributors (e.g. HEB, Sysco)
Delaware - non-renewable fuel cells added to net metering, two fuel cell buses. home to major fuel cell component suppliers
Florida - Cleantech Industry Cluster includes fuel cells
Maryland - FuelWorks research center at University of Maryland, Whole Foods forklift fleet among country’s largest
UK H₂ Mobility plans fuel cell taxis at the 2012 London Olympics as a part of their greater goal to ensure the UK is positioned for the commercial roll-out of FCEVs

London landscape - largest urban zone in the EU with 23.8 million transport trips per average London day

- Clean Air Zone already implemented; clean-up of London buses (particulate filters, new hybrids); age limit to taxis; focus on ultra low emission vehicles (free access to congestion charge zones)
- Mayor Boris Johnson proponent – quoted in Leading to a Greener London: “London has an unrivalled opportunity to benefit from an emphatic shift to a low carbon economy. The time for trials and experiments is over. We are putting in place large scale programmes that can deliver significant CO2 reductions and billions of pounds in energy savings”
- The Greater London Authority has set aims and objectives to promote clean transportation via adoption of the London Hydrogen Action Plan:
  - Creating conditions for the deployment of hydrogen refuelling infrastructures
  - Considering all aspects of hydrogen supply and storage to ensure a future proof solution
  - Vehicle fleets (buses) being implemented in service

Intelligent Energy and HyTEC consortium is bringing the first zero emission taxi fleet to the streets of London for launch in time for the Olympics

5 taxis planned for use throughout Olympics
### Portable Power Targets

<table>
<thead>
<tr>
<th></th>
<th>Portable Power Applications, Under 2W¹</th>
<th>Portable Power Applications, 10-50 W¹</th>
<th>Portable Power Applications, 100-250 W¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Units</strong></td>
<td><strong>2011 Status</strong></td>
<td><strong>2015 Target</strong></td>
<td><strong>2011 Status</strong></td>
</tr>
<tr>
<td>Specific Power²</td>
<td>W/kg</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Power Density²</td>
<td>W/L</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Specific Energy²³</td>
<td>Wh/kg</td>
<td>110</td>
<td>230</td>
</tr>
<tr>
<td>Energy Density²³</td>
<td>Wh/L</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>Cost⁴</td>
<td>$/system</td>
<td>150</td>
<td>70</td>
</tr>
<tr>
<td>Durability⁵,⁶</td>
<td>hours</td>
<td>1500</td>
<td>5000</td>
</tr>
<tr>
<td>Mean Time Between Failures⁶,⁷</td>
<td>hours</td>
<td>500</td>
<td>5000</td>
</tr>
</tbody>
</table>

Revised FCT fuel cell APU targets published in 2010

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>2011 Status</th>
<th>2013 Targets</th>
<th>2015 Targets</th>
<th>2020 Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical efficiency at rated power</td>
<td>25%</td>
<td>30%</td>
<td>35%</td>
<td>40%</td>
</tr>
<tr>
<td>Power density</td>
<td>17 W/L</td>
<td>30 W/L</td>
<td>35 W/L</td>
<td>40 W/L</td>
</tr>
<tr>
<td>Specific power</td>
<td>20 W/kg</td>
<td>35 W/kg</td>
<td>40 W/kg</td>
<td>45 W/kg</td>
</tr>
<tr>
<td>Factory cost, stack plus required BOP</td>
<td>$750/kW</td>
<td>$700/kW</td>
<td>$600/kW</td>
<td>$500/kW</td>
</tr>
<tr>
<td>Factory cost, system</td>
<td>$2,000/kW</td>
<td>$1,400/kW</td>
<td>$1,200/kW</td>
<td>$1,000/kW</td>
</tr>
<tr>
<td>Transient response (10 to 90% rated power)</td>
<td>5 min</td>
<td>4 min</td>
<td>3 min</td>
<td>2 min</td>
</tr>
<tr>
<td>Start-up time from: 20 °C Standby conditions</td>
<td>50 min</td>
<td>45 min</td>
<td>45 min</td>
<td>30 min</td>
</tr>
<tr>
<td>Degradation with cycling</td>
<td>2.6%/1,000 h</td>
<td>2%/1,000 h</td>
<td>1.3%/1,000 h</td>
<td>1%/1,000 h</td>
</tr>
<tr>
<td>Operating lifetime</td>
<td>3,000 h</td>
<td>10,000 h</td>
<td>15,000 h</td>
<td>20,000 h</td>
</tr>
<tr>
<td>System availability</td>
<td>97%</td>
<td>97.5%</td>
<td>98%</td>
<td>99%</td>
</tr>
</tbody>
</table>

APU targets were developed using:
- Comparison with incumbent technology (diesel ICE APUs)
- An RFI process to obtain input from stakeholders
- Direct discussion with developers

Example: 2020 power density target

Stakeholder recommendations: 20 – 55 W/L

Incumbent technology: 11 – 33 (mean 20) W/L

Final DOE 2020 target: 40 W/L – within range suggested by stakeholders and superior to incumbent technology

Assumptions and supporting information can be found here:
http://hydrogen.energy.gov/pdfs/11001_apu_targets.pdf
**Micro-CHP Targets**

*Targets developed with input from stakeholders and the research community*

*Cost and durability are the major challenges*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>2011 Status</th>
<th>2015 Targets</th>
<th>2020 Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical efficiency at rated power(^b)</td>
<td>34-40%</td>
<td>42.5%</td>
<td>&gt;45% (^c)</td>
</tr>
<tr>
<td>CHP energy efficiency(^d)</td>
<td>80-90%</td>
<td>87.5%</td>
<td>90%</td>
</tr>
<tr>
<td>Equipment cost(^e), 2-kW(_{avg}) system</td>
<td>NA</td>
<td>$1,200/kW(_{avg})</td>
<td>$1,000/kW(_{avg})</td>
</tr>
<tr>
<td>Equipment cost(^e), 5-kW(_{avg}) system</td>
<td>$2,300 - $4,000/kW(_{avg})</td>
<td>$1,700/kW(_{avg})</td>
<td>$1,500/kW(_{avg})</td>
</tr>
<tr>
<td>Equipment cost(^e), 10-kW(_{avg}) system</td>
<td>NA</td>
<td>$1,900/kW(_{avg})</td>
<td>$1,700/kW(_{avg})</td>
</tr>
<tr>
<td>Transient response (10 90% rated power)</td>
<td>5 min</td>
<td>3 min</td>
<td>2 min</td>
</tr>
<tr>
<td>Start-up time from 20°C ambient temperature</td>
<td>&lt;30 min</td>
<td>30 min</td>
<td>20 min</td>
</tr>
<tr>
<td>Degradation with cycling(^h)</td>
<td>&lt;2%/1,000 h</td>
<td>0.5%/1,000 h</td>
<td>0.3%/1,000 h</td>
</tr>
<tr>
<td>Operating lifetime(^i)</td>
<td>12,000 h</td>
<td>40,000 h</td>
<td>60,000 h</td>
</tr>
<tr>
<td>System availability(^j)</td>
<td>97%</td>
<td>98%</td>
<td>99%</td>
</tr>
</tbody>
</table>

Assumptions and supporting information can be found here: http://hydrogen.energy.gov/pdfs/11016_micro_chp_target.pdf

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**2010 Independent Assessment of CHP Fuel Cell Status & Targets**

- Confident that by 2015, LT-PEM & HT-PEM can achieve 40,000 hr
- 45% electrical efficiency (2020 target) for 1-10kW systems is feasible for HT-PEM, LT-PEM depends on improved catalysts & higher operating temps
- SOFC systems are likely to achieve DOE targets for electrical and CHP efficiencies. 90% CHP efficiency is likely to be attainable by SOFC systems.
- Confident that by 2020, LT-PEM & HT-PEM can achieve $450-$750/kW, while SOFC can achieve $1000-2000/kW
### Funding ($ in thousands)

<table>
<thead>
<tr>
<th>EERE Program</th>
<th>FY 2010 Appropriation</th>
<th>FY 2011 Allocation</th>
<th>FY 2012 Appropriation</th>
<th>FY 2013 Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen &amp; Fuel Cell Technologies</td>
<td>170,297</td>
<td>95,847</td>
<td>103,624</td>
<td>80,000</td>
</tr>
<tr>
<td>Biomass &amp; Biorefinery Systems R&amp;D</td>
<td>216,225</td>
<td>179,979</td>
<td>199,276</td>
<td>270,000</td>
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<tr>
<td>Solar Energy</td>
<td>243,396</td>
<td>259,556</td>
<td>288,951</td>
<td>310,000</td>
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<tr>
<td>Wind Energy</td>
<td>79,011</td>
<td>78,834</td>
<td>93,254</td>
<td>95,000</td>
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<tr>
<td>Geothermal Technologies</td>
<td>43,120</td>
<td>36,992</td>
<td>37,862</td>
<td>65,000</td>
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<tr>
<td>Water Power</td>
<td>48,669</td>
<td>29,201</td>
<td>58,787</td>
<td>20,000</td>
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<tr>
<td>Vehicle Technologies</td>
<td>304,223</td>
<td>293,151</td>
<td>328,807</td>
<td>420,000</td>
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<tr>
<td>Building Technologies</td>
<td>219,046</td>
<td>207,310</td>
<td>219,204</td>
<td>310,000</td>
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<tr>
<td>Advanced Manufacturing</td>
<td>94,270</td>
<td>105,899</td>
<td>115,580</td>
<td>290,000</td>
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<tr>
<td>Federal Energy Management Program</td>
<td>32,000</td>
<td>30,402</td>
<td>29,891</td>
<td>32,000</td>
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<tr>
<td>Facilities &amp; Infrastructure</td>
<td>19,000</td>
<td>51,000</td>
<td>26,311</td>
<td>26,400</td>
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<tr>
<td>Weatherization and Intergovernmental</td>
<td>270,000</td>
<td>231,300</td>
<td>128,000</td>
<td>195,000</td>
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<tr>
<td>Program Direction</td>
<td>140,000</td>
<td>170,000</td>
<td>165,000</td>
<td>164,700</td>
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<tr>
<td>Strategic Programs</td>
<td>45,000</td>
<td>32,000</td>
<td>25,000</td>
<td>58,900</td>
</tr>
<tr>
<td>Adjustments</td>
<td>292,135</td>
<td>(29,750)</td>
<td>(9,909)</td>
<td>(69,667)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2,216,392</strong></td>
<td><strong>$1,771,721</strong></td>
<td><strong>$1,809,638</strong></td>
<td><strong>$2,267,333</strong></td>
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</table>
### DOE Hydrogen Budget

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EERE Hydrogen &amp; Fuel Cells</td>
<td>189,511</td>
<td>206,241</td>
<td>195,865</td>
<td>170,297</td>
<td>95,847</td>
<td>101,087</td>
<td>77,850</td>
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<tr>
<td>Fossil Energy (FE)</td>
<td>21,513</td>
<td>14,891</td>
<td>20,151</td>
<td>13,970</td>
<td>11,394</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Nuclear Energy (NE)</td>
<td>18,855</td>
<td>9,668</td>
<td>7,340</td>
<td>5,000</td>
<td>2,800</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Science (SC)</td>
<td>36,388</td>
<td>36,483</td>
<td>38,284</td>
<td>38,053</td>
<td>34,611</td>
<td>~34,611</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>DOE TOTAL</strong></td>
<td><strong>266,267</strong></td>
<td><strong>267,283</strong></td>
<td><strong>261,640</strong></td>
<td><strong>227,320</strong></td>
<td><strong>144,652</strong></td>
<td><strong>~135,698</strong></td>
<td><strong>TBD</strong></td>
</tr>
</tbody>
</table>

#### Notes

Nuclear Energy: In 2010 and 2011, development of HTSE at the Idaho National Laboratory (INL) continued with funding from the NGNP project. Several industry partners now have stack technologies for high temperature steam electrolysis in development. After demonstration of pressurized HTSE stack operation in FY 2012 by INL, the technology readiness is expected to be sufficiently advanced (TRL5) to allow for further development by industry. EERE: FY 2012 appropriation and FY 2013 request exclude the estimated SBIR/STTR funding.