Overview of Hydrogen & Fuel Cell Activities

February 17, 2011

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U.S. Department of Energy
Fuel Cell Technologies Program
Program Manager
Agenda

- Overview
  - EERE Priorities
- FY12 Budget
- Examples of Collaboration & Leveraging Activities
  - Office of Science, DOD, DOT, SBIRs, International
  - Conferences and Workshops
- Analysis Update
- Recent HTAC Input & Future Needs
Examples of Innovative Applied R&D

Developed high surface area nanostructures for fuel cell electrodes that helped increase fuel cell power density and reduce fuel cell system cost by >45% since 2007.

“Whiskerettes” of Pt grow off sides of organic crystalline whisker core

Microalgae – 300% increase in conversion of sunlight to energy

$51/kW high-volume projection on track to meet $30/kW 2015 target.

• More than 30% reduction since 2008
• More than 80% reduction since 2002

Fuel Cell FY10 Budget Breakdown ($174M)

200 patents and nearly 30 commercial technologies have been developed due to EERE funding

Accelerating Commercialization

EERE-funded Fuel Cell Technologies that are Commercially Available
$42 million from the 2009 American Recovery and Reinvestment Act to fund 12 projects to deploy up to 1,000 fuel cells

Exceeded 2010 target for Recovery Act fuel cell installations by more than 90% at 230 fuel cells installed:

- 206 lift trucks (35 with FedEx, 14 with Nuvera, 98 with Sysco, and 59 with GENCO)
- 24 telecommunication backup power units provided by ReliOn for AT&T.

Major companies such as FedEx, Coca Cola, Whole Foods, Sprint, AT&T, Sysco and Wegmans are installing fuel cells

Federal Agencies: DOD-DLA: ~120 fuel cell life trucks to four distribution centers, FAA: ~26 back-up power fuel cells ; CERL: >200 kW in fuel cell backup power across nine federal installations.

ARRA Fuel Cell Units in Operation - Current and Projected Quantities

Approximately $54 million in cost-share funding from industry participants—for a total of about $96 million.
The Program selects partners with strong technical skills. For example, three PIs have been recognized by the White House for their excellence.

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
Communication and Outreach Activities include:

- Launched Webinar Series:
  - Genetic Optimization of Algae with almost 200 attendees
  - Next webinar scheduled for 03/07 – Carbon-Neutral Energy Research of Kyushu University
- MotorWeek: PBS to air a fuel cell vehicle episode in mid February 2011
- FedEx: 35 Hydrogen fuel cell fork lifts are have been deployed at the Springfield, Mo. service center
- Kimberly-Clark: 25 fork lifts are operational in Graniteville, S.C. distribution center
- Department of Defense: Largest defense depo in the US has deployed 55 fuel cell fork lifts

Blogs Published to Energy.gov website include:

- Civil War Icon (Fort Sumter)
- 2011 Hydrogen Student Design Contest
- Aiming to Green NASCAR’s Future
- Sysco Deploys Hydrogen Powered Pallet Trucks

Road Tours and Ride & Drives

Today we have events to educate the community with Fuel Cell Vehicles from 6 OEMs.
FCT Updates and Accomplishments

• New fact sheets on:
  – FCT’s Subprograms
  – Fuel Cells
  – Production & Delivery
  – Storage
  – Safety, Codes & Standards
  – Technology Validation
  – Case studies
  – Backup Power
  – MHE
  – CHHP
  – Financing
  – Accomplishments
FY 12 Budget
FY 2012 Budget

Funding priorities sustain Hydrogen Fuels R&D and Fuel Cell Systems R&D for near- and long-term technologies, including stationary, transportation, and portable applications.

The FY 2012 Budget Request:

Continues new sub-programs for:

- **Fuel Cell Systems R&D**
  - Consolidates four sub-programs: *Fuel Cell Stack Components R&D*, *Transportation Fuel Cell Systems*, *Distributed Energy Fuel Cell Systems*, and *Fuel Processor R&D*
  - Technology-neutral fuel cell systems R&D for diverse applications

- **Hydrogen Fuel R&D**
  - Consolidates *Hydrogen Production & Delivery* and *Hydrogen Storage* activities

- **Recognizes critical need for Safety Codes and Standards**

Defers funding for

- **Education**
- **Market Transformation**
## EERE H₂ & Fuel Cells Budgets

<table>
<thead>
<tr>
<th>Key Activity</th>
<th>FY 2009&lt;sup&gt;4&lt;/sup&gt;</th>
<th>FY 2010 Current Appropriation</th>
<th>FY 2012 Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell Systems R&amp;D&lt;sup&gt;1&lt;/sup&gt;</td>
<td>-</td>
<td>75,609</td>
<td>45,450</td>
</tr>
<tr>
<td>Fuel Cell Stack Component R&amp;D</td>
<td>61,133</td>
<td></td>
<td></td>
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<tr>
<td>Transportation Systems R&amp;D</td>
<td>6,435</td>
<td></td>
<td></td>
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<tr>
<td>Distributed Energy Systems R&amp;D</td>
<td>9,750</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Processor R&amp;D</td>
<td>2,750</td>
<td></td>
<td></td>
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<tr>
<td>Hydrogen Fuel R&amp;D&lt;sup&gt;2&lt;/sup&gt;</td>
<td>-</td>
<td>45,750</td>
<td>35,000</td>
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<tr>
<td>Hydrogen Production &amp; Delivery R&amp;D</td>
<td>10,000</td>
<td></td>
<td></td>
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<tr>
<td>Hydrogen Storage R&amp;D</td>
<td>57,823</td>
<td></td>
<td></td>
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<tr>
<td>Technology Validation</td>
<td>14,789&lt;sup&gt;5&lt;/sup&gt;</td>
<td>13,005</td>
<td>8,000</td>
</tr>
<tr>
<td>Market Transformation&lt;sup&gt;3&lt;/sup&gt;</td>
<td>4,747</td>
<td>15,005</td>
<td>-</td>
</tr>
<tr>
<td>Early Markets</td>
<td>4,747</td>
<td>15,005</td>
<td>-</td>
</tr>
<tr>
<td>Safety, Codes &amp; Standards</td>
<td>12,238&lt;sup&gt;5&lt;/sup&gt;</td>
<td>8,653</td>
<td>7,000</td>
</tr>
<tr>
<td>Education</td>
<td>4,200&lt;sup&gt;5&lt;/sup&gt;</td>
<td>2,000</td>
<td>-</td>
</tr>
<tr>
<td>Systems Analysis</td>
<td>7,520</td>
<td>5,408</td>
<td>3,000</td>
</tr>
<tr>
<td>Manufacturing R&amp;D</td>
<td>4,480</td>
<td>4,867</td>
<td>2,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$195,865</strong></td>
<td><strong>$170,297</strong></td>
<td><strong>$100,450</strong>&lt;sup&gt;6&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Fuel Cell Systems R & D includes Fuel Cell Stack Component R&D, Transportation Systems R&D, Distributed Energy Systems R&D, and Fuel Processor R&D  
<sup>2</sup> Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D  
<sup>3</sup> No Market Transformation in FY 2012.  
<sup>4</sup> FY 2009 Recovery Act funding of $42.967M not shown in table  
<sup>5</sup> Under Vehicle Technologies Budget in FY 2009  
<sup>6</sup> Includes SBIR/STTR funds to be transferred to the Science Appropriation; all prior years shown exclude this funding
## DOE H₂ & Fuel Cells Budgets: FY07 – FY12

<table>
<thead>
<tr>
<th></th>
<th>Funding ($ in thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EERE Hydrogen &amp; Fuel Cells</td>
<td>189,511</td>
</tr>
<tr>
<td>Fossil Energy (FE)¹</td>
<td>21,513</td>
</tr>
<tr>
<td>Nuclear Energy (NE)</td>
<td>18,855</td>
</tr>
<tr>
<td>Science (SC)</td>
<td>36,388</td>
</tr>
<tr>
<td><strong>DOE TOTAL</strong></td>
<td><strong>266,267</strong></td>
</tr>
</tbody>
</table>

Note: No funding requested for SECA Program FY12 (FE)
Hydrogen and Fuel Cell Technologies

Program Focus: Develop cost competitive hydrogen and fuel cell technologies for diverse applications to meet long-term goals of $30/kW for transportation, $750/kW for stationary power, and $2-4/gge for hydrogen production and delivery.

FY12 Key Activities- Examples

- **Fuel Cell Systems R&D (45.5M):** Maintains critical R&D for stationary, transportation and portable power. Key goals include:
  - Reduce costs by increasing PEM fuel cell power output per gram of platinum-group catalyst from 2.8 kW/g (in 2008) to 6.0 kW/g in 2012 and 8.0 kW/g by 2016.

- **Hydrogen Fuel R&D ($35.0M):** Will focus on materials R&D to achieve a 25% reduction in electrolyzer capital cost by 2012, reducing the total hydrogen cost to less than $5/gge compared to $6/gge in 2009. Develop materials with photoelectrochemical conversion efficiency of 10% in 2012 compared to 4% baseline.

- **Safety, Codes and Standards ($7.0M):** Will determine and demonstrate hydrogen storage system testing procedures to enable publication of a Global Technical Regulation by 2012.

- **Manufacturing R&D ($2.0M):** Will develop low-cost, high-volume, continuous in-line MEA quality control measurement technologies in 2012, on track to develop continuous fabrication and assembly processes for polymer electrolyte membranes by 2016.

- **Technology Validation ($8.0M):** Will collect real-world data from fuel cells operating in forklifts, backup power, vehicles, and buses including 2012 projects with DOD (e.g. Hawaii).

- **Systems Analysis ($3.0M):** Will determine technology gaps, economic/jobs potential, and quantify 2012 technology advancement.

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*a These activities are funded under Market Transformation in FY 2011.*

*b Due to deployments and ongoing data collection and analyses underway through the Recovery Act, these activities are deferred in FY 2012.*
### Funding ($ in thousands)

<table>
<thead>
<tr>
<th>Activity</th>
<th>FY 2009</th>
<th>FY 2010 Current Approp.</th>
<th>FY 2012 Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass and Biorefinery Systems</td>
<td>214,245</td>
<td>216,225</td>
<td>340,500</td>
</tr>
<tr>
<td>Building Technologies</td>
<td>138,113</td>
<td>219,046</td>
<td>470,700</td>
</tr>
<tr>
<td>Federal Energy Management Program</td>
<td>22,000</td>
<td>32,000</td>
<td>33,072</td>
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<tr>
<td>Geothermal Technology</td>
<td>43,322</td>
<td>43,120</td>
<td>101,535</td>
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<tr>
<td>Hydrogen Technology</td>
<td>164,638</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hydrogen and Fuel Cell Technologies</td>
<td>0</td>
<td>170,297</td>
<td>100,450</td>
</tr>
<tr>
<td>Water Power</td>
<td>39,082</td>
<td>48,669</td>
<td>38,500</td>
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<tr>
<td>Industrial Technologies</td>
<td>88,196</td>
<td>94,270</td>
<td>319,784</td>
</tr>
<tr>
<td>Solar Energy</td>
<td>172,414</td>
<td>243,396</td>
<td>457,000</td>
</tr>
<tr>
<td>Vehicle Technologies</td>
<td>267,143</td>
<td>304,223</td>
<td>588,003</td>
</tr>
<tr>
<td>Weatherization &amp; Intergovernmental Activities</td>
<td>516,000**</td>
<td>270,000</td>
<td>393,798</td>
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<tr>
<td>Wind Energy</td>
<td>54,370</td>
<td>79,011</td>
<td>126,859</td>
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<tr>
<td>Facilities &amp; Infrastructure</td>
<td>76,000</td>
<td>19,000</td>
<td>26,407</td>
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<tr>
<td>Strategic Programs</td>
<td>18,157</td>
<td>45,000</td>
<td>53,204</td>
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<tr>
<td>Program Direction</td>
<td>127,620</td>
<td>140,000</td>
<td>176,605</td>
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<td>Congressionally Directed Activities</td>
<td>228,803</td>
<td>292,135</td>
<td>0</td>
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<tr>
<td>RE-ENERGYSE</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Adjustments</td>
<td>-13,238</td>
<td>0</td>
<td>-26,364</td>
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<tr>
<td><strong>Total</strong></td>
<td>$2,156,865</td>
<td>2,216,392</td>
<td>3,200,053</td>
</tr>
</tbody>
</table>

* SBIR/STTR funding transferred in FY 2009 was $19,327,840 for the SBIR program and $2,347,160 for the STTR program.
* ** Includes $250.0 million in emergency funding for the Weatherization Assistance Grants program provided by P.L. 111-6, “The Continuing Appropriations Resolution, 2009.”
Examples of Collaboration
Leveraging Activities
<table>
<thead>
<tr>
<th>Program</th>
<th>Program Key Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings ($471M)</td>
<td>Develop and scale up deployment of technologies, tools, and standards for making residential and commercial buildings more energy-efficient, affordable, and better performing.</td>
</tr>
<tr>
<td>Industrial Technologies ($320M)</td>
<td>Research and develop advanced manufacturing and materials technologies and accelerate industrial adoption of energy efficient and clean energy technologies. Help U.S. producers to become global leader in production of clean energy technologies.</td>
</tr>
<tr>
<td>Solar ($457M) (e.g. EFRC)</td>
<td>“Sun Shot” – Enable grid parity before the end of the decade by achieving $1/W installed price for PV (without subsidies). Develop new innovative materials and thermal storage to enable CSP to compete with intermediate and baseload power markets.</td>
</tr>
<tr>
<td>Biomass ($331M)</td>
<td>Develop and transform domestic biomass resources into biofuels, bioproducts, &amp; biopower: 1) Complete steps to achieve a modeled cost of less than $2/gal (by volume) of cellulosic ethanol in 2012 and progress towards $3/gal for renewable hydrocarbon fuels by 2017 (both in 2007$), 2) Collaborate with Office of Sc. to develop synthetic-biology tools to enhance national capability in biomanufacturing, 3) validate 15 M gallons of annual advanced biofuel production capacity, 4) Provide incentive for advanced biofuel production via a reserve auction.</td>
</tr>
<tr>
<td>Vehicle Technologies ($588M)</td>
<td>Strategic research, development and deployment activities supporting the goal of 1 M electric drive vehicles on U.S. roads by 2015.</td>
</tr>
<tr>
<td>FEMP ($33M) - Federal facilities - EO 13514</td>
<td>Facilitates the Federal Government’s implementation of sound, cost effective energy management and investment practices resulting in lifecycle saving of over 52 trillion Btus. Increased funding for technical assistance will support Federal cost and GHG reduction efforts by developing guidance, technical assistance and GHG reporting protocols.</td>
</tr>
<tr>
<td>ARPA-E ($550M) Innovative concepts</td>
<td>Focuses exclusively on high risk, high payoff concepts - technologies promising genuine transformation in the ways we generate, store and utilize energy.</td>
</tr>
</tbody>
</table>
Management Coordination and Strategic Planning

- DOE Coordination Group (meets monthly)
- Participation in National Academies & GAO Reviews
- Integrated Program Plan (Strategic Plan) across SC, EERE, FE, NE
- Examples of Coordination:
  - Energy Frontier Research Center (EFRCs) Center for Electrocatalysis, Transport Phenomena and Materials for Innovative Energy Storage through LBNL (GE)
  - Participating in Office of Science program to stimulate competitive research (EPSCoR)
  - Project at University of New Mexico on Materials for Energy Conversion specifically ethanol reforming to produce hydrogen and direct electrochemical oxidation of ethanol.

Execution

- Working Groups (PIs)
  - Biological Hydrogen Production
  - Photoelectrochemical (PEC) Hydrogen Production
- Joint Workshops
  - Example: Theory Workshops for Hydrogen Storage Materials
- Identified areas for more R&D
  - Coordination at major conferences (e.g. ACS, MRS, etc.)

Evaluation

- Annual Merit Reviews
  - SC-funded PIs present posters/orals along EERE-funded PIs and serve as reviewers
  - Specific topic selected each year for SC focus (rotate between production, storage, and fuel cells)
- Review proposals for funding
- Provide input to SC RFPs
- Attend contractors’ and proposal review meetings
Discovering new MoS$_2$ nano-catalysts, and developing novel macro-structures for integration into practical photoelectrochemical (PEC) hydrogen production devices

**Fundamental Science:**
Based on fundamental principles of quantum confinement, nanoparticle MoS$_2$ catalysts exhibit bandgap enlargement from 1.2 eV (bulk) to ~1.8 eV when diameter is reduced to ~5 nm.

**Applied R&D:**
A macroporous scaffold consisting of a transparent conducting oxide (TCO) is being developed upon which the MoS$_2$ nanoparticles can be vertically integrated for support, confinement and electronic contact.


Stanford University
University of Louisville

![TCO scaffold](image)
Fundamental research has demonstrated high activity of Pt monolayer catalysts, leading to development of practical core-shell catalysts through applied R&D.

**Fundamental Science**

High activity of Pt monolayer surfaces was demonstrated on model (single-crystal) surfaces. Substrate metal modifies Pt electronic structure, allowing tuning of catalytic activity and durability.

**Applied R&D**

Addition of other metals to core, along with interlayers between shell and core, further enhance core-shell activity and durability.

Demonstration of Pt monolayer on a Pd core – a promising high activity, high durability, low-loading PGM catalyst.

Scale-up to gram-level quantities of core-shell catalysts in EERE-funded partnership with Cabot, as well as external CRADAs.

Adzic et al., BNL
Example for Potential Science Collaboration: Adsorbents

Weak chemisorption (Spillover) materials have potential to store hydrogen at ambient temperature, but have poor reproducibility & slow uptake kinetics.

### Possible BES Topics
- Surface science studies of hydrogen bonding and surface diffusion as a function of surface composition
- Novel techniques to characterize bonding of low concentrations of hydrogen atoms on surfaces
- Theoretical modeling of hydrogen surface diffusion kinetics and thermodynamics
- Translate observed physisorption and/or chemisorption interactions to thermodynamic and kinetic barriers
- Theoretical modeling of possible reaction mechanisms to improve kinetics

### EERE Activities
- NREL led task force in FY11
  - With 4 defined materials, establish uniform protocols, conduct round robin synthesis, testing and characterization effort
  - Partners in the US, Germany and France; leverages IEA HIA Task 22 Hydrogen Storage expertise
  - Not a material development effort; solely validation, determines likely potential
- Past modeling efforts included thermodynamic modeling to indicate when spillover is possible
  - Predictive versus observed hydrogen-catalyst-substrate interactions
  - Translate observed physisorption and/or chemisorption interactions to thermodynamic and kinetic barriers
Enhance Energy Security MOU

Goals: Identify a framework for cooperation and partnership between DOE and DOD to strengthen coordination of efforts to enhance national energy security, and demonstrate Government leadership in transitioning America to a low carbon economy.

DoD Energy Consumption by Type of Fuel

Purpose:
• To begin discussing collaboration across DOD and DOE in keeping with the MOU
• To motivate RD&D for APU applications

Next Steps
• Identify specific POCs for DOD activities
• Develop GSE Strategic Demo Plan

Purpose:
• To identify DOD-DOE waste-to-energy opportunities using fuel cells
• To identify challenges and determine actions to address them

Next Steps
• Set up an on-going WG to begin coordination, collaboration, assistance
• Develop a guidance document for Feds using third party financing

Purpose:
• March 2011
• Organized by ONR
Biogas Resource Example: Methane from Waste Water Treatment

Biogas from waste water treatment plants is ideally located near urban centers to for stationary power or to supply hydrogen for fuel cell vehicles.

- ~500,000 MT/yr of methane available from waste water treatment plants
- If ~50% of the biomethane was available, ~3,500 GWh could be produced from fuel cell CHP
- Could produce enough renewable hydrogen to fuel ~680,000 fuel cell vehicles per day (~680,000 kg/day)

Source: NREL report A Geographic Perspective on Current Biomass Resource Availability in the United States, 2005
Biogas from landfills is located near large urban centers and could provide renewable energy for both stationary power and transportation.

- Approximately 12.4 million MT per year of methane available from landfills in the U.S.
- Bio-methane could be used to produce ~86,000 GWh from fuel cell CHP or enough renewable hydrogen to fuel ~8 million fuel cell vehicles per day (~8M kg/day).

Source: NREL report A Geographic Perspective on Current Biomass Resource Availability in the United States, 2005
California Example: Potential Sources of Biogas

Example:

Landfills offer ~1.6 M tons/yr of biomethane.

- Only ~50% of the landfill biomethane is used
Preliminary Analysis - Resources near Military Sites

This 2008 study estimates the technical biomass resources currently available in the United States by county. It includes the following feedstock categories:

- Agricultural residues (crops and animal manure);
- Wood residues (forest, primary mill, secondary mill, and urban wood);
- Municipal discards (methane emissions from landfills and domestic wastewater treatment);
- Dedicated energy crops (switchgrass on Conservation Reserve Program lands).

See additional documentation for more information at http://www.nrel.gov/docs/fy08osti/39181.pdf

Source: Homeland Security Infrastructure Program (2008 Gold)

U.S. Department of Energy
National Renewable Energy Laboratory
January 11, 2010
Hawaii’s Hydrogen Initiative (H2I)

A public/private effort that seeks to be a major component of the solution to Hawaii’s energy challenges

• Letter of Understanding signed on Dec 8, 2010 by DOE and DOD, among others
  • State of Hawaii, the Hawaii Gas Company, University of Hawaii, General Motors, Fuel Cell Energy, and others

• Mission is to fill a strategic role that supports Hawaii’s transformation to a clean energy economy

• Part of a portfolio approach of technologies and fuels for reducing emissions and petroleum use
  • Supports the deployment of fuel cell vehicles to Hawaii as a means of reducing petroleum consumption as well as greenhouse gas emissions
  • Takes advantage of the existing gas pipelines to deliver hydrogen for dispensing hydrogen to fuel cell vehicles
DOE – DOT Collaborations

DOE and DOT support the development and deployment of fuel cell technology

DOE RD&D

- Developed low Pt approach
- Reduced cost by >30% since 2008, 80% since 2002

National Bus Program
($49 million for 4 years)

DOT Deployment

Data Collection & Validation

NREL

Accomplishments

- Demonstrated:
  - Doubled fuel economies (8 mpg, >2X compared to diesel buses)
  - 41% increase in average miles between roadcall with new fuel cell system (~8,500 MBRC)
  - Demonstrated more than 7,000 hr fuel cell durability

Fuel Cell buses: 39% to 141% better fuel economy than conventional buses
Fuel Cell Bus Buildout Analysis

Potential deployment strategies envisioned for Fuel Cell Buses deployment scenario analysis identified in California’s Action Plan.

### Bus Rollout Scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>17</td>
</tr>
<tr>
<td>2012</td>
<td>20 – 60</td>
</tr>
<tr>
<td>2013</td>
<td>60 – 150</td>
</tr>
</tbody>
</table>

### Potential H₂ Fueling Station Buildout for Buses

<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulative Number of Hydrogen Fueling Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>100 kg/d Station: 2 500 kg/d Station: 0</td>
</tr>
<tr>
<td>2012</td>
<td>100 kg/d Station: 1 500 kg/d Station: 1</td>
</tr>
<tr>
<td>2013</td>
<td>100 kg/d Station: 0 500 kg/d Station: 1</td>
</tr>
<tr>
<td>2014</td>
<td>100 kg/d Station: 0 500 kg/d Station: 1</td>
</tr>
<tr>
<td>2015</td>
<td>100 kg/d Station: 0 500 kg/d Station: 1</td>
</tr>
<tr>
<td>2016</td>
<td>100 kg/d Station: 0 500 kg/d Station: 1</td>
</tr>
<tr>
<td>2017</td>
<td>100 kg/d Station: 0 500 kg/d Station: 1</td>
</tr>
</tbody>
</table>

### Table: Number of Fuel Cell Buses and Fueling Stations

<table>
<thead>
<tr>
<th>Phase</th>
<th>Number of Fuel Cell Buses*</th>
<th>Minimum Number of 100 kg/d Stations</th>
<th>Minimum Number of 500 kg/d Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>17</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>20 – 60</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>III</td>
<td>60 – 150</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes: The station requirements for the fuel cell bus build out was based on ANL analysis with the HDSAM delivery model.

Leveraging SBIRs
Topic 3: Hydrogen and Fuel Cells

- Subtopic 3a – Reducing the Cost of High Pressure Hydrogen Storage Tanks
- Subtopic 3b – Fuel Cell Balance-of-Plant
- Subtopic 3c – Hydrogen Odorant Technology
- Subtopic 3d – Demonstration of Alternative-Fuel Cells as Range Extenders for Battery-Powered Airport Ground Support Equipment (GSE)

- Subtopic 3e – Other: Should address one of the four subtopics (a-d). However, the proposal can take an approach that is not specified in the subtopic description but that will still meet the technical targets, goals or objectives, which are referenced in the description.

Closed on 11/15/2010
Currently in process of reviewing.
Announcement expected in May 2011.
FY10 Project Kick-Off Meetings

FY10 Phase II Project Kick-Off Meeting – November 2, 2010 at DOE Headquarters

- “Utilized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi”  
  (Giner Electrochemical Systems, LLC)
- “Process Intensification of Hydrogen Using an Electrochemical Device”  
  (H2 Pump LLC)
- “Hydrogen by Wire – Home Refueling System”  
  (Proton Energy Systems)

FY10 Phase III Project Kick-Off Meeting – Scheduled for March 10, 2011 at DOE Headquarters (Webex Meeting Link provided in hyperlink)

- “Dimensionally Stable High Performance Membrane”  
  (Giner Electrochemical Systems, LLC)
- “Bio-Fueled Solid Oxide Fuel Cells”  
  (TDA Research, Inc.)
- “Power Generation from an Integrated Biomass Reformer and Solid Oxide Fuel Cell”  
  (InnovaTek, Inc.)
- “Large-Scale Testing, Demonstration and Commercialization of the Nanoparticle-based Fuel Cell Coolant”  
  (Dynalene, Inc.)

Example of Recent International Collaboration:

University of Illinois – Kyushu University collaboration directed by Petros Sofronis to advance the fundamental science for a “Carbon-Neutral Energy Fueled World” and offer science driven solutions for energy technologies that will enable environmentally friendly and sustainable development.
Upcoming Conferences and Workshops
Focus on reducing the cost of hydrogen while increasing availability for market readiness. Identify and collect stakeholder feedback on:

- Cost reduction opportunities from economies of scale
- Cost reduction opportunities from focused R&D areas and priorities
- Specific examples from which early markets can provide increased demand and reduce hydrogen infrastructure costs

Agenda

- Early Market End User Experiences
- Outlook for Infrastructure Cost Reductions
- Vehicle Deployment and Station Cost Questionnaires
- Cost Reductions & Rollout Strategies
  - Component level cost reductions
  - System station cost reductions
  - Planning and permitting
  - Business operations
- Requirements for Market Readiness
  - Stations for light duty vehicles
  - Fueling for material handling equipment
  - Fueling depots for transit buses
  - Station utilization, revenue and retail business models
The ICHS 2011 will focus on the improvement, knowledge, and understanding of hydrogen safety to overcome barriers to the wide spread use of hydrogen as an energy carrier. Therefore, this conference seeks papers focused on the following three major themes:

1) International Progress on Enabling Opportunities
2) Latest Advances in Hydrogen Safety R&D and
3) Risk Management of Hydrogen Technologies. All contributions to be included in the ICHS 2011 will be evaluated exclusively in the light of their scientific content and relevance to hydrogen safety.

The conference will improve public awareness and trust in hydrogen technologies by communicating a better understanding of both the hazards and risks associated with hydrogen and their management.
This workshop will include government agencies, private companies and research organizations from key countries to present government policy and industrial activity in the area of stationary FC.

Examples of Participants:


Agenda

- Government Session
  - Focus on governmental programs and their main stationary technologies/application areas.

- Residential & Micro CHP Applications
  - Focus on opportunities for cooperation, solutions for commercialization and best practices in overcoming hurdles.

- Industrial Applications
  - Focus on opportunities for cooperation, solutions for commercialization and best practices in overcoming hurdles.

- Technology and Market
  - Focus on challenges and solutions for overcoming hurdles to commercialization and ways to promote cooperation.
You are invited to attend the Reversible Fuel Cells Workshop on Tuesday, April 19, 2011 at Renaissance Capitol View, Crystal City, VA from 9:00 AM to 4:00 PM.

For information email Robert.Remick@nrel.gov

Organized by:

You are invited to attend the 2011 Alkaline Membrane Fuel Cell Workshop on May 8 - 9, 2011 at Crystal Gateway Marriott, Crystal City, VA.

For information email AMFCWorkshop@nrel.gov
Or visit http://dell.communicateandgrow.com/nrelva.html

Organized with the U.S. Army Research Office (ARO)
### Additional DOE Workshops - Summary

<table>
<thead>
<tr>
<th>Delivery</th>
<th>Safety, Codes and Standards</th>
<th>Manufacturing</th>
<th>Market Transformation</th>
<th>Systems Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Participation in Systems Analysis and Storage workshops addressing</td>
<td>• Insurability of Hydrogen and FC Technologies</td>
<td>• Stationary Manufacturing R&amp;D</td>
<td>• DOD-DOE MOU Workshop on Shipboard</td>
<td>• Infrastructure workshop on station</td>
</tr>
<tr>
<td>Infrastructure and Physical Storage topics.</td>
<td>(Spring-Summer 2011)</td>
<td>FY11 (TBD)</td>
<td>APUs (March 2011)</td>
<td>cost identification and identification</td>
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<tr>
<td></td>
<td>• Collaborative Safety R&amp;D (March 2011, Japan)</td>
<td></td>
<td>(March 2011)</td>
<td>of R&amp;D gaps</td>
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<tr>
<td></td>
<td>• Assessment of Sensor Technology and Targets</td>
<td></td>
<td></td>
<td>• Workshop planned for FCHEA</td>
</tr>
<tr>
<td></td>
<td>(Summer-Fall 2011)</td>
<td></td>
<td></td>
<td>Conference (Feb. 16 &amp; 17, 2011)</td>
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</tr>
<tr>
<td>Storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Workshop to develop roadmap for lower cost compressed H2 storage</td>
<td></td>
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<tr>
<td>activities (February 14, 2011)- e.g. leverage C fiber cost reduction</td>
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<tr>
<td>• Workshop to identify key R&amp;D issues for cryo-compressed/cryo-sorption</td>
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<td>H2 storage (February 15, 2011)</td>
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<tr>
<td>• Follow-up workshops on hydrogen sorbents (Q3/4 FY 2011)</td>
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<tr>
<td>• Workshops on interface issues between the infrastructure and on board</td>
<td></td>
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<tr>
<td>storage (TBD)</td>
<td></td>
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<tr>
<td>• Workshop to develop roadmap/strategies for future storage materials</td>
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<tr>
<td>R&amp;D (TBD)</td>
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<tr>
<td>Fuel Cells</td>
<td></td>
<td></td>
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<tr>
<td>• Reversible fuel cells (4/19)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>• AFC workshop: Status, prospects and R&amp;D needs (5/8-9)</td>
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<td></td>
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</tbody>
</table>

**Fuel Cell Technologies Program**  
Source: US DOE 3/19/2013  
eere.energy.gov
Analysis Update
### Impact of 1603 and 48C

#### Section 48C: Manufacturing Tax Credit

<table>
<thead>
<tr>
<th>Business</th>
<th>Location</th>
<th>Amount</th>
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</thead>
<tbody>
<tr>
<td>UTC Power Corporation</td>
<td>CT</td>
<td>$5,300,100</td>
</tr>
<tr>
<td>W.L. Gore &amp; Associates</td>
<td>MD</td>
<td>$604,350</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$5,904,450</strong></td>
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</table>

#### Section 1603: Payments in Lieu of Tax Credits

<table>
<thead>
<tr>
<th>Business</th>
<th>Property Location</th>
<th>Fuel Cell MWe</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gills Onions, LLC</td>
<td>California</td>
<td>0.6</td>
<td>$1,141,560</td>
</tr>
<tr>
<td>M&amp;L Commodities, Inc.</td>
<td>California</td>
<td>0.6</td>
<td>$997,913</td>
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<tr>
<td>Preservation Properties, Inc.</td>
<td>California</td>
<td>0.1</td>
<td>$300,000</td>
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<tr>
<td>Logan Energy Corporation</td>
<td>Hawaii</td>
<td>0.3</td>
<td>$900,000</td>
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<tr>
<td>Plug Power, Inc.</td>
<td>Illinois</td>
<td>0.28</td>
<td>$723,334</td>
</tr>
<tr>
<td>Logan Energy Corporation</td>
<td>South Carolina</td>
<td>0.05</td>
<td>$148,988</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td><strong>1.9</strong></td>
<td><strong>$4,211,795</strong></td>
</tr>
</tbody>
</table>

Source: US DOE 3/19/2013
ARRA purchases have had a measurable impact on fuel cell material handling and backup power.

Material handling fuel cell sales increased from 477 to 803 due to the ARRA, while backup power sales were boosted from 894 to 1,221 in spite of unfavorable economic conditions.

David Greene, et al
Early Market Cost Reduction Analysis

Comparison of 2008 ORNL Study and 2010 Fuel Cell Cost Estimates

<table>
<thead>
<tr>
<th>PEM Stack</th>
<th>$/kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kW Back-up Power System</td>
<td>$4,000</td>
</tr>
<tr>
<td>5 kW Back-up Power System</td>
<td>$3,000</td>
</tr>
<tr>
<td>5 kW Materials Handling Unit</td>
<td>$2,000</td>
</tr>
<tr>
<td>5 kW CHP Methane Reforming</td>
<td>$1,000</td>
</tr>
<tr>
<td>2005 Average</td>
<td>2010 Predicted</td>
</tr>
<tr>
<td>$0</td>
<td>$1,000</td>
</tr>
<tr>
<td>$1,000</td>
<td>$2,000</td>
</tr>
<tr>
<td>$2,000</td>
<td>$3,000</td>
</tr>
<tr>
<td>$3,000</td>
<td>$4,000</td>
</tr>
</tbody>
</table>

Costs reduced by ½ or more
2005:2010
Not included in 2008 study
2008 model generally underestimated cost reductions

2005 and 2010 averages based on estimates supplied by OEMs. 2010 predicted assumed government procurements of 2,175 units per year, total for all market segments. Predictions assumed a progress ratio of 0.9 and scale elasticity of -0.2.
U.S. fuel cell material handling manufacturing would likely have ended in 2011 without existing policy support.

**Projected Sales of Material Handling 5 kW**

- **With Policy Support**
- **No Policy Support**

Only ARRA purchases have been excluded from the “No Policy” case. Other government procurements prior to 2011 are included in both cases. Progress ratio of 0.9, scale elasticity of -0.2. Government and private procurements of 100 units/yr. for demonstrations continue in the policy case.

Without continuation of the ITC beyond 2010, the U.S. market would likely collapse.

ITC assumed to expire after 2015.

David Greene, et al
Without current policy support, MHE fuel cell costs will increase or manufacturing facilities will close.

Progress ratio of 0.9, scale elasticity of -0.2. Government and private procurements of 100 units/yr. for demonstrations continue in the current policy case.

David Greene, et al
Assumptions and key points.

• Assumptions and generalizations:
  – All OEMs represented by three generic products
    • 5 kW CHP
    • 5 kW Backup Power
    • 5 kW Forklift
  – Number of OEMs constant until scale economies reached
  – No change in the cost of competing products
  – Progress ratios = 0.9, scale elasticities = -0.2
  – Model estimates indicative of status and trends, not precise

• Key Points:
  – Dramatic cost reductions and performance improvements have been achieved for all products since 2005.
  – Still, few firms could continue without current policy support.
  – Cost and performance appear to be on a trajectory to achieve competitiveness in niche markets in 5-10 years.

David Greene, et al
Recent HTAC Feedback & DOE Status

• Program Plan (revised Posture Plan)
  – Valuable feedback in the process of being incorporated

• Hydrogen Threshold Cost Analysis
  – Incorporated valuable feedback on analysis with National Lab experts and communication rollout strategy

• Working Groups
  – In process (TBD)

• Annual Report
Feedback from HTAC

• Examples of Future Needs
  – Portfolio optimization
    • Constrained budget scenario
    • Strategies for addressing early markets as well as sustaining long term goals
  – Infrastructure
    • Strategies for early markets as well as FCEVs
    • Fostering innovation for H2 production (e.g. point/local sources, energy storage, TBD)
  – Communication
    • Opportunities and venues for HFCT within broader portfolio
  – Policies
    • Opportunities for accelerating commercialization (lessons learned)

Future: Interaction with ERAC (EERE Advisory Committee)
Thank you

Sunita.Satyapal@ee.doe.gov

www.hydrogenandfuelcells.energy.gov
Back up
Without the ITC and California SGIP incentives, fuel cell CHP sales would likely disappear.

Purchases for demonstrations by private sector and all levels of government assumed to continue at 100 units per year from 2011 to 2020. Assumed progress ratio of 0.9 and scale elasticity of -0.2. At production levels shown, only one OEM is assumed.
Domestic sales of backup power fuel cells would be low for several years without existing incentives.

Projected Sales of Back-up Power 5 kW

- With Policy Support
- No Policy Support

Units per Year

2010 2015 2020 2025

Without continuation of the ITC beyond 2010, the U.S. market would likely collapse.

ITC assumed to expire after 2015.

Only ARRA purchases have been excluded from the “No Policy” case. Other government procurements prior to 2011 are included in both cases. Progress ratio of 0.9 and scale elasticity of -0.2. Number of OEMs is assumed to be 3. Government and private purchases for demonstration are 100 units/yr. in the policy case.

David Greene, et al

Preliminary Analysis
Collaborations

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

**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

**DOE Fuel Cell Technologies Program***

- **Applied RD&D**
- **Efforts to Overcome Non-Technical Barriers**
- **Internal Collaboration with Fossil Energy, Nuclear Energy and Basic Energy Sciences**

**Industry Partnerships & Stakeholder Assn’s.**
- FreedomCAR and Fuel Partnership
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- Hydrogen Utility Group
- ~ 65 projects with 50 companies

**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)

**Abbreviations:**
- P&D = Production & Delivery; S = Storage; FC = Fuel Cells; A = Analysis; SC&S = Safety, Codes & Standards; TV = Technology Validation; MN = Manufacturing
Fuel Cell Technologies Program
RD&D Activities

**Fuel Cell RD&D activities range from applied research to operational environment demonstration.**

<table>
<thead>
<tr>
<th>PROGRAM ACTIVITIES</th>
<th>TECHNOLOGY PIPELINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL #1</td>
<td>TRL #2</td>
</tr>
<tr>
<td><strong>FY 10</strong></td>
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</tr>
<tr>
<td>Total (millions of $)</td>
<td>0</td>
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<tr>
<td>% of Total</td>
<td>0%</td>
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<tr>
<td><strong>FY 12</strong></td>
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<tr>
<td>Total (millions of $)</td>
<td>0</td>
</tr>
<tr>
<td>% of Total</td>
<td>0%</td>
</tr>
</tbody>
</table>

The Office of Science conducts basic research (TRL#1)

To maintain a balanced portfolio, the percentage of funding for each TRL changes as advances are made.

Non R&D activities such as Systems Analysis, Codes & Standards and Program Support, etc. represents 17% and 18% for FY10 and FY12 respectively.
Annual Merit Review & Peer Evaluation Proceedings
Includes downloadable versions of all presentations at the Annual Merit Review
- Latest edition released June 2010
  www.hydrogen.energy.gov/annual_review10_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
- Released January 2011
  http://www.hydrogen.energy.gov/annual_review10_report.html

Annual Progress Report
Summarizes activities and accomplishments within the Program over the preceding year, with reports on individual projects
- Released February 2011
  www.hydrogen.energy.gov/annual_progress.html

Next Annual Review: May 9 – 13, 2011
Washington, D.C.
http://annualmeritreview.energy.gov/