Overview of DOE Hydrogen and Fuel Cell Activities

Dr. Sunita Satyapal
United States Department of Energy
Fuel Cell Technologies Program

Gordon Research Conference: Fuel Cells, Rhode Island
August 1, 2010
Administration’s Clean Energy Goals

- Double Renewable Energy Capacity by 2012
- Invest $150 billion over ten years in energy R&D to transition to a clean energy economy
- Reduce GHG emissions 83% by 2050
U.S. Energy Consumption

U.S. Primary Energy Consumption by Source and Sector

- Coal: 23%
- Natural Gas: 24%
- Petroleum: 37%
- Renewable Energy: 7%
- Nuclear Electric Power: 9%

Transportation: 37%
Industrial: 19%
Residential and Commercial: 22%
Electric Power: 28%

Total U.S. Energy = 99.3 Quadrillion Btu
Energy Efficiency and Resource Diversity

→ Fuel cells offer a highly efficient way to use diverse fuels and energy sources.

Greenhouse Gas Emissions and Air Pollution:

→ Fuel cells can be powered by emissions-free fuels that are produced from clean, domestic resources.
Fuel Cells — Where are we today?

Fuel Cells for Stationary Power, Auxiliary Power, and Specialty Vehicles

The largest markets for fuel cells today are in stationary power, portable power, auxiliary power units, and forklifts.

~75,000 fuel cells have been shipped worldwide.

~24,000 fuel cells were shipped in 2009 (> 40% increase over 2008).

Fuel cells can be a cost-competitive option for critical-load facilities, backup power, and forklifts.

Fuel Cells for Transportation

In the United States:

> 200 fuel cell vehicles
> 20 fuel cell buses
~ 60 fueling stations

Several manufacturers—including Toyota, Honda, Hyundai, Daimler, GM, and Proterra (buses) — have announced plans to commercialize vehicles by 2015.

Production & Delivery of Hydrogen

In the U.S., there are currently:

~9 million metric tons of H₂ produced annually

> 1200 miles of H₂ pipelines

The Role of Fuel Cells in Transportation

- Fuel Cell
- E-REV
- BEV
- Stationary Power
- Portable Power
- Auxiliary Power Units
- Specialty Vehicles

Several manufacturers—including Toyota, Honda, Hyundai, Daimler, GM, and Proterra (buses) — have announced plans to commercialize vehicles by 2015.
Systems Analysis — Examples of Benefits

Analysis shows DOE’s portfolio of transportation technologies will reduce emissions of greenhouse gases and oil consumption.

### Well-to-Wheels Greenhouse Gas Emissions
*(life-cycle emissions, based on a projected state of the technologies in 2020)*

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Conventional Vehicles</th>
<th>Hybrid Electric Vehicles</th>
<th>Plug-in Hybrid Electric Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>410</td>
<td>540</td>
<td>250</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn Ethanol – E85</td>
<td>190</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulosic Ethanol – E85</td>
<td>&lt;65°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulosic Ethanol – E85</td>
<td>240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulosic Ethanol – E85</td>
<td>&lt;150°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂ from Distributed Natural Gas</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂ from Coal w/Sequestration</td>
<td>&lt;110°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂ from Biomass Gasification</td>
<td>&lt;55°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂ from Nuclear High-Temp Electrolysis</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂ from Central Wind Electrolysis</td>
<td>&lt;40°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Well-to-Wheels Petroleum Energy Use
*(based on a projected state of the technologies in 2020)*

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Conventional Vehicles</th>
<th>Hybrid Electric Vehicles</th>
<th>Plug-in Hybrid Electric Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>4550</td>
<td>6070</td>
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<tr>
<td>Natural Gas</td>
<td>25</td>
<td>2710</td>
<td>320</td>
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<tr>
<td>Gasoline</td>
<td>25</td>
<td>2370</td>
<td>320</td>
</tr>
<tr>
<td>Diesel</td>
<td>850</td>
<td>2370</td>
<td>320</td>
</tr>
<tr>
<td>Corn Ethanol – E85</td>
<td>860</td>
<td>2370</td>
<td>320</td>
</tr>
<tr>
<td>Cellulosic Ethanol – E85</td>
<td>1530</td>
<td>2370</td>
<td>320</td>
</tr>
<tr>
<td>Gasoline</td>
<td>1530</td>
<td>2370</td>
<td>320</td>
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<tr>
<td>Cellulosic Ethanol – E85</td>
<td>530</td>
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<tr>
<td>H₂ from Distributed Natural Gas</td>
<td>30</td>
<td>2370</td>
<td>320</td>
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<tr>
<td>H₂ from Coal w/Sequestration</td>
<td>45</td>
<td>2370</td>
<td>320</td>
</tr>
<tr>
<td>H₂ from Biomass Gasification</td>
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<tr>
<td>H₂ from Nuclear High-Temp Electrolysis</td>
<td>25</td>
<td>2370</td>
<td>320</td>
</tr>
<tr>
<td>H₂ from Central Wind Electrolysis</td>
<td>15</td>
<td>2370</td>
<td>320</td>
</tr>
</tbody>
</table>

DOE Program Record #9002,
[www.hydrogen.energy.gov/program_records.html](http://www.hydrogen.energy.gov/program_records.html).
Key Challenges

The Program has been addressing the key challenges facing the widespread commercialization of fuel cells.

Technology Barriers*

Fuel Cell Cost & Durability

- Targets*: 
  - *Stationary Systems*: $750 per kW, 40,000-hr durability
  - *Vehicles*: $30 per kW, 5,000-hr durability

Hydrogen Cost

- Target: $2 – 3 /gge, delivered (revision underway)

Hydrogen Storage Capacity

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

Technology Validation:

- Technologies must be demonstrated under real-world conditions.

Economic & Institutional Barriers

Safety, Codes & Standards Development

Domestic Manufacturing & Supplier Base

Public Awareness & Acceptance

Hydrogen Supply & Delivery Infrastructure

Market Transformation

Assisting the growth of early markets will help to overcome many barriers, including achieving significant cost reductions through economies of scale.

Hydrogen Storage Capacity

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

*Metrics available/under development for various applications
**Projected* High-Volume Cost of Hydrogen (Delivered) — Status & Targets**

($/gallon gasoline equivalent [gge], untaxed)

**NEAR TERM:**
Distributed Production
- Natural Gas Reforming
- Bio-Derived Renewable Liquids
- Electrolysis

**LONGER TERM:**
Centralized Production
- Biomass Gasification
- Nuclear

Projected* High-Volume Cost of Hydrogen (Delivered)

- Cost Target: $2 – 3/gge

FUTURE MILESTONES

2005
2010
2015
2020

Cost Target: $2 – 3/gge

**We’ve reduced the cost of hydrogen delivery* —**

- ~30% reduction in tube trailer costs
- >20% reduction in pipeline costs
- ~15% reduction liquid hydrogen delivery costs

Cost targets under revision

*Projected cost, based on analysis of state-of-the-art technology
Compressed gas offers a near-term option for initial vehicle commercialization and early markets

- Validated driving range of up to ~ 430 mi
- Cost of composite tanks is challenging
  - carbon fiber layer estimated to be >75% of cost
- Advanced materials R&D under way for the long term

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**Projected Capacities for Complete 5.6-kg H₂ Storage Systems**

**Gravimetric**

**Volumetric**

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350-bar Base Case Factory Cost¹ = $2,500
$13/kWh based on 5.6 kg usable H₂ (6 kg stored H₂)

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>$18</td>
</tr>
<tr>
<td>Balance of Tank</td>
<td>$100</td>
</tr>
<tr>
<td>Valves</td>
<td>$82</td>
</tr>
<tr>
<td>Other BOP</td>
<td>$130</td>
</tr>
<tr>
<td>Regulator</td>
<td>$160</td>
</tr>
<tr>
<td>Assembly and</td>
<td>$38</td>
</tr>
<tr>
<td>Inspection</td>
<td></td>
</tr>
<tr>
<td>Carbon Fiber Layer</td>
<td>$1,970</td>
</tr>
</tbody>
</table>

TIAAX 12/2009

¹ Cost estimate in 2005 USD. Includes processing costs.
Projected high-volume cost of fuel cells has been reduced to $61/kW (2009)

- More than 15% reduction in the last two years
- More than 75% reduction since 2002
- 2008 cost projection was validated by independent panel**

As stack costs are reduced, balance-of-plant components are responsible for a larger % of costs.

*Based on projection to high-volume manufacturing (500,000 units/year).

**Panel found $60 – $80/kW to be a “valid estimate”: http://hydrogendoedev.nrel.gov/peer_reviews.html
From 2008 to 2009, key cost reductions were made by:

- Reducing platinum group metal content from 0.35 to 0.18 g/kW
- Increasing power density from 715 to 833 mW/cm²

These advances resulted in a $10/kW cost reduction.

Key improvements enabled by using novel organic crystalline whisker catalyst supports and Pt-alloy whiskerettes.

There are ~ 5 billion whiskers/cm².

Whiskers are ~ 25 X 50 X 1000 nm.
Catalysts and Supports

Challenges:
- Platinum (Pt) cost is ~34% of total stack cost
- Catalyst durability needs improvement

Four Strategies for Catalysts & Supports R&D:
- Lower PGM Content
  - Improved Pt catalyst utilization and durability
- Pt Alloys
  - Pt-based alloys with comparable performance to Pt and cost less
- Novel Support Structures
  - Non-carbon supports and alternative carbon structures
- Non-PGM catalysts
  - Non-precious metal catalysts with improved performance and durability

Stack Cost - $26/kW

DTI, 2009 analysis, scaled to high volume production of 500,000 units/yr
Used $1100/Troy Ounce for Pt Cost
Ultra-low Pt Content Catalysts

Pd Interlayer Effect on ORR Activity

- **Highlight:** 0.35 A/mg<sub>PGM</sub> at 0.90 V – an improvement of 0.08 A/mg<sub>PGM</sub> due to Pd interlayer (better lattice constant for Pt overlayer)

- **Highlight:** E<sub>1/2</sub> loss after 30,000 cycles of only 19 mV vs. 39 for Pt/C

- Pd not significantly oxidized (XAS); good substrate for Pt compared to other metals, e.g. iridium

Next Steps: Improve activity and durability. In-cell testing.

*R. Adzic and P. Zelanay 2009 DOE Hydrogen Program Review*
• Screening of multiple new alloys at 3M revealed anomalously high ORR activity for $\text{Pt}_x\text{Ni}_y$ at high Ni content.

• Dramatic and sharp mass activity peak at $\text{Pt}_3\text{Ni}_7$ (gravimetric) vs 60at% Ni and 76at% Ni by EMP and XRF respectively.

• Definite gains in kinetic performance but not a practical catalyst yet due to performance limitations above 1 A/cm$^2$.

Next Steps: Improve high current density performance.
Argonne National Laboratory approach: Materials by design to characterize, synthesize, and test nanosegregated multi-metallic nanoparticles and nanostructured thin metal films

Nano-segregated Cathode Catalysts

Models

Monte Carlo Simulations

HRTEM

As-prepared PtNi → PtNi_{1-y} Skeleton → Annealing → 400°C

PtNi/Pt core/shell

PtNi/Pt core/shell catalyst has 7X activity over same size Pt/C.

Next Steps: Evaluate in-cell durability, scale-up

N. Markovic, 2010 DOE Hydrogen Program Review
Los Alamos National Laboratory Approach: Cyanamide –Fe-C Catalysts

- High ORR activity reached with several non-PGM catalysts by LANL, including cyanamide-Fe-C catalyst (shown).
- Intrinsic catalyst activity is projected to exceed DOE 2010 activity target of 130 A/cm$^3$ at 0.80 V.

Next Steps: Determine active site. Improve activity to PGM catalyst level.

D. Papageorgopoulos, 2010 DOE Hydrogen Program Review
## Fuel Cell Technologies — Catalysts
### Technical Targets vs. Status

<table>
<thead>
<tr>
<th>Electrocatalysts for Transportation Applications</th>
<th>Status(^a)</th>
<th>Targets(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>Platinum group metal (PGM) total content (both electrodes)</td>
<td>0.2 g/kW</td>
<td>0.15 g/kW</td>
</tr>
<tr>
<td>PGM Total Loading</td>
<td>0.15 mg/cm(^2)</td>
<td>0.15 mg/cm(^2)</td>
</tr>
<tr>
<td>Loss in catalytic (mass) activity(^c)</td>
<td>TBD</td>
<td>&lt;40% loss of initial</td>
</tr>
<tr>
<td>Catalyst support loss(^d)</td>
<td>TBD</td>
<td>&lt; 10% mass loss</td>
</tr>
<tr>
<td>Mass activity(^e)</td>
<td>0.16 A/mg Pt in MEA &gt;0.44 A/mg PGM new alloy in RDE</td>
<td>0.44 A/mg PGM</td>
</tr>
<tr>
<td>Activity per volume of supported catalyst (non-PGM)(^f)</td>
<td>155 A/cm(^3)</td>
<td>&gt;130 A/cm(^3)</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\(_{\text{IR-free}}\)
\(^f\) baseline @ 800mV\(_{\text{IR-free}}\)

Update of Multiyear RD&D Plan in process
Membrane R&D: High-Temperature, Low Humidity Conductivity

- Phase segregation (polymer & membrane)
- Non-aqueous proton conductors
- Hydrophilic additives

High Conductivity and Durability Across Operating Range with Cycling

- Mechanical support or membrane reinforcement
- Chemical stabilization (additives, end-group capping)
- Polymer structure (side chain length, grafting, cross-linking, backbone properties, blends, EW)
- Processing parameters (temperature, solvents)
- New materials

Challenges:

- Membranes account for 48% of stack cost at low volume
- Limits on operating range
- Chemical and mechanical durability

Stack Cost - $137/kW

DTI, 2009 analysis, production of 1,000 units/yr

Used $453/m² for membrane Cost
## Strategies for Hi-T Membrane R&D

### High conductivity at 120°C 50% RH achieved with a variety of approaches

<table>
<thead>
<tr>
<th>Conduction Mechanism</th>
<th>Morphology</th>
<th>Molecular Approach</th>
<th>Additive Approach</th>
<th>Micro/nano engineering approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Other Polymer</td>
<td>Block Copolymer</td>
<td>Rigid Rods</td>
</tr>
<tr>
<td><strong>Aqueous</strong></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>FC-SO3H</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC-SO3H</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrous Metal Oxides</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfluoro imide acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Potential Non Aqueous</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>polyPOMs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphonic acids</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heterocyclic bases</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionic liquids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **≥ 0.1 S/cm at 120°C and 50%RH**
- **> 50% of target**
- **Less than 50% of target**
- **NRE 212 < 50% of target**

* Measured in-house and by a second party
** Measured in-house
Conductivity Results (120 °C, 50% RH)

Need to go to even lower humidity to simplify fuel cell system designs: Need high conductivity at low RH

Exceeded 0.1 S/cm at 120 °C and 50% RH using several conducting groups.

For a given conducting group, morphology can have a large effect on conductivity.

Additives can also have a large effect.
Dimensionally Stabilized Membranes

Giner Electrochemical Systems approach: Engineering polymer matrix provides mechanical properties. Low-EW ionomer provides conductivity.


C. Mittelsteadt, 2010 DOE Hydrogen Program Review
Nanocapillary Network Membranes

Vanderbilt University approach: Simultaneously electrospin dual nanofiber mat, one fiber is ionomer, the other is an inert polymer. Melt one fiber around other.

**Generation 1:** PFSA/SPOSS nanofiber mat that is impregnated with inert polymer

**Generation 2:** Co-spin PFSA and polysulfone nanofibers then process into membrane

![Image of nanofiber mat](image)

Nafion® matrix (~70 vol%), polyphenylsulfone nanofibers

Simultaneous electro-spinning of PFSA and polyphenylsulfone (inert matrix) – eliminates need for impregnation step; also can create PFSA nanofibers with polysulfone matrix from the same dual fiber mat.


P. Pintauro, 2009, 2010 DOE Hydrogen Program Review

Membrane: 60 wt% 3M PFSA (825EW) + 35 wt% SPOSS + 5 wt% poly(acrylic acid) with NAO63 (inert matrix)

SPOSS = sulfonated polyhedral oligomeric silsesquioxanes
Rigid-rod Structure

Case Western Reserve University approach: Molecular design with frozen-in free volume retains H$_2$O at low RH

Neopentyl benzene graft (4%) provides water insoluble film with decent mechanical properties

Demonstrates good conductivity at low RH

Next Steps: Improve mechanical properties. Homopolymers are water soluble. Grafting with non-polar moieties yields insoluble polymers with high conductivity at low RH. Grafting not easily scaled-up.
Demonstrated concept of HPA-based polymeric ionomers for high conductivity at low RH.

Next Steps: Improve mechanical properties and oxidative stability. Currently developing chemistry to attach POM to more robust polymers.

A. Herring, 2010 DOE Hydrogen Program Review
Multi-acid Side Chain Polymers

3M Approach: Per Fluoro Imide Acid (PFIA) and Sulfonic Acid

- Multi Acid Side-chains (MASC) allow Lower EW while maintaining higher crystallinity
- Starting with an 835 EW polymer, prepared a MASC PFIA ionomer with 625 EW
- Membrane has >100 mS/cm conductivity at 120ºC, 50% RH – similar to about 700 EW PFSA

Next Steps: Evaluate durability of PFIA.
## DOE membrane targets

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>2010 target</th>
<th>2015 target</th>
<th>Nafion® NRE211</th>
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</thead>
<tbody>
<tr>
<td>Maximum operating temperature</td>
<td>°C</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Area specific resistance at:</td>
<td>ohm cm²</td>
<td>0.02</td>
<td>0.02</td>
<td>0.186</td>
</tr>
<tr>
<td>Maximum operating temp and water partial pressures from 40 to 80 kPa</td>
<td></td>
<td>0.02</td>
<td>0.02</td>
<td>0.03-0.12</td>
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<tr>
<td>80 °C and water partial pressures from 25 - 45 kPa</td>
<td></td>
<td>0.03</td>
<td>0.03</td>
<td>0.049</td>
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<tr>
<td>30 °C and water partial pressures up to 4 kPa</td>
<td></td>
<td>0.2</td>
<td>0.2</td>
<td>0.179</td>
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<tr>
<td>-20 °C</td>
<td></td>
<td>2</td>
<td>2</td>
<td>2.7</td>
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<tr>
<td>Oxygen crossover</td>
<td>mA/cm²</td>
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<tr>
<td>Hydrogen crossover</td>
<td>mA/cm²</td>
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</tr>
<tr>
<td>Cost</td>
<td>$/m²</td>
<td>20</td>
<td>20</td>
<td></td>
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<tr>
<td>Durability</td>
<td></td>
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<tr>
<td>Mechanical</td>
<td>Cycles w/&lt;10 sccm crossover</td>
<td>20,000</td>
<td>20,000</td>
<td>5000</td>
</tr>
<tr>
<td>Chemical</td>
<td>H₂ crossover mA/cm²</td>
<td>20</td>
<td>20</td>
<td>6</td>
</tr>
</tbody>
</table>
Summary of Key Issues

- **Catalysts**
  - Durability of low-PGM and non-PGM catalysts
  - Effects of impurities on low-PGM and non-PGM catalysts
  - Durability of catalyst supports
  - Water management with high-activity catalysts
  - Cost of PGM catalysts

- **Membranes**
  - Low RH performance
  - Durability of new membranes
  - Cost at low volumes

- **MEAs**
  - Low-temperature performance
  - Water management
  - High-current operation
This talk covered only some of the technical challenges and aspects of the DOE portfolio. Other areas being addressed by DOE are:

Water management – freeze issues, materials properties

Modeling – durability, transport

Impurity effects – fuel, air, system-generated

Cell hardware – plates, seals

Stationary fuel cells – APU$s$, CHP
Process and analyze fuel cell stack data

Report to data provider and publish Composite Data Products


Contact Info
Jennifer Kurtz
jennifer.kurtz@nrel.gov
303-275-4061

Example: CDP Lab#01 - Operation data from lab testing for automotive, backup, material handling, and stationary power applications
Technology Validation

Demonstrations are essential for validating the performance of technologies in integrated systems, under real-world conditions.

**RECENT ACCOMPLISHMENTS**

**Vehicles & Infrastructure**
- 144 fuel cell vehicles and 23 hydrogen fueling stations have reported data to the project
- Over 2.5 million miles traveled
- Over 150,000 kg- H₂ produced or dispensed* 
- Fuel cell durability- 2,500 hours (nearly 75K miles)
- Fuel cell efficiency 53-59%
- Vehicle Range: ~196 – 254 miles

**Buses**
- DOE is evaluating real-world bus fleet data (DOT collaboration)
  - H₂ fuel cell buses have 39% to 141% better fuel economy when compared to diesel & CNG buses

**Forklifts**
- Forklifts at Defense Logistics Agency site have completed more than 10,000 refuelings

**Recovery Act**
- NREL is collecting data (backup power, forklifts, etc.)

*Not all hydrogen produced is used in vehicles*
Education, Safety, Codes, & Standards

• Safety & Code Officials
  – Trained >90 first responders in 3 advanced-level first responder training courses in 18 states and deployed an Intro to Hydrogen web course for code officials

• Schools & Universities
  – Working with 5 universities to finalize & teach >25 university courses & curriculum modules specializing in H₂ and fuel cells

• End Users
  – Provided day-long educational seminars to lift truck users, including hands-on forklift demos and real-world deployment data

• State & Local Governments
  – Conducted >19 workshops and seminars across the country to educate decision-makers on fuel cell deployments

• CNG H₂ Fuels Workshop
  – Brazil, Canada, China, India and U.S. identified critical gaps and lessons learned from CNG vehicles

• H₂ Fuel Quality Specification
  – Technical Specification published and harmonized with SAE J2719

• Separation Distances
  – Incorporated Quantitative Risk Assessment for separation distances into codes (NFPA2)

• Materials & Components Compatibility
  – Completed testing to enable deployment of 100 MPa stationary storage tanks
  – Forklift tank lifecycle testing program underway to support the development of CSA HPIT1
Market Transformation

Example: Government acquisitions could significantly reduce the cost of fuel cells through economies of scale, and help to support a growing supplier base.

Impact of Government Acquisitions on Fuel Cell Stack Costs (for non-automotive fuel cells)

- Recovery Act funding will deploy up to 1000 fuel cells, in the private sector, by 2012.

We are facilitating the adoption of fuel cells across government and industry:
- >100 fuel cells are being deployed, through interagency agreements.
- More interagency agreements under development.
DOE announced ~$42 million from the American Recovery and Reinvestment Act to fund 12 projects to deploy more than 1,000 fuel cells — to help achieve near term impact and create jobs in fuel cell manufacturing, installation, maintenance & support service sectors.

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>AWARD</th>
<th>APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delphi Automotive</td>
<td>$2.4 M</td>
<td>Auxiliary Power</td>
</tr>
<tr>
<td>FedEx Freight East</td>
<td>$1.3 M</td>
<td>Specialty Vehicle</td>
</tr>
<tr>
<td>GENCO</td>
<td>$6.1 M</td>
<td>Specialty Vehicle</td>
</tr>
<tr>
<td>Jadoo Power</td>
<td>$2.2 M</td>
<td>Backup Power</td>
</tr>
<tr>
<td>MTI MicroFuel Cells</td>
<td>$3.0 M</td>
<td>Portable</td>
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<tr>
<td>Nuvera Fuel Cells</td>
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<td>Plug Power, Inc. (1)</td>
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<td>CHP</td>
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<td>Plug Power, Inc. (2)</td>
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<td>University of North Florida</td>
<td>$2.5 M</td>
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<td>ReliOn Inc.</td>
<td>$8.5 M</td>
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<tr>
<td>Sprint Comm.</td>
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<tr>
<td>Sysco of Houston</td>
<td>$1.2 M</td>
<td>Specialty Vehicle</td>
</tr>
</tbody>
</table>

FROM the LABORATORY to DEPLOYMENT:

DOE funding has supported R&D by all of the fuel cell suppliers involved in these projects.

Approximately $51 million in cost-share proposed by industry participants—for a total of nearly $93 million.
We are assessing the costs and benefits of various technology pathways and conducting a range of analyses including sensitivity analysis, life cycle analysis and job creation analysis.

Successful Commercialization Will Have Significant Impact on Employment (% increase from base case)

Example: Need to reduce H₂ cost (production, delivery & storage)
Representatives from the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) compiled fuel cell cost estimates for automotive applications to identify potential R&D focus areas.

Cost range for 500,000 – 1M units/year: system status

Cost range for 500,000 units/year: stack status

• Range of cost estimates varies widely for some components
• Catalyst cost reduction is clearly required

Ref: www.iphe.net/docs/Resources/IPHE%20Fuel%20Cell%20Cost%20Comparison%20Report.pdf
## Workshops & WG Activities

<table>
<thead>
<tr>
<th>Working Group (WG)</th>
<th>DOE Representative</th>
<th>Leads</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Temp Membrane</td>
<td>Nancy Garland</td>
<td>Jim Fenton (UCF/FSEC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>John Kopasz (ANL)</td>
</tr>
<tr>
<td>Durability</td>
<td>Donna Ho</td>
<td>Debbie Myers (ANL)</td>
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<tr>
<td></td>
<td></td>
<td>Rod Borup (LANL)</td>
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<tr>
<td>Transport Modeling</td>
<td>Dimitrios Papageorgopoulos</td>
<td>Adam Weber (LBNL)</td>
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<tr>
<td></td>
<td></td>
<td>R. Mukundan (LANL)</td>
</tr>
<tr>
<td>Stationary</td>
<td>Jason Marcinkoski</td>
<td>TBD</td>
</tr>
</tbody>
</table>

### Examples of Workshops

- Analysis, Tank Safety - China, 9/10
- Reversible Fuel Cells - TBD
- Product/Component Validation - TBD
- Energy Storage - TBD

**Other Ideas?**

What more can DOE be doing to help accelerate progress and maximize value?
Collaborations

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 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
- National Hydrogen Association
- U.S. Fuel Cell Council
- Hydrogen Utility Group
- ~ 65 projects with 50 companies

Universities
- ~ 50 projects with 40 universities

International
- IEA Implementing agreements – 25 countries
- International Partnership for the Hydrogen Economy – 16 countries, 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
- Argonne
  A, FC, P&D
- Los Alamos
  S, FC, SC&S
- Sandia
  P&D, S, SC&S
- Pacific Northwest
  SC&S, P&D, S, FC, A
- Oak Ridge
  P&D, S, FC, A
- Lawrence Berkeley
  FC, A
- Lawrence Livermore
  P&D, S
- Savannah River
  S, P&D
- Brookhaven
  S, FC
- Idaho
  P

Other Federal Labs: Jet Propulsion Lab, National Institute of Standards & Technology, National Energy Technology Lab

P&D = Production & Delivery; S = Storage; FC = Fuel Cells; A = Analysis; SC&S = Safety, Codes & Standards; TV = Technology Validation

* Office of Energy Efficiency and Renewable Energy
**Analysis & Testing**
- ANL
- DTI
- TIAX
- LANL
- NIST
- ORNL
- Battelle

**Catalysts & Supports**
- 3M
- General Motors
- ANL
- BNL
- LANL
- LBNL
- NREL
- PNNL
- UTC Power
- Illinois Institute of Technology
- University of South Carolina
- Northeastern University

**Cross-cutting**
- Case Western Reserve University
- Kettering University
- Stark State
- University of Connecticut

**Distributed Energy Systems**
- Acumentrics
- Intelligent Energy
- Plug Power
- IdaTech
- Versa Power Systems

**Durability**
- UTC Power
- LANL
- Ballard Power Systems
- ANL
- Nuvera Fuel Cells
- DuPont

**Hardware**
- ANL
- Treadstone
- ORNL
- UTC Power

**Impurities**
- Clemson University
- LANL
- NREL
- University of Hawaii
- University of Connecticut

**Membranes**
- 3M
- Arizona State University
- Arkema
- Case Western Reserve University
- Colorado School of Mines
- FuelCell Energy
- Giner Electrochemical Systems
- LBNL
- University of Central Florida
- Vanderbilt University
- LANL
- Ion Power

**Portable Power**
- LANL
- NREL
- Arkema
- University of North Florida

**Transportation Systems**
- ANL
- Cummins
- Delphi
- Honeywell
- W.L. Gore

**Water Transport and Freeze**
- CFD Research Corp.
- LANL
- Nuvera Fuel Cells
- Rochester Institute of Technology
- SNL
- LBNL
- Giner Electrochemical Systems
- Plug Power
- General Motors
Key Program Documents

Fuel Cell Program Plan
Outlines a plan for fuel cell activities in the Department of Energy
→ Replacement for current Hydrogen Posture Plan
→ To be released in 2010

Annual Merit Review 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
→ Latest edition released October 2009
www.hydrogen.energy.gov/annual_review08_report.html

Annual Progress Report
Summarizes activities and accomplishments within the Program over the preceding year, with reports on individual projects
→ Latest edition published November 2009
www.hydrogen.energy.gov/annual_progress.html

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

http://www.eere.energy.gov/hydrogenandfuelcells

Sunita.Satyapal@ee.doe.gov