**Goal and Objectives**

**GOAL:** Develop and demonstrate fuel cell power system technologies for stationary, portable, and transportation applications

**Objectives**

- By 2015, a fuel cell system for portable power (<250 W) with an energy density of 900 Wh/L.

- By 2017, a 60% peak-efficient, 5,000 hour durable, direct hydrogen fuel cell power system for transportation at a cost of $30/kW.

- By 2020, distributed generation and micro-CHP fuel cell systems (5 kW) operating on natural gas or LPG that achieve 45% electrical efficiency and 60,000 hours durability at an equipment cost of $1500/kW.

- By 2020, medium-scale CHP fuel cell systems (100 kW–3 MW) with 50% electrical efficiency, 90% CHP efficiency, and 80,000 hours durability at an installed cost of $1,500/kW for operation on natural gas, and $2,100/kW when configured for operation on biogas.

- By 2020, APU fuel cell systems (1–10 kW) with a specific power of 45 W/kg and a power density of 40W/L at a cost of $1000/kW.
Challenges & Strategy

The Fuel Cells sub-program supports research and development of fuel cell and fuel cell systems with a primary focus on reducing cost and improving durability. Efforts are balanced to achieve a comprehensive approach to fuel cells for near-, mid-, and longer-term applications.

**Fuel Cell MYRD&D Plan recently updated:**
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

**R&D portfolio is technology-neutral and includes different types of fuel cells.**

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**FOCUS AREAS**

- **Stack Components**
  - Catalysts
  - Electrolytes
  - MEAs, Gas diffusion media, and Cells
  - Seals, Bipolar plates, and Interconnects

- **Operation and Performance**
  - Mass transport
  - Durability
  - Impurities

- **Systems and Balance of Plant (BOP)**
  - BOP components
  - Stationary power
  - Fuel processor subsystems
  - Portable power
  - APU and emerging markets

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**Strategy**

Materials, components, and systems R&D to achieve low-cost, high-performance fuel cell systems.

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**Fuel Cell R&D**

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**Testing and Cost/Technical Assessments**

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**Barriers**

- Cost
- Durability
- Performance
Application-driven targets for commercial viability (in terms of cost and performance) were recently revised and updated.

- Targets revised for the complete portfolio guiding R&D for transportation, stationary, and portable applications
- Revised targets in recently released MYRD&D Plan
  http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

Examples of system-level targets:

<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</td>
<td>34-40%</td>
<td>42.5%</td>
<td>&gt;45%</td>
</tr>
<tr>
<td>CHP energy efficiency</td>
<td>80-90%</td>
<td>87.5%</td>
<td>90%</td>
</tr>
<tr>
<td>Equipment cost, 2-kW&lt;sub&gt;avg&lt;/sub&gt; system</td>
<td>NA</td>
<td>$1,200/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>$1,000/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
</tr>
<tr>
<td>Equipment cost, 5-kW&lt;sub&gt;avg&lt;/sub&gt; system</td>
<td>$2,300 - $4,000/kW</td>
<td>$1,700/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>$1,500/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
</tr>
<tr>
<td>Equipment cost, 10-kW&lt;sub&gt;avg&lt;/sub&gt; system</td>
<td>NA</td>
<td>$1,900/kW&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>$1,700/kW&lt;sub&gt;avg&lt;/sub&gt;</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</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</td>
<td>12,000 h</td>
<td>40,000 h</td>
<td>60,000 h</td>
</tr>
<tr>
<td>System availability</td>
<td>97%</td>
<td>98%</td>
<td>99%</td>
</tr>
</tbody>
</table>
Challenges and Strategy: Automotive Applications

- **Strategic technical analysis guides focus areas for R&D and priorities.**
- **Need to reduce cost from $49/kW to $30/kW and increase durability from 2,500 to 5,000 hours.**
- **Advances in PEMFC materials and components could benefit a range of applications.**

**Strategies to Address Challenges**
- Lower PGM Content
- Pt Alloys
- Novel Support Structures
- Non-PGM catalysts

**Key Focus Areas for R&D**
- 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
Further reduction in capital cost of medium scale DG/CHP (100kW-3 MW) and natural gas availability will facilitate commercialization.

Challenges and Strategy: Stationary Applications

- Natural gas availability and fuel cell performance (efficiency) gains will enhance the technology’s market attractiveness.
- Further reduction of fuel cell system cost required to expedite commercialization.
- Development of a cost-effective process for removing fuel contaminants would allow for fuel flexibility.

Sensitivity analysis around 2015 targets assesses impact of fuel cell system cost and durability on commercialization prospects.

**Technical Parameters (2015)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Efficiency (LHV)</td>
<td>45.0%</td>
</tr>
<tr>
<td>Combined Efficiency (LHV)</td>
<td>87.5%</td>
</tr>
<tr>
<td>Size, MWe</td>
<td>1</td>
</tr>
<tr>
<td>Operating Life, years</td>
<td>20</td>
</tr>
<tr>
<td>Equipment, $/kWe</td>
<td>2,300</td>
</tr>
<tr>
<td>Engineering &amp; Installation, $/kWe</td>
<td>700</td>
</tr>
<tr>
<td>Fixed O&amp;M, $/MWh</td>
<td>13</td>
</tr>
<tr>
<td>Variable O&amp;M, $/MWh</td>
<td>8.0</td>
</tr>
</tbody>
</table>
**Challenges and Strategy: New Stationary Cost Analysis**

Analysis highlights need for fuel processor cost reduction.

### LT-PEM (≈ 80 °C)

<table>
<thead>
<tr>
<th>Sys/yr</th>
<th>1 kW</th>
<th>5 kW</th>
<th>25 kW</th>
<th>100 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$12K</td>
<td>$3.9K</td>
<td>$1.7K</td>
<td>$1.1K</td>
</tr>
<tr>
<td>1,000</td>
<td>$9.3K</td>
<td>$3.1K</td>
<td>$1.4K</td>
<td>$0.9K</td>
</tr>
<tr>
<td>10,000</td>
<td>$7.9K</td>
<td>$2.6K</td>
<td>$1.1K</td>
<td>$0.7K</td>
</tr>
<tr>
<td>50,000</td>
<td>$7.2K</td>
<td>$2.4K</td>
<td>$1K</td>
<td>$0.6K</td>
</tr>
</tbody>
</table>

### HT-PEM (≈ 160 °C)

<table>
<thead>
<tr>
<th>Sys/yr</th>
<th>1 kW</th>
<th>5 kW</th>
<th>25 kW</th>
<th>100 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$11K</td>
<td>$4.2K</td>
<td>$1.7K</td>
<td>$1.3K</td>
</tr>
<tr>
<td>1,000</td>
<td>$8.8K</td>
<td>$3.3K</td>
<td>$1.5K</td>
<td>$1.1K</td>
</tr>
<tr>
<td>10,000</td>
<td>$7.5K</td>
<td>$2.8K</td>
<td>$1.2K</td>
<td>$0.8K</td>
</tr>
<tr>
<td>50,000</td>
<td>$6.9K</td>
<td>$2.5K</td>
<td>$1K</td>
<td>$0.7K</td>
</tr>
</tbody>
</table>

**SOFC system analysis currently underway**

* *B. D. James et al., SA*
**Fuel Cells Budget**

**FY 2012 Appropriation = $45.0 M**  
**FY 2013 Request = $38.0 M**

**EMPHASIS:**

- Develop improved ultra-low PGM and non-PGM fuel cell catalysts and membrane electrolytes
- Improve PEM-MEAs through integration of state-of-the-art MEA components
- Identify degradation mechanisms and approaches for mitigating the effects
- Characterize and optimize transport phenomena improving MEA and stack performance
- Investigate and quantify effects of impurities on fuel cell performance
- Develop low-cost, durable, system balance-of-plant components
- Maintain core activities in components, subsystems and systems specifically tailored for stationary and portable power applications

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*Subject to appropriations*
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.
**Progress – Durability Assessment**

Aggregated results provide a benchmark in time of state-of-the-art fuel cell durability.

NREL is analyzing and aggregating durability results by application, providing a benchmark of state-of-the-art fuel cell durability (time to 10% voltage degradation). 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 Fuelcelldatacenter@ee.doe.gov
Progress: De-alloyed Catalysts

Low-PGM de-alloyed catalysts meet mass activity and durability targets.

GM 50 cm² MEAs, at 0.1 mg₉Pt/cm²
H₂/air, 80°C, 170 kPa abs, stoichs 2/2

- PtCo₃ and PtNi₃ meet 0.44 A/mg₉PGM mass activity target
- PtCo₃ meets 30,000 cycle durability target
- PtNi₃ meets 0.56 V @ 1.5 A/cm² milestone

0.46 A/mg₉PGM for PtCo₃,
0.52 A/mg₉PGM for PtNi₃ in 50 cm² MEA testing

F. Wagner et al., GM
Roll-to-roll PtNi NSTF catalyst meets 0.44 A/mg$_{\text{PGM}}$ mass activity target.

- Achieved 0.44 A/mg$_{\text{PGM}}$ target on roll-to-roll produced MEAs through improvements in Pt$_3$Ni$_7$ catalyst processing techniques
- Reduced PGM total content to 0.14 – 0.18 g/kW, with 0.15 mg/cm$^2$ (2017 targets: 0.125 g/kW, 0.125 mg/cm$^2$)
- Progress in improving high-current performance of Pt$_3$Ni$_7$; still opportunity for further improvement
Membranes containing multi-acid side chains or additives demonstrate conductivity higher than 0.1 S/cm under hot, dry conditions.

**Progress: Membranes**

FuelCell Energy: mC² membranes use short side chains and additives to reach high conductivity

**3M: multi-acid side chain polymers have met most membrane targets**

**Table:**

<table>
<thead>
<tr>
<th>Condition</th>
<th>ASR (Ohm cm²)</th>
<th>3M PFIA Status</th>
<th>DOE 2017 Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASR at 120°C (pH₂O 40-80 kPa)</td>
<td>0.023 (40 kPa)</td>
<td>0.012 (80 kPa)</td>
<td>≤0.02</td>
</tr>
<tr>
<td>ASR at 80°C (pH₂O 25-45 kPa)</td>
<td>0.013 (25 kPa)</td>
<td>0.006 (44 kPa)</td>
<td>≤0.02</td>
</tr>
<tr>
<td>ASR at 30°C (pH₂O 4 kPa)</td>
<td>0.02 (3.8 kPa)</td>
<td></td>
<td>≤0.03</td>
</tr>
<tr>
<td>ASR at -20°C</td>
<td>0.1</td>
<td></td>
<td>≤0.2</td>
</tr>
<tr>
<td>O₂ Crossover</td>
<td>&lt;1.0</td>
<td></td>
<td>≤2</td>
</tr>
<tr>
<td>H₂ crossover</td>
<td>&lt;1.8</td>
<td></td>
<td>≤2</td>
</tr>
<tr>
<td>Mechanical Durability</td>
<td>&gt;20,000</td>
<td></td>
<td>≥20,000</td>
</tr>
<tr>
<td>Chemical Durability (OCV)</td>
<td>2,025</td>
<td></td>
<td>≥500</td>
</tr>
</tbody>
</table>

L. Lipp et al., FuelCell Energy

S. Hamrock et al., 3M
**Progress: Durable Catalysts**

3M catalysts demonstrate durability under startup, shutdown, and cell reversal.

IrRu-modified cathodes have achieved the SU/SD Go/No Go requirement: 5,000 cycles with end voltage < 1.60 V, ECSA loss <10% with < 0.09 mg/cm² PGM

IrRu-modified anodes have achieved the cell reversal Go/No Go requirement: 200 cycles with end voltage < 1.80 V, with < 0.045 mg/cm² PGM

All Go/No-go milestones surpassed at:
- PGM loading < 0.135 mg/cm² total
- Voltages meet the set goals

R. Atanasoski et al., 3M
Progress: Portable Power

High-activity catalysts developed for liquid fuels

- JMFC’s ternary PtRuSn/C DMFC catalyst combines advantages of PtSn at low overpotentials and PtRu at high overpotentials
- PtRuSn/C outperforms the best thrifted PtRu/C catalyst

PtRuSn/C methanol mass activity exceeds 500 mA/mgPt at 0.35 V, 150% higher than FY12 milestone

- DME fuel cell outperforms DMFC at low current due to low DME crossover

DME fuel cell achieves 150 mA/cm² at 0.5 V – 60% higher than FY11, 130% higher than best published data
Progress: Portable Power

Passive water recovery DMFC enables BOP reduction.

- >10,000 hour stack durability demonstrated in steady-state testing
- Startup/shutdown durability improvements still needed

Cathode liquid barrier layer retains water; passive recirculation returns water to anode

Average cell voltage at 120 mA/cm², 0.8 M methanol and 50°C for an 8 cell stack

| DOE Technical Targets: Portable Power Fuel Cell Systems (10-50 Watts) |
|------------------|-----------------|----------------|----------------|------------------|
| Characteristic   | Units           | DOE 2011 Status | UNF Status (25 W Net)¹ | 2013 Targets | 2015 Targets |
| Specific Power   | W/kg            | 15             | 26.3             | 30              | 45             |
| Power Density    | W/l             | 20             | 28.0             | 35              | 55             |
| Specific Energy  | (W-hr)/kg       | 150            | 263              | 430             | 650            |
| Energy Density   | (W-hr)/l        | 200            | 280              | 500             | 800            |

¹ Values based on 10 hour operation duration.

J. Fletcher et. al., UNF
Progress: Balance of Plant

Compact, low-cost humidifier module projected to meet $100/unit 2017 cost target

High performance, cost-effective humidification membranes developed

- Flow field, pleat geometry and module design optimization to take advantage of very high transport rate materials, while maintaining low-cost assembly process.

- Membrane pocket over plate assembly concept selected

- Scale-up of these materials is underway.

- Module performance consistent with single cell and ex situ testing shows loss of performance of 20-30% over 5500 hours.

- Developed understanding of source of durability loss – chemical changes in PFSA

- Sub-scale module design complete; sub-scale prototypes built and under test

- Final full scale module to be built

Module cost estimated to be ~$100 at high volumes.

W. B. Johnson et al., Gore
Progress: Stack technology for material handling

**Increased freeze-tolerance and durability for material handling applications**

- Air cooled stack technology enabled reduction in projected order picker cost by 57%, life cycle cost by 32%.
- Minimal degradation seen from freeze start-ups from -10 °C.
- Substantial operation at -30 °C possible with system mitigation strategies.

- Next Generation Order Picker based on technology developed in this project, with over 100 units shipped to at least 4 customers in Q4 2011.
- Units can operate in a freezer environment; operating range -30°C to +40°C.

D. Hancock et al., Plug Power
Catalyst Scale-up

**Brookhaven core-shell catalyst technology licensed by leading catalyst manufacturer**

- Jan. 3, 2012 – N.E. Chemcat Corporation, a leading catalyst and precious metal compound manufacturer, licensed core-shell electrocatalysts developed by BNL under previous EERE project.

  - Includes catalysts with Pd or Pd-alloy cores, Pt shells

  - N.E. Chemcat also licensed innovative methods for making the catalysts and an apparatus design used in manufacturing them.

Current BNL project is developing new core-shell structures and improving performance and durability.

Pt monolayer on PdAu nanorod

R. Adzic, et al., BNL
Demonstrated a kW-scale reversible SOFC stack with daily cycling between fuel cell and electrolysis mode, with SOFC degradation rate of ~1.6% per 1,000 hours.

Successfully completed 8,000 hrs desulfurizer testing and 1,000 hrs catalytic partial oxidation (CPOX) reformer testing as part of 1 MW SOFC powerplant concept running on pipeline natural gas.

R. Petri et al., Versa Power Systems

M. Perna et al., Rolls Royce Fuel Cell Systems
Key Milestones and Future Plans

- Updated Multi Year RD&D Plan & Targets Released
- Flow Cells Workshop
- New FOA* Awards
- Cost analyses updates
- Develop an experimentally validated model describing mass transport in PEMFCs.
- Develop a 10-fold accelerated test for high-temperature fuel cell durability testing
- Develop PEM bipolar plates with a cost less than or equal to $5/kW

FY 2012
- Cost analysis projects kicked off
- RFI for MHE released
- FOA Awards Announced

FY 2013
- Develop truck APU with projected durability of 10,000 hours, at a cost of $1400/kW, operating on standard ultra-low sulfur diesel.

FY 2014
- Develop new FOA Awards
- Subject to Appropriations
New Fuel Cell Projects

5 new projects announced in FY 2011 (cost analysis) and FY 2012 (R&D) — total award of ~$10M

**Cost Analysis**

*Transportation (Strategic Analysis)*
- Analyze and estimate the cost of transportation fuel cell systems for use in vehicles including light-duty vehicles and buses

*Stationary and Emerging Markets (Battelle, LBNL)*
- Develop total cost models and provide cost assessments for stationary and emerging market fuel cell system technologies

**Research & Development**

*MEA Integration (3M)*
- Approach is based upon integration of 3M’s state-of-the-art nanostructured thin film catalyst technology platform with other components of the MEA

*System BOP (Eaton)*
- Develop and demonstrate an efficient and low-cost fuel cell air management system
# New Targets for Fuel Cell Buses

Commercialization targets have been established for fuel cell buses.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>2012 Status</th>
<th>Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Lifetime</td>
<td>years/miles</td>
<td>5/100,000</td>
<td>12/500,000</td>
</tr>
<tr>
<td>Power Plant Lifetime</td>
<td>hours</td>
<td>12,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Bus Availability</td>
<td>%</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td>Fuel Fills</td>
<td>per day</td>
<td>1</td>
<td>1 (&lt; 5 min)</td>
</tr>
<tr>
<td>Bus Cost</td>
<td>$</td>
<td>2,000,000</td>
<td>600,000</td>
</tr>
<tr>
<td>Power Plant Cost</td>
<td>$</td>
<td>700,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Hydrogen Storage Cost</td>
<td>$</td>
<td>100,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Road Call Frequency (All/Fuel Cell System)</td>
<td>miles between road calls</td>
<td>2,500/10,000</td>
<td>4,000/20,000</td>
</tr>
<tr>
<td>Operation Time</td>
<td>hours per day/ days per week</td>
<td>19/7</td>
<td>20/7</td>
</tr>
<tr>
<td>Scheduled and Unscheduled Maintenance Cost</td>
<td>$/mile</td>
<td>1.24</td>
<td>0.38</td>
</tr>
<tr>
<td>Range</td>
<td>miles</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Fuel Economy</td>
<td>miles per gallon diesel equivalent</td>
<td>6.5</td>
<td>8</td>
</tr>
</tbody>
</table>

- Targets were developed through a joint workshop and a joint RFI with the Department of Transportation.
- Status information was supplemented with data from the NREL Hydrogen Fuel Cell Bus Evaluations.

DOE Hydrogen and Fuel Cells Program Record #12012
Preliminary cost, performance, and durability targets for backup power and for class I, II, and III lift trucks proposed; feedback from stakeholders requested.

Preliminary targets based on input from ARRA projects and NREL analysis

Questions and RFI responses may be addressed to MHBPtargets@go.doe.gov
Fuel Cell Collaborations

**DOE**

*(Energy Efficiency & Renewable Energy - EERE)*

- Fuel Cells sub-program
- **Fuel Cell System R&D**
  - ARRA Projects
  - SBIR Projects
  - 33 R&D projects

**INTERNATIONAL ACTIVITIES**

- FCT Program
- IEA Hydrogen Implementing Agreements
  - 22 countries
  - European Union
- IPHE
  - 17 counties
  - European Commission

**INDUSTRY**

- Fuel Cells Tech Team

**TECHNOLOGY VALIDATION** *(DOE EERE)*

**DOE – Basic Energy Sciences**

- ~30 Projects

**NSF**

- New projects in basic science

**NIST**

- Neutron imaging facility

**DOT**

- Bus Applications

**Fossil Energy**

- Solid Oxide Fuel Cells

National Collaboration *(inter- and intra-agency efforts)*
For More Information

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