Fuel Cells Program

- Plenary Presentation-

Dimitrios Papageorgopoulos
Fuel Cell Technologies Office

2014 Annual Merit Review and Peer Evaluation Meeting
June 16 - 20, 2014
Objectives

• By 2020, a 60% peak-efficient, 5,000 hour durable, direct hydrogen fuel cell power system for transportation at a cost of $40/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 40 W/L at a cost of $1000/kW.

• Other specific objectives are in the Fuel Cell MYRD&D Plan.
The Fuel Cells program supports research and development of fuel cells and fuel cell systems with goals of 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:**
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html
To be revised in early FY 2015

R&D portfolio is technology-neutral and includes different types of fuel cells.
Market-driven targets ensure competitive strategy

Automotive fuel cell cost targets: $40 / kW by 2020 and $30 / kW ultimate

FC system cost targets were revised and updated, reflecting need to compete with incumbent technology on a lifecycle cost basis. Stakeholders provided comments via RFI in 2013.

Durability and Cost are the primary challenges to fuel cell commercialization and must be met concurrently.

Durability (h) 5000 h

Start from -20 °C (s) 30 s

Energy efficiency @ 1/4 rated power (%) 60%

Stack power density (W/L) 2500 W/L

Stack specific power (W/kg) 2000 W/kg

System cost ($/kW) 40 $/kW
Technical analysis tracks fuel cell system cost

Automotive fuel cell system cost analysis project assumptions revised

Updated analysis reflects updated system requirement and economic factors such as increased Pt price

- System must meet heat rejection target \( \frac{Q}{\Delta T} \leq 1.45 \)*, required due to the constraints on the radiator size inherent in automotive applications

- Pt price adjusted from $1100 / oz. to $1500 / oz.

\* \( \frac{Q}{\Delta T} = \left[ \text{Stack power (90kW)} \times (1.25V - \text{Voltage at Rated Power}) / (\text{Voltage at Rated Power}) \right] / \left[ (\text{Stack Coolant out temp (°C)} - \text{Ambient temp (40°}) \right] \). Target assumes 90kW stack gross power required for 80 kW net power (http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/fuel_cells.pdf)
High-Impact Areas Addressed – PEMFCs for Automotive Applications

- Strategic technical analysis guides focus areas for R&D and priorities
- Advances in PEMFC materials and components could benefit a range of applications

**Key Focus Areas for R&D**

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

**Catalyst cost is projected to be the largest single component of the cost of a PEMFC manufactured at high volume.**

**Strategy**

- Lower PGM Content
- Pt Alloys
- Novel Support Structures
- Non-PGM catalysts
High-Impact Areas Addressed – Durability/Performance

System/stack durability assessment
Continued in FY 2015
Data from OEMs aggregated and reported as a composite data product at NREL

NFCTEC

Market-driven targets set for a range of applications

<table>
<thead>
<tr>
<th>System</th>
<th>Status</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>80-kW_e Automotive</td>
<td>2,500 h</td>
<td>5,000 h</td>
</tr>
<tr>
<td>Bus</td>
<td>12,000 h</td>
<td>25,000 h</td>
</tr>
<tr>
<td>100 kW–3 MW CHP</td>
<td>40,000–80,000 h</td>
<td>80,000 h</td>
</tr>
<tr>
<td>Backup power</td>
<td>2,500 h</td>
<td>10,000 h*</td>
</tr>
<tr>
<td>Forklifts</td>
<td>10,000 h</td>
<td>20,000 h*</td>
</tr>
</tbody>
</table>

*Preliminary

Performance and durability models developed to address micro-structural mitigation strategies for PEMFCs

Example: FC-APOLLO Simulation Suite
Application Package using Open-source for Long Life Operation

• Features:
  - Performance and durability simulations
  - Optimize catalyst electrodes
  - Assess Accelerated Stress Test effects
  - Scalable from 1D to 3D simulations
  - Published validation data using FC-STC hardware is available through the US DOE (DE-EE0000466)

• Source code available via Source Forge
  www.sourceforge.net/projects/fcapollo

S. Wessel, D. Harvey and coworkers, Ballard
**EMPHASIS**

- Focus on approaches that will increase activity and utilization of current PGM and PGM-alloy catalysts, as well as non-PGM catalyst approaches for long-term applications
- Develop ion-exchange membrane electrolytes with enhanced performance and stability at reduced cost
- Improve PEM-MEAs through integration of state-of-the-art MEA components
- Develop transport models and in-situ and ex-situ experiments to provide data for model validation
- Identify degradation mechanisms and develop approaches to mitigate their effects
- Maintain core activities on components, subsystems and systems for stationary applications

**Budget**

**FY 2015 Request = $33.0M**  
**FY 2014 Appropriation = $33.4M**

*Subject to appropriations*

New projects awarded in FY2012 and FY2013 for BOP, MEA, and membrane R&D were fully funded up front
Cost Estimates:

- **$55/kW**  
  *(next-gen lab technology scaled up to 500,000 sys/year)*

- **More than 30% reduction since 2008**

- **More than 50% reduction since 2006**

- **$280/kW†**  
  *(current technology at 20,000 sys/year)*

- **Expected cost for initial FCEV commercialization**

*SA, bottom-up analysis of model system manufacturing cost  †ORNL, top-down analysis based on OEM input*
Accomplishments: Cost Analysis for Stationary and Emerging Market Fuel Cell Applications

Projected PEMFC CHP System Costs

- Projected cost meets 2015 equipment cost targets at high volume
- Future year analysis will examine total cost of ownership model for HT-PEM systems and manufacturing cost model for SOFC CHP and power-only systems

Projected PEMFC 10 kW Backup Power System Costs

- BOP cost dominates at higher volumes for 10kW PEMFC backup power system cost
- Projected cost is approximately $1000/kW at high volume

M. Wei et al., LBNL
Accomplishments: Nanosegregated Catalysts

New nanoframe catalysts developed with BES/EERE funding have mass activity more than 30X Pt/C in RDE testing

- PtNi nanoframe catalysts synthesized through a novel spontaneous corrosion and annealing procedure
- High ORR activity in RDE testing – mass activity more than 30X Pt/C
- Minimal activity loss after 10,000 potential cycles in RDE
- MEA testing is underway

“Highly Crystalline Multimetallic Nanoframes with Three-Dimensional Electrocatalytic Surfaces”

Science, 343 (2014) 1339

V. Stamenkovic, P. Yang and coworkers, ANL & LBNL
Accomplishments: Dealloyed Catalysts

Dealloyed PtNi and PtCo catalysts that meet DOE targets are being stack tested

**MEA Testing**

- **Wet**
  - $H_2/\text{air}, 80^\circ\text{C}, 100/100\% \text{RH}_{\text{in}}, \text{stoich } 1.5/2, 170/170\text{kPa}_{\text{abs}}$
  - Voltage at 1.5A/cm$^2$
  - Data points for D-PtNi 12/280 with R.F. values:
    - 46, 43, 39, 48, 44, 38, 47, 44, 37
  - EOT target: 0.56V
  - Cycling: 0.6-0.925V
  - 50mV/1, $H_2/N_2, 80^\circ\text{C}, 100\% \text{RH}$
  - Cathode loadings: 0.086-0.100 mgPt/cm$^2$

- **Dry**
  - $H_2/\text{air}, 80^\circ\text{C}, 32/32\% \text{RH}_{\text{in}}, \text{stoich } 1.5/1.8, 150/150\text{kPa}_{\text{abs}}$
  - Voltage at 1.5A/cm$^2$

**Stack Testing**

- **High Power**
  - Graph showing power density vs. material:
    - JM PtNi, 0.20mg/cm$^2$
    - JM PtNi, 0.15mg/cm$^2$
    - JM PtNi, 0.10mg/cm$^2$
    - JM PtNi, 0.10mg/cm$^2$, Hi I/C
    - JM PtCo, 0.10mg/cm$^2$
  - Graph indicates slightly higher performance for PtCo vs. PtNi at same loading

- **Catalysts tested meet mass activity targets at BOL and after 30,000 cycles in MEAs**
- **High-current performance and durability meet targets with revised cycling conditions**
- **Critical ionomer to carbon ratios identified for high performance and durability in MEAs**
- **Stack testing of most promising catalysts currently underway – initial results show slightly higher performance for PtCo vs. PtNi at same loading**

*A. Kongkanand et al., GM*
Accomplishments: MEA Integration

**MEA integration R&D leads to improved NSTF performance and robustness**

- Improved MEAs produce 6.2 kW/$g_{PGM}$ under conditions that satisfy Q/$\Delta T$ target (2008 baseline 2.8 kW/$g_{PGM}$; 2013 status 6 kW/$g_{PGM}$)

- Further work required to meet performance and durability targets simultaneously

- New anode GDLs improve cold-start capabilities

- Improved performance correlates with increased water removal via anode

---

**Performance**

- 2014 Best of Class NSTF MEA - 0.129mg/$g_{PGM}$/cm² Total
  - AN.: 0.019PtCoMn/NSTF, CATH.: 0.11PtNi, (DEALLOY), PEM: 3M 20µ 850EW, GDL: 2979/2979.

- Kinetic+HFR Only Pol. Curve Through 1/4 Power, Rated Power, and Q/$\Delta T$(90°C) Targets

- 2014 BOC MEA 0.129mg/$g_{PGM}$/cm²

- Pre-Contract Status
  - 2012 BOC MEA 0.151mg/$g_{PGM}$/cm²

**Robustness**

- Temperature Sens. v. Anode GDL

- New anode GDLs improve cold-start capabilities

- Improved performance correlates with increased water removal via anode

---

*A. Steinbach et al., 3M*
Accomplishments: RDE Testing Protocol Standardization

RDE test protocol and best practices developed and validated at NREL and ANL

Protocols

| Break-in | CV | ORR |
| 1.2 V vs RHE | 1.0 V vs RHE | 1.0 V vs RHE |
| 0.4 V | 0.4 V | ~0.01 V |
| 0.025 V | 0.025 V | 0.02 V/s |

Statistical Reproducibility Pt/C Specific Activity ($\mu$A/cm$^2_{Pt}$) at NREL (Spin Coating Method)

- 485 ± 10% (n = 49) TKK
- 515 ± 5% (n = 29) JM
- 344 ± 8% (n = 24) Umicore

Pt/C Mass Activity (mA/mg$_{Pt}$) Inter-lab Comparison (Spin Coating Method)

- 46.4 wt% Pt; d~2.5nm
- 37.6 wt% Pt; d<2nm
- 47.2 wt% Pt; d~4.9nm

S. Kocha, NREL; D. Myers, ANL; V. Stamenkovic, ANL

ORR Protocol Details

| Gas | N$_2$ or O$_2$ |
| Temperature | r.t. |
| Rotation Rate [rpm] | 1600 |
| Potential Range [V vs. RHE] | −0.01 to 1.0 (anodic) |
| Scan Rate [V/s] | 0.02 |
| $R_{sol}$ measurement method | i-interrupter or EIS (HFR) |
| iR compensation | applied during measurement |
| Background Subtraction | LSV (O$_2$)−LSV (N$_2$) |
New Fuel Cell R&D Projects

Selected from Fuel Cell R&D FOA

New Fuel Cell Membranes with Improved Durability & Performance
3M Company, with General Motors Company, Vanderbilt University
3 year, $4.2M project fully funded in FY 2013, initiated in FY2014

Advanced Hybrid Membranes for Next Generation PEMFC Automotive Applications
Colorado School of Mines, with Nissan USA, NREL, 3M Company
3 year, $1.9M project fully funded in FY 2013, initiated in FY2014

‘Smart’ Matrix Development for Direct Carbonate Fuel Cell
FuelCell Energy, with UConn and IIT
3 year, $3.2M project to be fully funded in FY 2014

Fuel Cell Project Selected for First Ever Technology-to-Market SBIR Award

Ionomer Dispersion Impact on Advanced Fuel Cell and Electrolyzer Performance and Durability
Giner Inc. in partnership with LANL

http://energy.gov/eere/articles/small-business-innovation-research-bringing-clean-energy-technologies-marketplace
Advances in fuel clean-up technology will enable fuel flexibility and reduce fuel cell system cost

Workshop Findings:

- Fuel cleanup is a barrier
- Fuel gas clean-up costs can be reduced through a combination of development efforts
- Opportunities to use APG onsite with fuel cells identified

Workshop report to be released for public comment
Stakeholder Engagement

Request for Information
R&D needs and technical barriers for fuel cells
5/5/2015-6/9/2014

6 Categories:
- Catalysts and supports
- Membrane electrode assembly (MEA) component integration
- Stack and component operation and performance
- Automotive balance-of-plant (BOP) component development
- Fuel cell systems for stationary and emerging market applications
- Subject areas for programmatic consideration

DOE FCTO Pre-Solicitation Workshop:
R&D Needs and Technical Barriers for PEMFC
Monday, June 16, 2014, 6:00-8:30 PM
Wardman Park Marriott, Washington DC
Meeting Room Virginia ABC

Objectives
- Solicit additional feedback from community on RFI questions
- Prioritize topic areas

2015 R&D FOA
(subject to appropriations)
Collaborations

Applied R&D is coordinated among national and international organizations

**INTERNATIONAL ACTIVITIES**
- International Energy Agency – H2 Implementing Agreement

**DOE-EERE**
- Fuel Cells R&D
  - Vehicle Technologies Office
  - SBIR
  - 42 projects

**INDUSTRY**
- U.S. DRIVE Partnership Fuel Cell Tech Team
- Codes & Standards Organizations

**TECHNOLOGY VALIDATION**

**National Collaborations (inter- and intra-agency efforts)**

- **DOE - FE**
  - SECA

- **DOE - BES**
  - Catalysts and Membranes

- **DOE – ARPA-E**
  - Reliable Electricity Based on Electrochemical Systems (REBELS)

- **DOT/FTA**
  - Fuel Cell Buses

- **DOD**
  - DOD/DOE MOU

- **DOC/NIST**
  - Neutron imaging
Recent and Upcoming Activities

Summary of activities and upcoming milestones

Stacks and Components
- Projects addressed cost reduction and performance and durability enhancement of stack components including catalysts, membranes and MEAs.
- cEMGI Center of Excellence will address non-PGM catalysts and interfaces: improved modeling for materials development, high-throughput screening, and advanced characterization.

Systems and Balance of Plant
- R&D will address components and sub-systems, including fuel cell air management.

Testing and Technical Assessments
- Analysis projects provide cost estimates for transportation, stationary and emerging market applications.

<table>
<thead>
<tr>
<th>FY 2014</th>
<th>FY 2015</th>
<th>FY 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Q 2014: Developed PEM bipolar plates with a cost less than or equal to $5/kW</td>
<td>1Q 2015: Release R&amp;D FOA*</td>
<td>4Q 2015: Demonstrate MEA with 6.9 kW/g_pgm at rated power</td>
</tr>
<tr>
<td>3Q 2014 RFI released</td>
<td>2Q 2015: Project selection from R&amp;D FOA*</td>
<td>* Subject to appropriations</td>
</tr>
<tr>
<td>Pre-solicitation workshop at AMR</td>
<td>4Q 2015: Alkaline membrane fuel cell workshop</td>
<td>4Q 2016: Demonstrate MEA with 6.9 kW/g_pgm at rated power</td>
</tr>
</tbody>
</table>

* Subject to appropriations
Acknowledgements: Tom Benjamin and John Kopasz (ANL); Cassidy Houchins (SRA International)

http://energy.gov/eere/fuelcells/fuel-cell-technologies-office