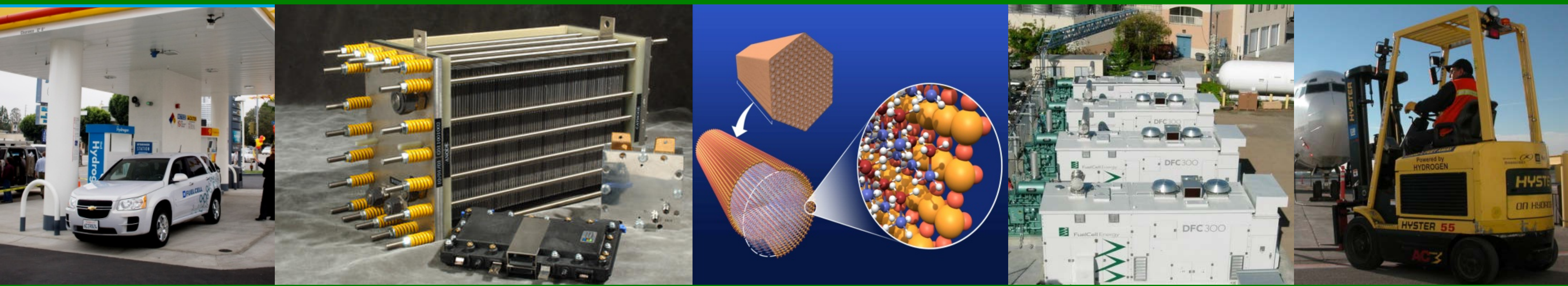
U.S. DEPARTMENT OF
ENERGY



Fuel Cells Program
- Plenary Presentation-

Dimitrios Papageorgopoulos
Fuel Cell Technologies Office

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

Goals and Objectives

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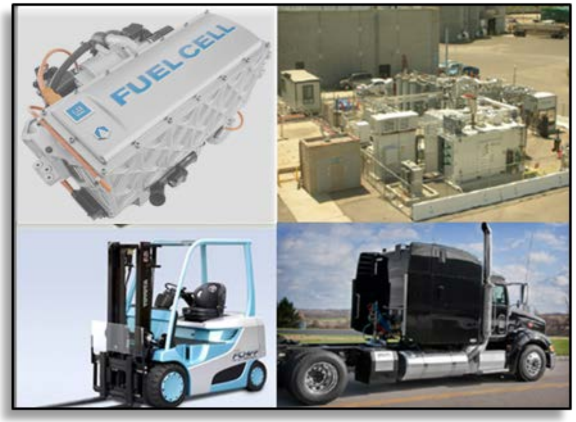
GOAL: Develop and demonstrate fuel cell power system technologies for transportation, portable, and stationary applications

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.



Challenges & Strategy

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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

Barriers

Cost
Durability
Performance

Strategy

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

Fuel Cell R&D

Testing and Cost/Technical Assessments

FOCUS AREAS

Stack Components
Catalysts
Electrodes
Electrolytes
MEAs and Cells
Gas diffusion media
Seals
Bipolar plates

Operation and Performance
Mass transport
Durability
Impurities

Systems and Balance of Plant (BOP)
BOP components
Fuel processors
Stationary power
Portable power
APUs and Emerging markets

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

Market-driven targets ensure competitive strategy

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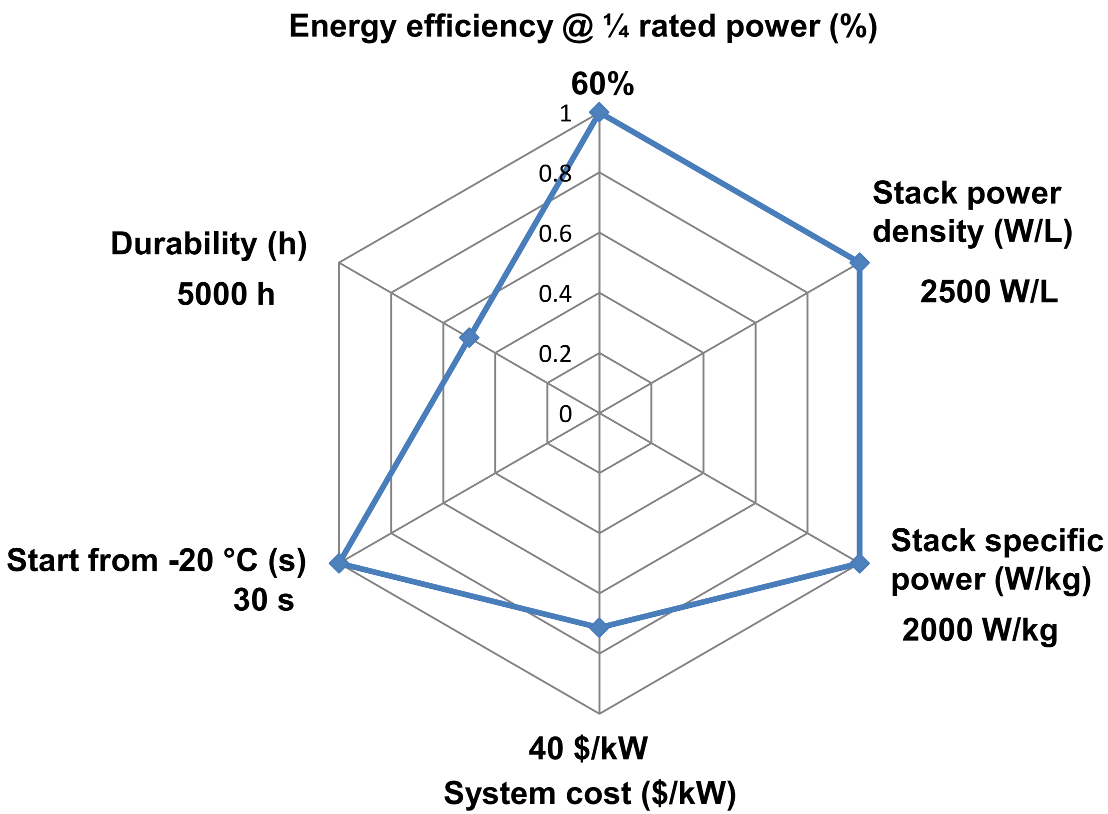
Automotive fuel cell cost targets: $40 / kW by 2020 and $ 30 / kW ultimate

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 <u>and</u> Cost are the primary challenges to fuel cell commercialization and must be met concurrently.



Technical analysis tracks fuel cell system cost

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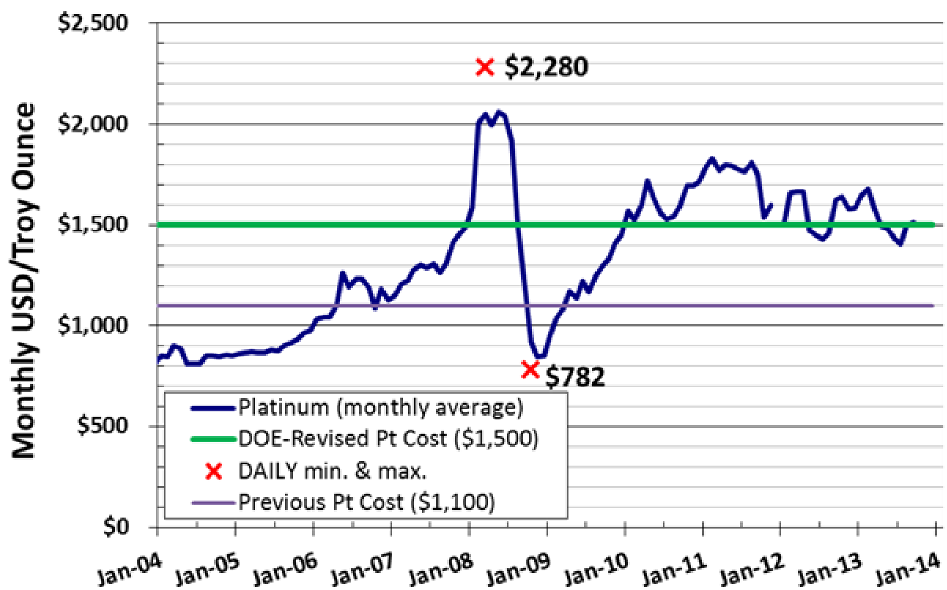
Automotive fuel cell system cost analysis project assumptions revised

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

- **System must meet heat rejection target (Q/ΔT ≤ 1.45)*, required due to the constraints on the radiator size inherent in automotive applications**
- **Pt price adjusted from $1100 /oz. to $1500 / oz.**



*Q/ΔT = [Stack power (90kW) x (1.25V - Voltage at Rated Power) / (Voltage at Rated Power)] / [(Stack Coolant out temp (°C) - Ambient temp (40°C)]. 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

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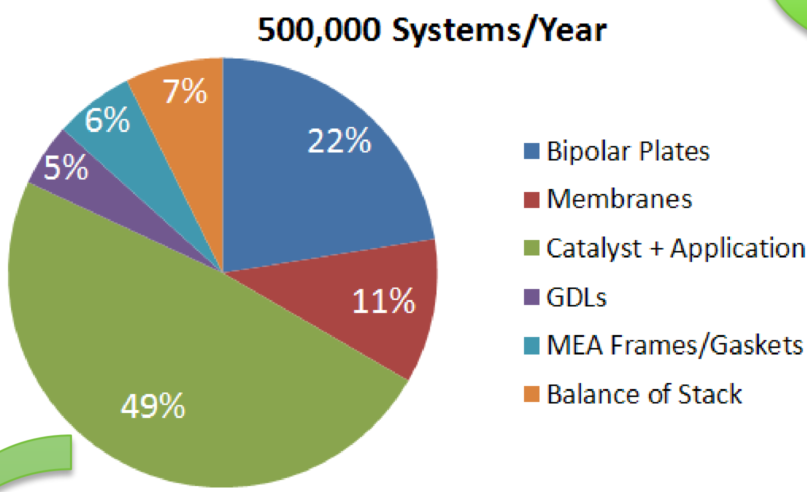
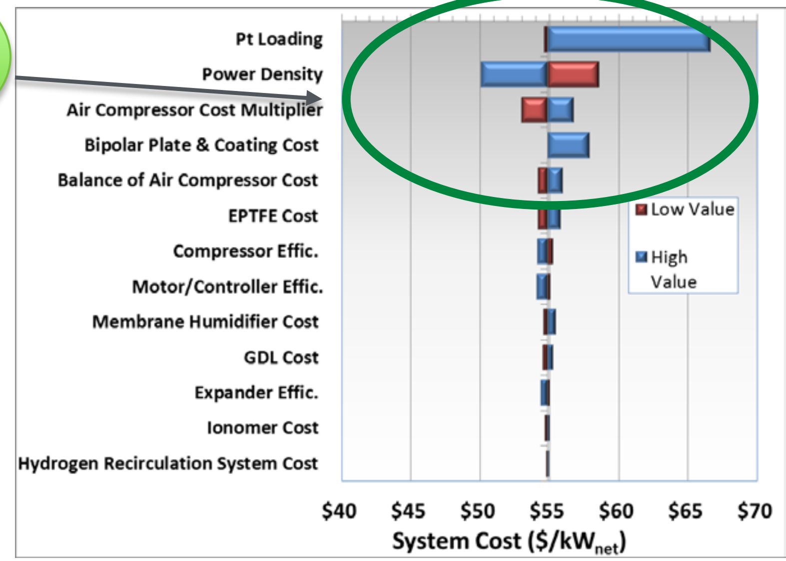
- *Strategic technical analysis guides focus areas for R&D and priorities*
- *Advances in PEMFC materials and components could benefit a range of applications*

PEMFC Stack Cost Breakdown



Key Focus Areas for R&D

Sensitivity Analysis helps guide R&D



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

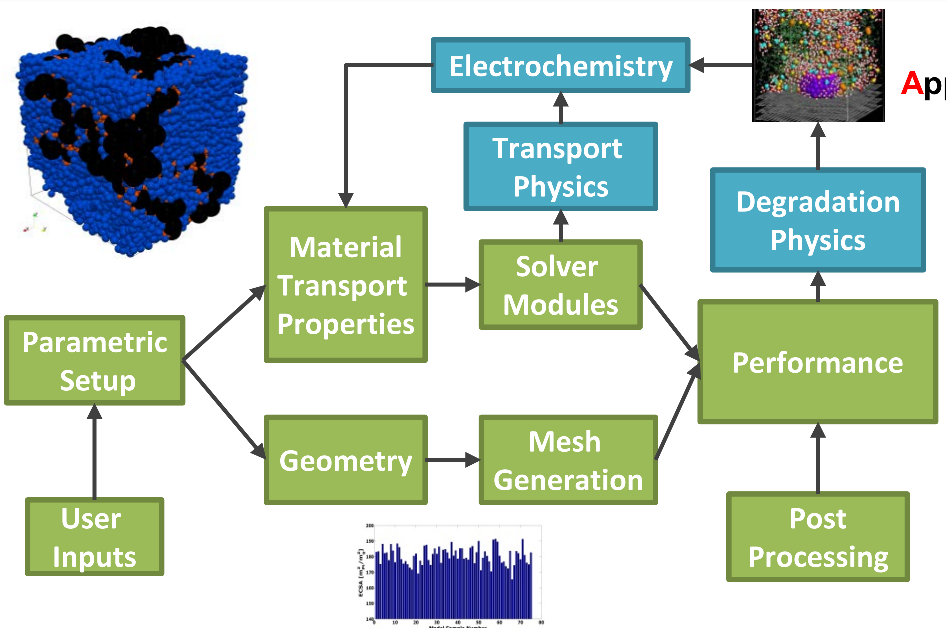
NFCTEC

Market-driven targets set for a range of applications Examples

System	Status	Target
80-kW$_e$ Automotive	2,500 h	5,000 h
Bus	12,000 h	25,000 h
100 kW–3 MW CHP	40,000–80,000 h	80,000 h
Backup power	2,500 h	10,000 h*
Forklifts	10,000 h	20,000 h*

*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

Budget

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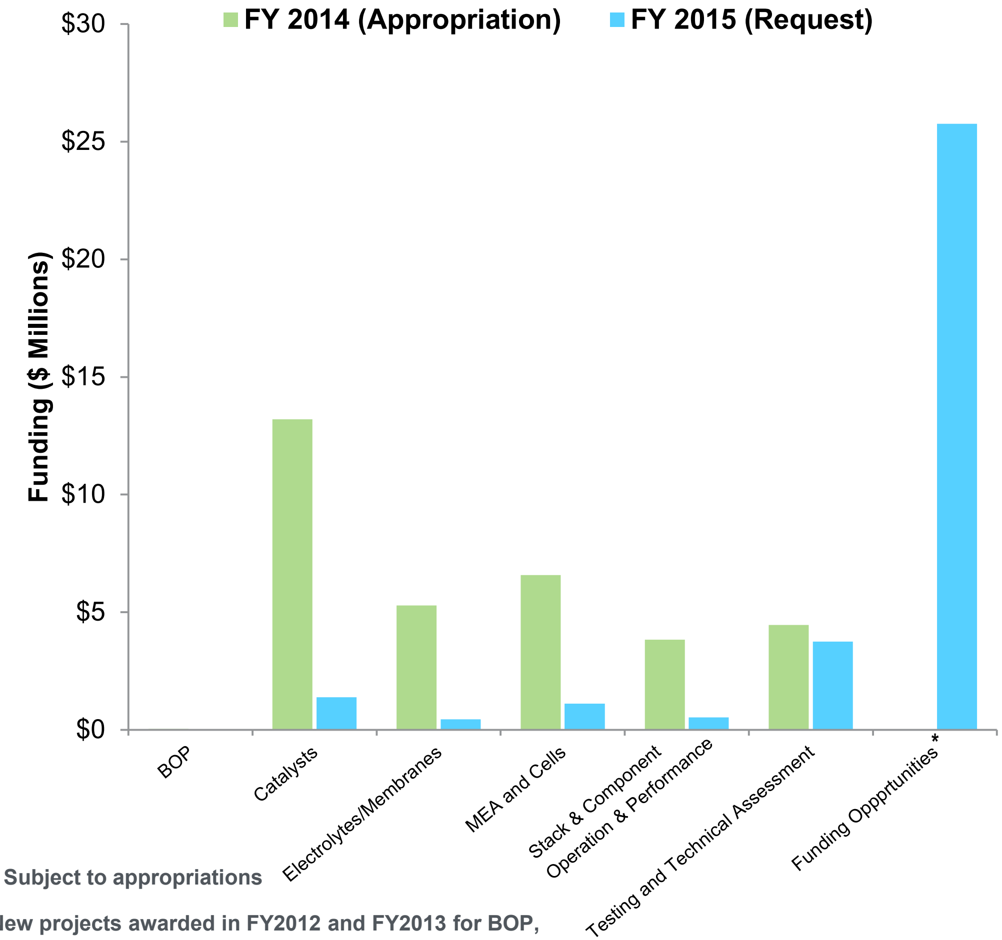
FY 2015 Request = $33.0M
FY 2014 Appropriation = $33.4M



*** Subject to appropriations**

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

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

Fuel Cell Cost

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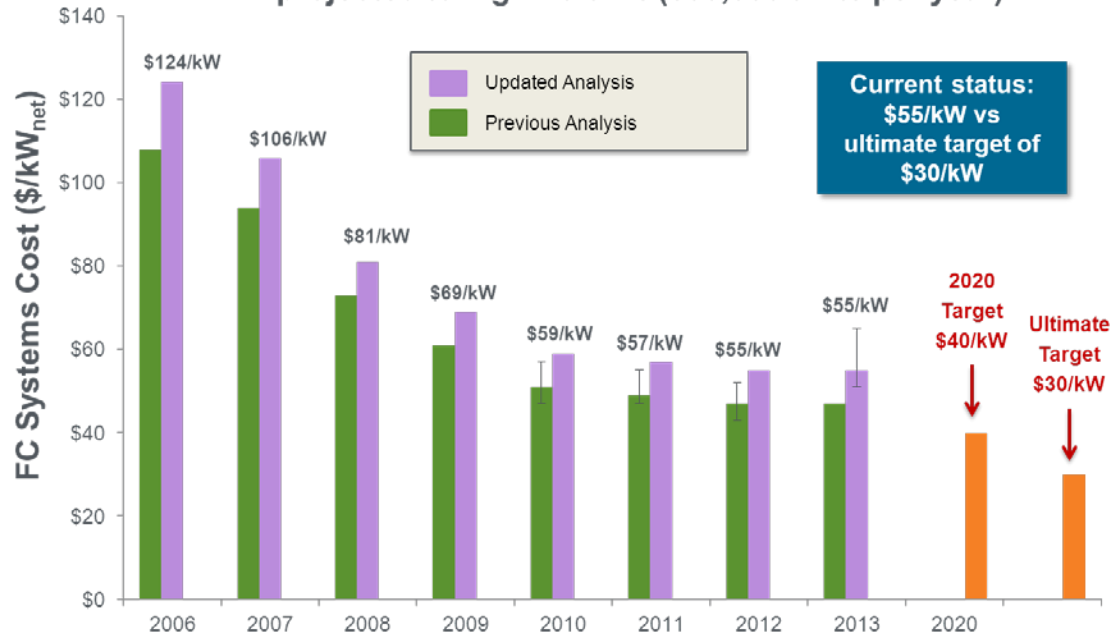
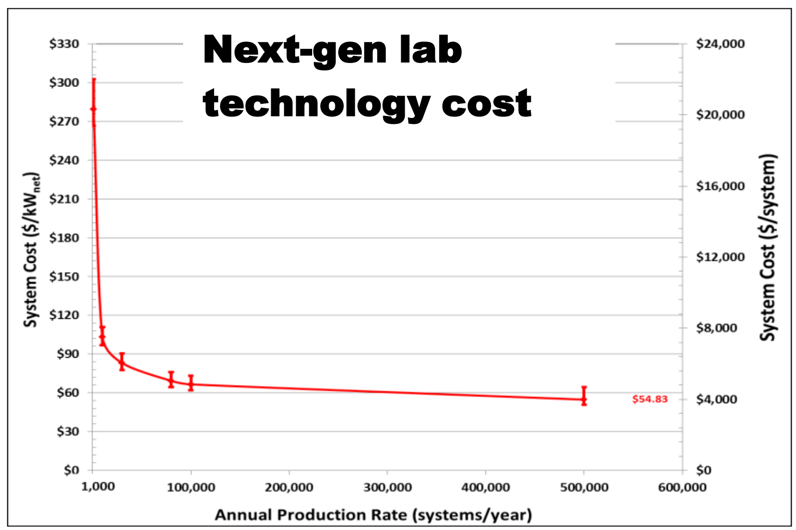
Cost Estimates:

- **$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***

Projected Transportation Fuel Cell System Cost
-projected to high-volume (500,000 units per year)-





Sys/Year	Nominal Value
1,000	$279
10,000	$103
30,000	$83
80,000	$69
100,000	$67
500,000	$55

***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

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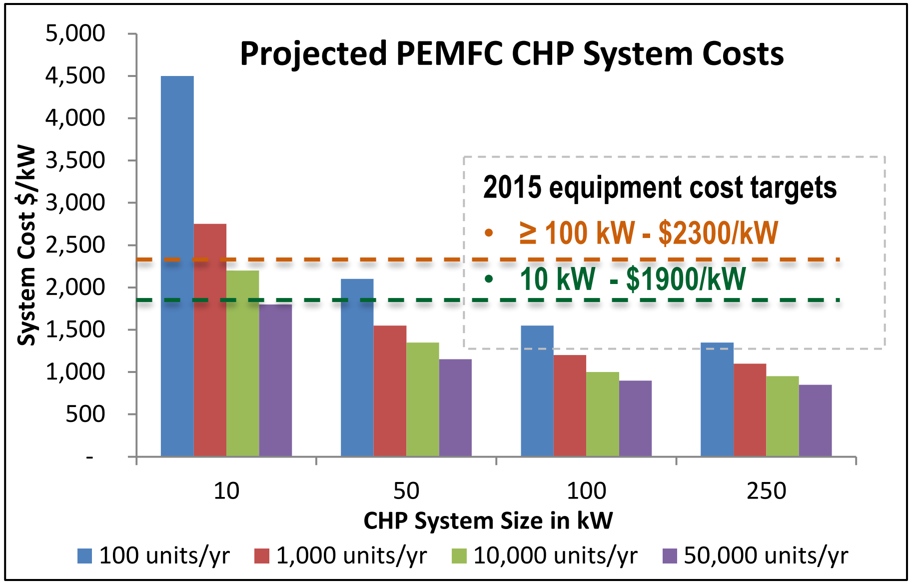
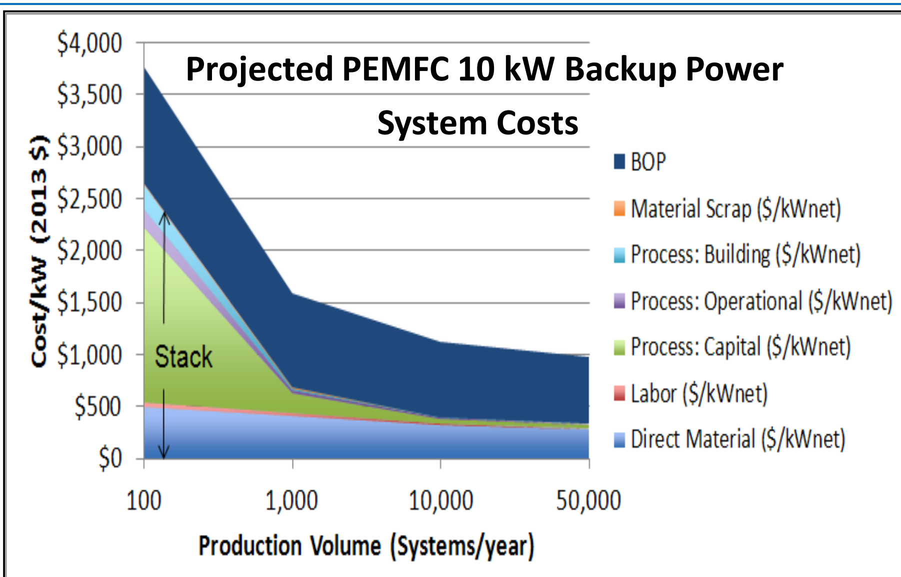


- Projected cost meets 2015 equipment cost targets at high volume
- Future year analysis will examine total cost of ownership model for HT-PEM systems and manufacturing cost model for SOFC CHP and power-only systems



- 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

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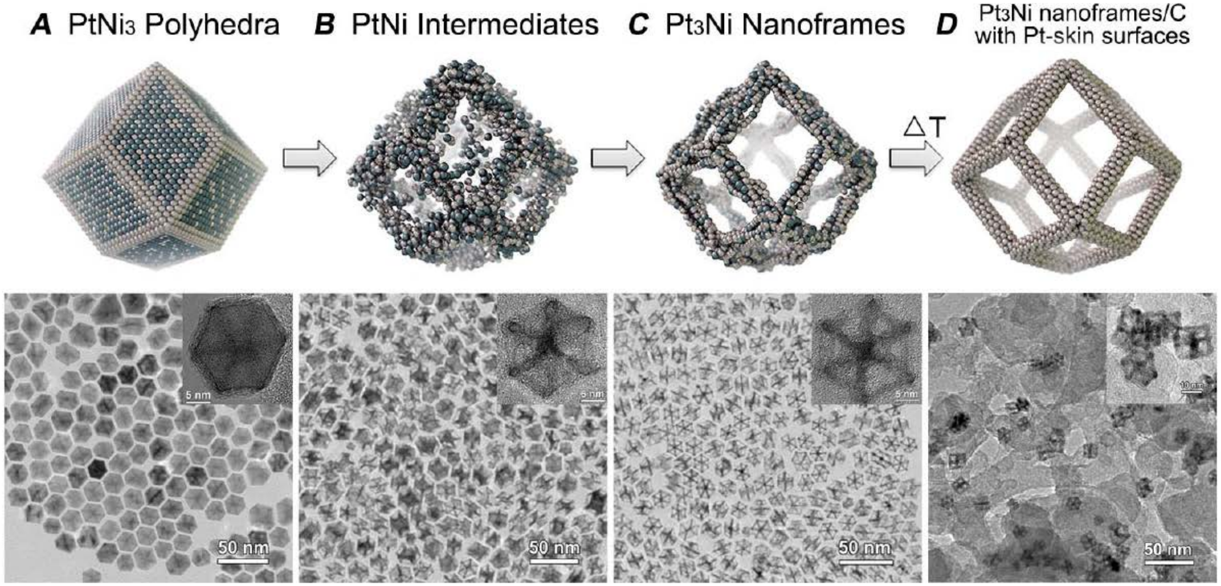
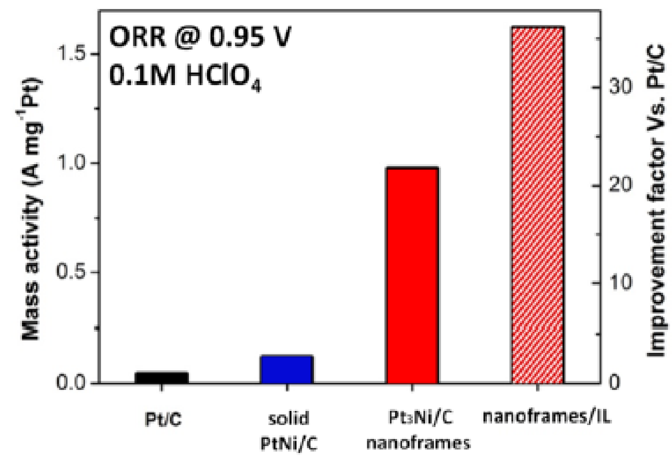
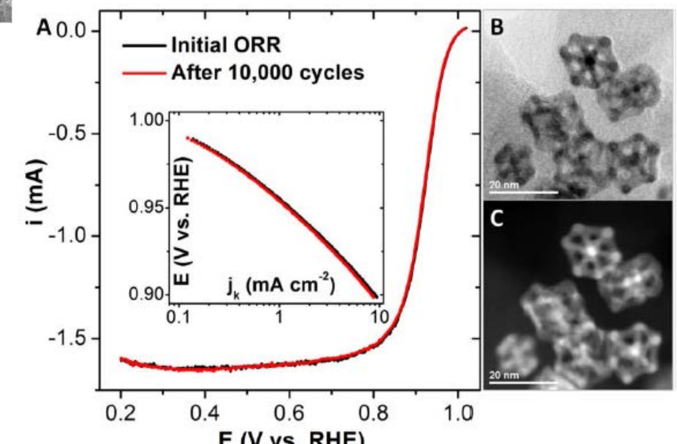
New nanoframe catalysts developed with BES/EERE funding have mass activity more than 30X Pt/C in RDE testing







- **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

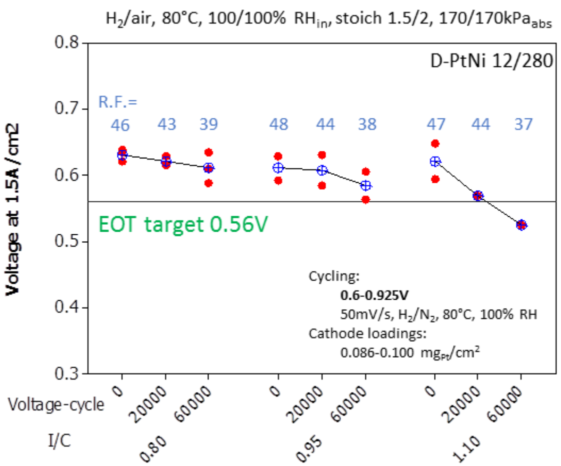
Accomplishments: Dealloyed Catalysts

U.S. DEPARTMENT OF ENERGY

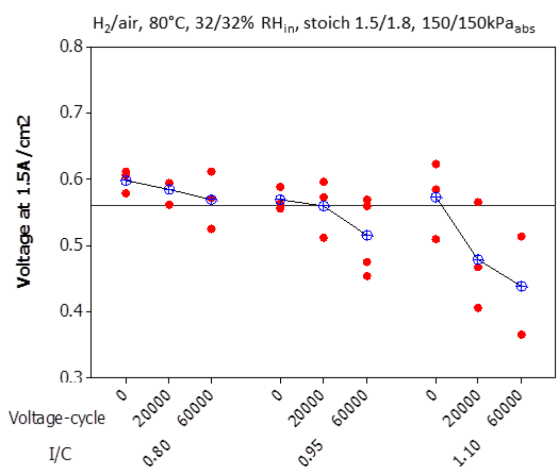
Dealloyed PtNi and PtCo catalysts that meet DOE targets are being stack tested

MEA Testing

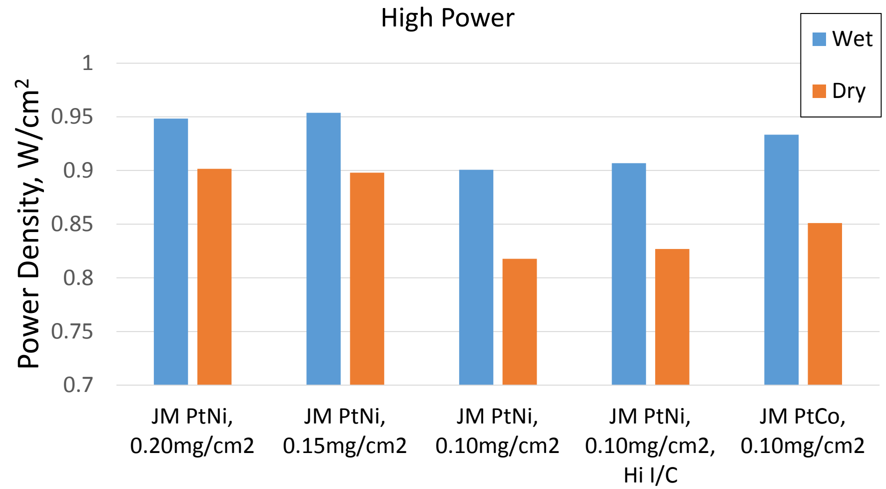
Wet



Dry



Stack Testing



- **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

12

Accomplishments: MEA Integration

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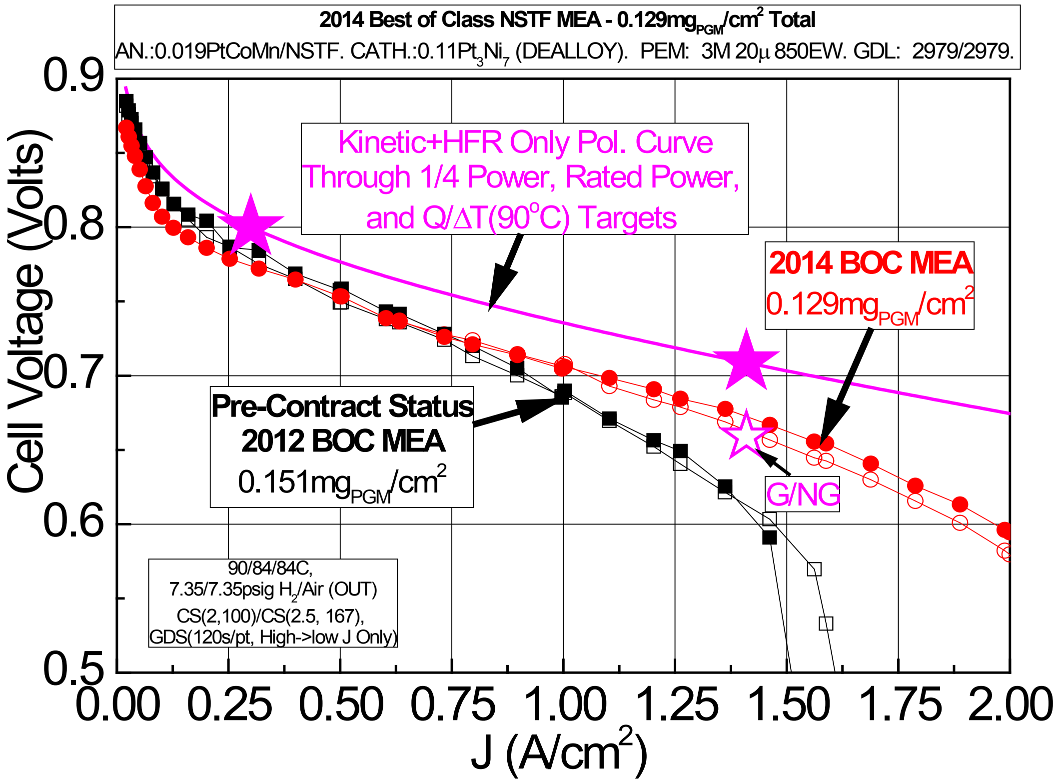
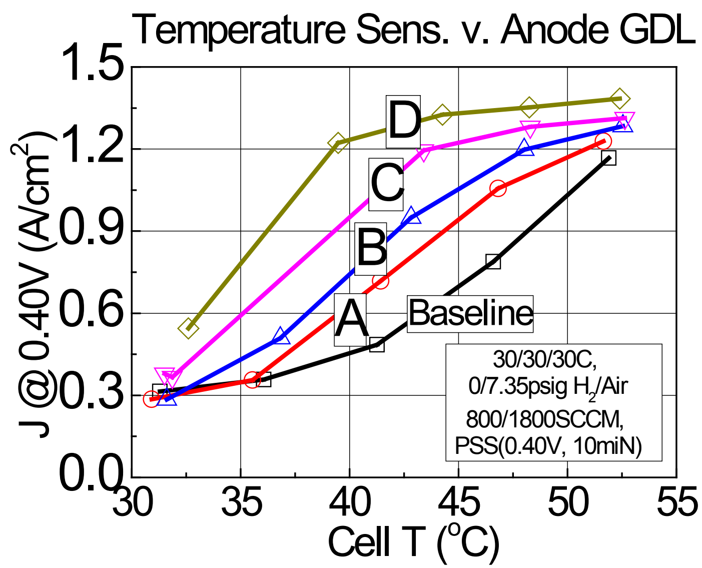
MEA integration R&D leads to improved NSTF performance and robustness

Performance



- Improved MEAs produce 6.2 kW/g_{PGM} under conditions that satisfy Q/ΔT target (2008 baseline 2.8 kW/g_{PGM}; 2013 status 6 kW/g_{PGM})
- Further work required to meet performance and durability targets simultaneously

Robustness



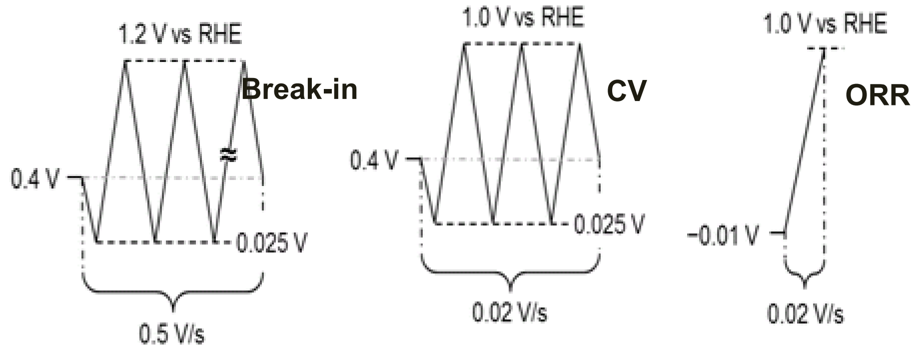
- New anode GDLs improve cold-start capabilities
- Improved performance correlates with increased water removal via anode

A. Steinbach et al., 3M

Accomplishments: RDE Testing Protocol Standardization

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

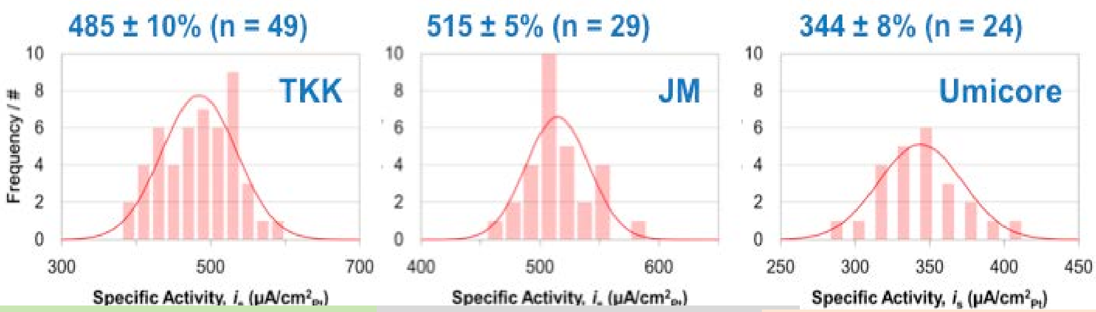
Protocols



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)

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

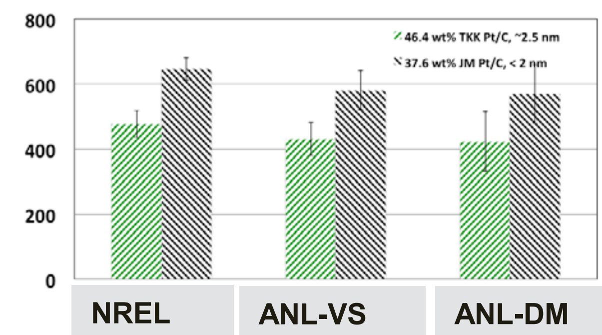


46.4 wt% Pt; d~2.5nm

37.6 wt% Pt; d<2nm

47.2 wt% Pt; d~4.9nm

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



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

New Fuel Cell R&D Projects

U.S. DEPARTMENT OF ENERGY

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

Gas Cleanup Workshop

U.S. DEPARTMENT OF ENERGY

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

Please Save the Date:

Thursday, March 6th and Friday, March 7th 2014
TCS Conference Center, Argonne, Illinois 60439
Organized by Argonne National Laboratory
Sponsored by the Fuel Cell Technology Office, Energy Efficiency and Renewable Energy, US Department of Energy

Workshop on Gas Clean-Up for Fuel Cell Applications

Objective
Exchange information and discuss research and development (R&D) needs to reduce the cost and complexity of removing impurities from natural gas, LPG, biogas, associated petroleum gas (APG), diesel, and biodiesel for fuel cell applications.

Workshop Activities will include discussions led by plenary speakers and break-out sessions. The workshop will identify and prioritize

- ✓ The impurities that have the greatest impact on the complexity and performance of the fuel cell plant
- ✓ R&D strategies that can alleviate the cost for onsite removal of impurities
- ✓ R&D strategies that will simplify the plant and reduce product cost (heat, power, hydrogen)
- ✓ Fuel processors and gas clean-up system designs facilitating modularity and fuel flexibility for a range of fuel cell technologies
- ✓ Opportunities to avoid APG flaring by using fuel cells

Desired Outcomes Include:

- A summary of the fuel impurities that pose the greatest technical challenge for the fuel cell powerplant
- A summary of the R&D requirements for cost-effective impurity removal and fuel flexibility
- Identification of opportunities for fuel cells in avoiding flaring of APG
- A workshop report for public review

Attendance is limited to ensure productive interaction within small breakout groups.
Registration information will follow.
For questions, please contact
Shabbir Ahmed (ahmeds@anl.gov)
or
Dimitrios Papageorgopoulos (Dimitrios.Papageorgopoulos@ee.doe.gov)

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

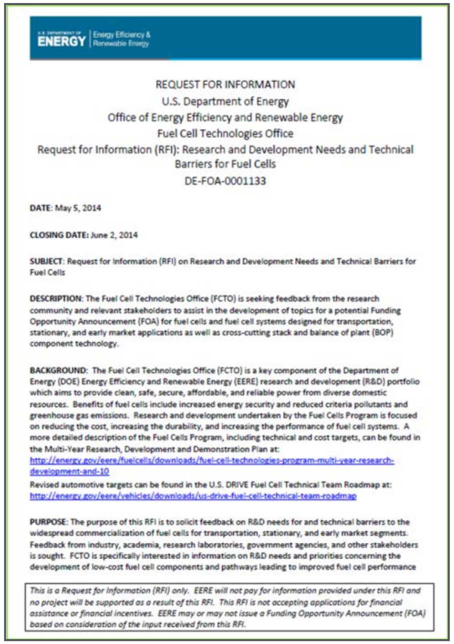
Monday, June 16, 2014, 6:00-8:30 PM

Wardman Park Marriott, Washington DC

Meeting Room Virginia ABC

Objectives

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



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

REQUEST FOR INFORMATION
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Fuel Cell Technologies Office
Request for Information (RFI): Research and Development Needs and Technical Barriers for Fuel Cells
DE-FOA-0001133

DATE: May 5, 2014

CLOSING DATE: June 2, 2014

SUBJECT: Request for Information (RFI) on Research and Development Needs and Technical Barriers for Fuel Cells

DESCRIPTION: The Fuel Cell Technologies Office (FCTO) is seeking feedback from the research community and relevant stakeholders to assist in the development of topics for a potential Funding Opportunity Announcement (FOA) for fuel cells and fuel cell systems designed for transportation, stationary, and early market applications as well as cross-cutting stack and balance of plant (BOP) component technology.

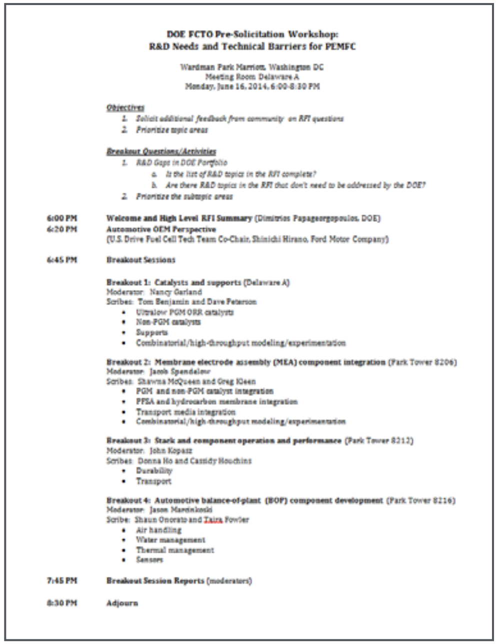
BACKGROUND: The Fuel Cell Technologies Office (FCTO) is a key component of the Department of Energy (DOE) Energy Efficiency and Renewable Energy (EERE) research and development (R&D) portfolio which aims to provide clean, safe, secure, affordable, and reliable power from diverse domestic resources. Benefits of fuel cells include increased energy security and reduced criteria pollutants and greenhouse gas emissions. Research and development undertaken by the Fuel Cells Program is focused on reducing the cost, increasing the durability, and increasing the performance of fuel cell systems. A more detailed description of the Fuel Cells Program, including technical and cost targets, can be found in the Multi-Year Research, Development and Demonstration Plan at:
http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-program-multi-year-research-development-and-10
Revised automotive targets can be found in the U.S. DRIVE Fuel Cell Technical Team Roadmap at:
http://energy.gov/eere/vehicles/downloads/us-drive-fuel-cell-technical-team-roadmap

PURPOSE: The purpose of this RFI is to solicit feedback on R&D needs for and technical barriers to the widespread commercialization of fuel cells for transportation, stationary, and early market segments. Feedback from industry, academia, research laboratories, government agencies, and other stakeholders is sought. FCTO is specifically interested in information on R&D needs and priorities concerning the development of low-cost fuel cell components and pathways leading to improved fuel cell performance

This is a Request for Information (RFI) only. EERE will not pay for information provided under this RFI and no project will be supported as a result of this RFI. This RFI is not accepting applications for financial assistance or financial incentives. EERE may or may not issue a Funding Opportunity Announcement (FOA) based on consideration of the input received from this RFI.

2015 R&D FOA

(subject to appropriations)



DOE FCTO Pre-Solicitation Workshop:
R&D Needs and Technical Barriers for PEMFC

Wardman Park Marriott, Washington DC
Meeting Room Delaware A
Monday, June 16, 2014, 6:00-8:30 PM

Objectives
1. *Solicit additional feedback from community on RFI questions*
2. *Prioritize topic areas*

Breakout Questions/Activities
1. *R&D Gaps in DOE Portfolio*
   a. *Is the list of R&D topics in the RFI complete?*
   b. *Are there R&D topics in the RFI that don't need to be addressed by the DOE?*
2. *Prioritize the subtopic areas*

6:00 PM **Welcome and High Level RFI Summary** (Dimitrios Papageorgopoulos, DOE)
6:20 PM **Automotive OEM Perspective**
(U.S. Drive Fuel Cell Tech Team Co-Chair, Shinichi Hirano, Ford Motor Company)

6:45 PM **Breakout Sessions**

Breakout 1: Catalysts and supports (Delaware A)
Moderator: Nancy Garland
Scribes: Tom Benjamin and Dave Peterson
- Ultralow PGM ORR catalysts
- Non-PGM catalysts
- Supports
- Combinatorial/high-throughput modeling/experimentation

Breakout 2: Membrane electrode assembly (MEA) component integration (Park Tower 8206)
Moderator: Jacob Spendelow
Scribes: Shawna McQueen and Greg Kleen
- PGM and non-PGM catalyst integration
- PFSA and hydrocarbon membrane integration
- Transport media integration
- Combinatorial/high-throughput modeling/experimentation

Breakout 3: Stack and component operation and performance (Park Tower 8212)
Moderator: John Kopasz
Scribes: Donna Ho and Cassidy Houchins
- Durability
- Transport

Breakout 4: Automotive balance-of-plant (BOP) component development (Park Tower 8216)
Moderator: Jason Marcinkoski
Scribe: Shaun Onorato and Taira Fowler
- Air handling
- Water management
- Thermal management
- Sensors

7:45 PM **Breakout Session Reports** (moderators)

8:30 PM **Adjourn**

Collaborations

U.S. DEPARTMENT OF ENERGY

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

U.S. DEPARTMENT OF ENERGY

Summary of activities and upcoming milestones

Stacks and Components

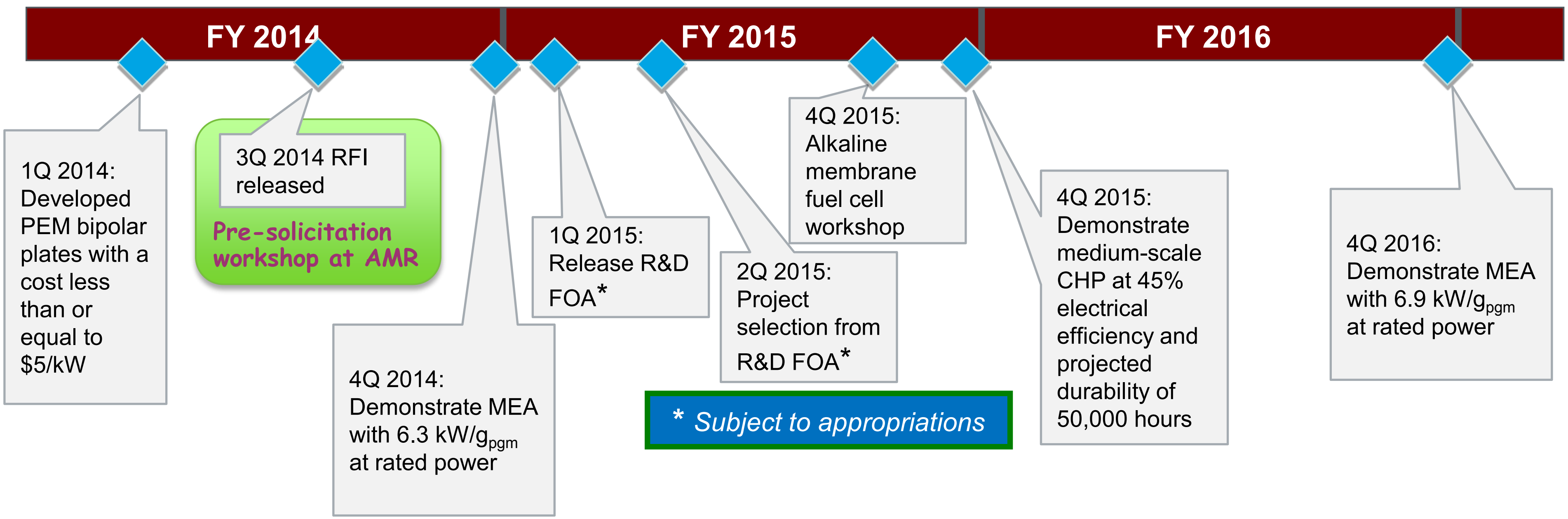
- Projects addressed cost reduction and performance and durability enhancement of stack components including catalysts, membranes and MEAs.
- cEMGI Center of Excellence will address non-PGM catalysts and interfaces: improved modeling for materials development, high-throughput screening, and advanced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



Contacts

Fuel Cells Program

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