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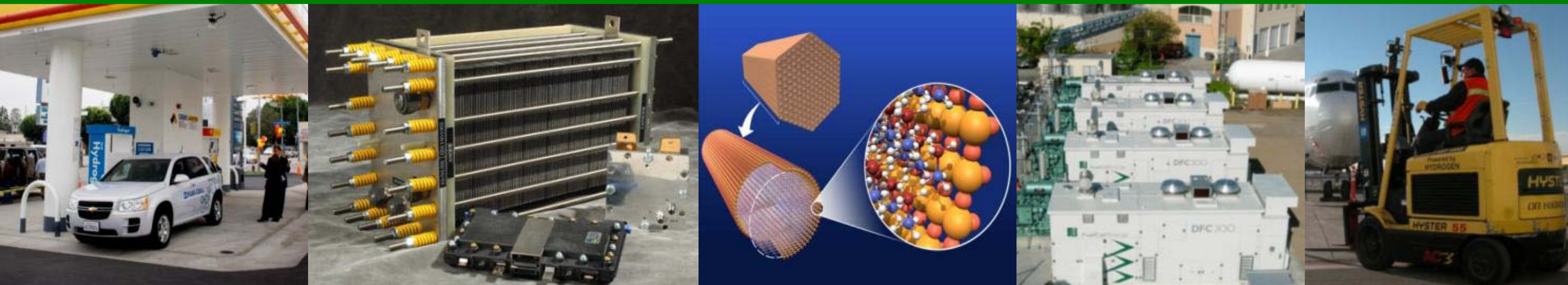
ENERGY



Fuel Cells Sub-program
- Session Introduction-

Dimitrios Papageorgopoulos

2011 Annual Merit Review and Peer Evaluation Meeting
May 10, 2011

Goal and Objectives

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

Develop fuel cell systems to meet DOE targets, including:

Transportation:

- Efficiency of 60% at 25% of rated power
- Cost of $30/kW
- Durability of 5000 hours

Stationary (CHP):

- Efficiency of 45%
- Durability of 60,000

Auxiliary Power Units:

- Efficiency of 40% at rated power
- Cost of $1000/kW
- Durability of 20,000 hours

Portable Power:

- Power density of 100 W/L
- Durability of 5000 hours

Challenges & Strategy

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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.

Barriers

Cost
Durability
Air/thermal/water management
Application Form Factor
Fuel flexibility for stationary applications

→

Strategy

Materials 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
Membranes
GDL s and Seals
Bipolar Plates
MEAs and Integration
High-Temperature Fuel Cells

Operation and Performance
Mass transport
Durability
Impurities

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

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

Challenges: Catalysts and Supports

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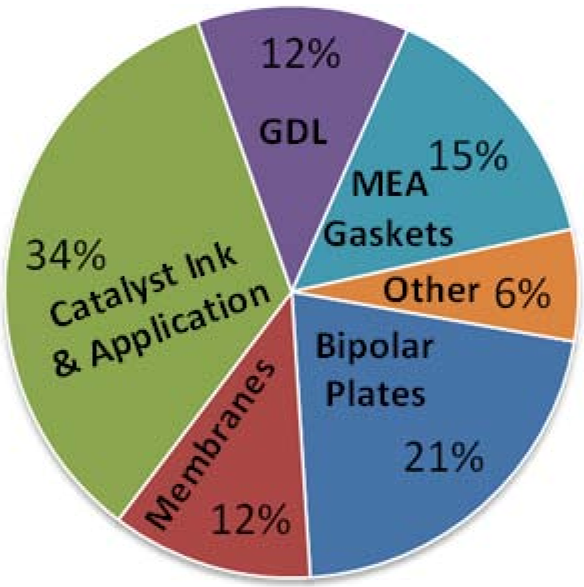
Challenges:
- ***Platinum (Pt) cost is ~34% of total stack cost***
- ***Catalyst durability needs improvement***

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 - $25/kW



DTI, 2010 analysis, scaled to high volume production of 500,000 units/yr

Used $1100/Troy Ounce for Pt Cost

Challenges: Membranes

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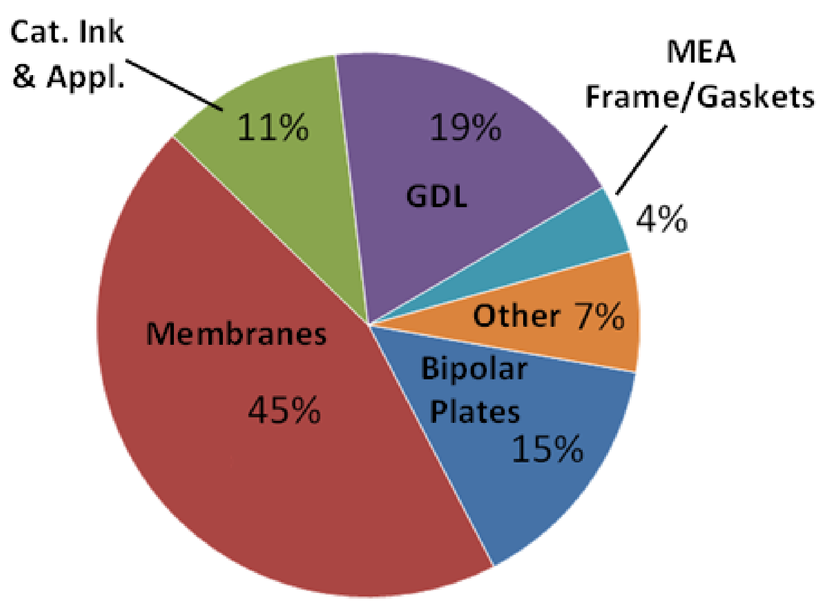
Challenges:
- ***Membranes account for 45% of stack cost at low volume***
- ***Limits on operating range***
- ***Chemical and mechanical durability***

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

Stack Cost - $144/kW



DTI, 2010 analysis, production of 1,000 units/yr

Challenges and Strategies: CHP

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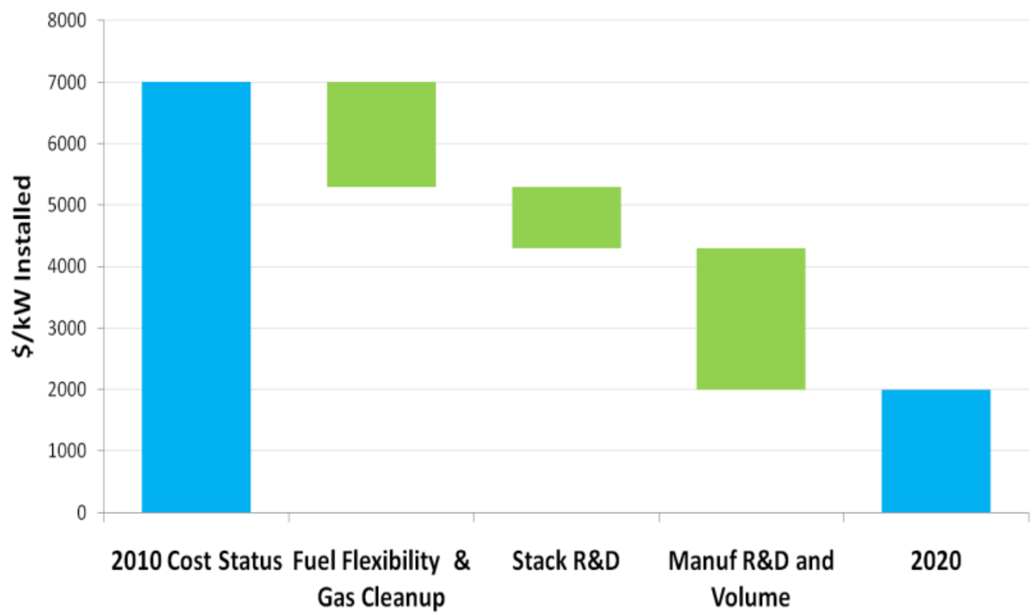
Technical and cost gap analyses of molten carbonate fuel cell (MCFC) and phosphoric acid fuel cell (PAFC) stationary power plants identify pathways for reducing costs.

Medium-Scale Fuel Cell CHP with Biogas



Development of a cost-effective process for removing fuel contaminants would allow for fuel flexibility.

Key areas identified:

➢For MCFC, the service life of the fuel cell stack needs to be extended by:

- reducing electrolyte losses
- reducing cathode dissolution
- increasing the stability of the electrolyte support material

➢For PAFC, cost reductions could be achieved by reducing:

- platinum loading
- the impact of the anion adsorption on the cathode catalyst

Fuel Cells Budget

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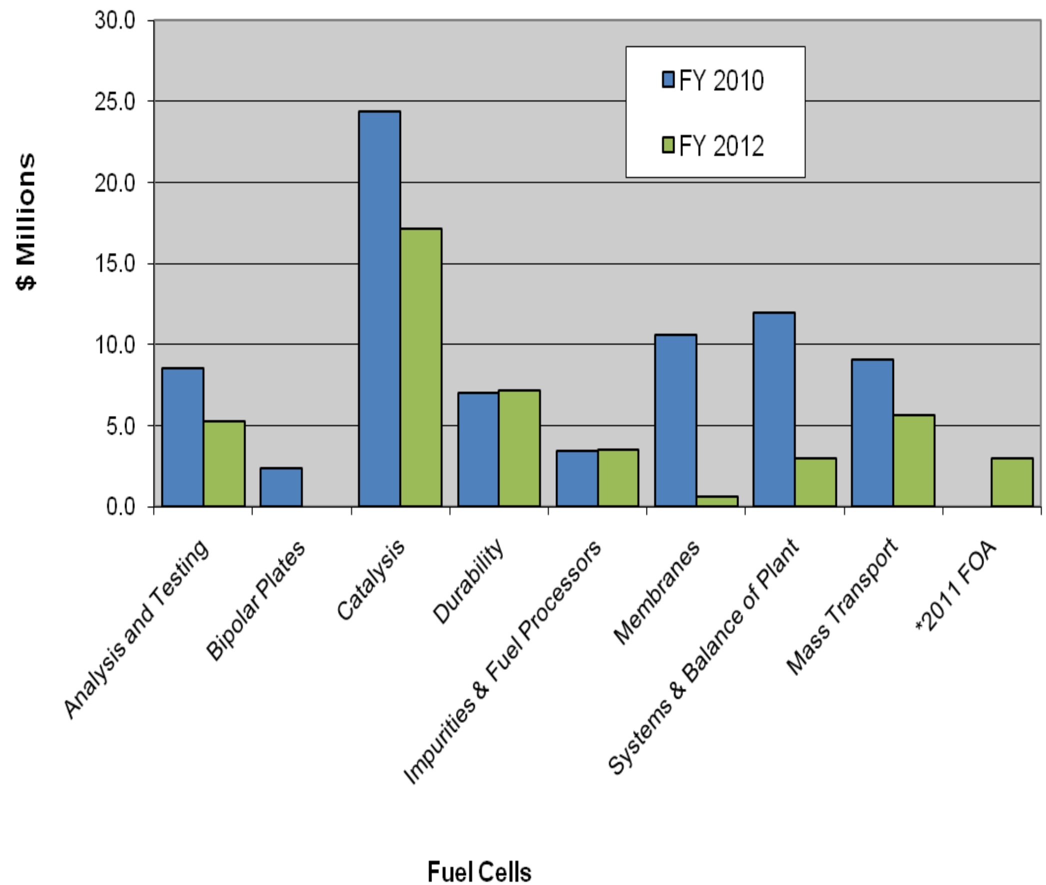
FY 2012 REQUEST = $45.4M

FY 2010 APPROPRIATION = $77.4M



[1]Systems & Balance of Plant includes Stationary and Portable Power

*subject to appropriations

EMPHASIS:
is on science and engineering at the cell level, and from a systems perspective, on integration and component interactions:

- Develop improved fuel cell catalysts and membrane electrolytes
- 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

Progress: Fuel Cells

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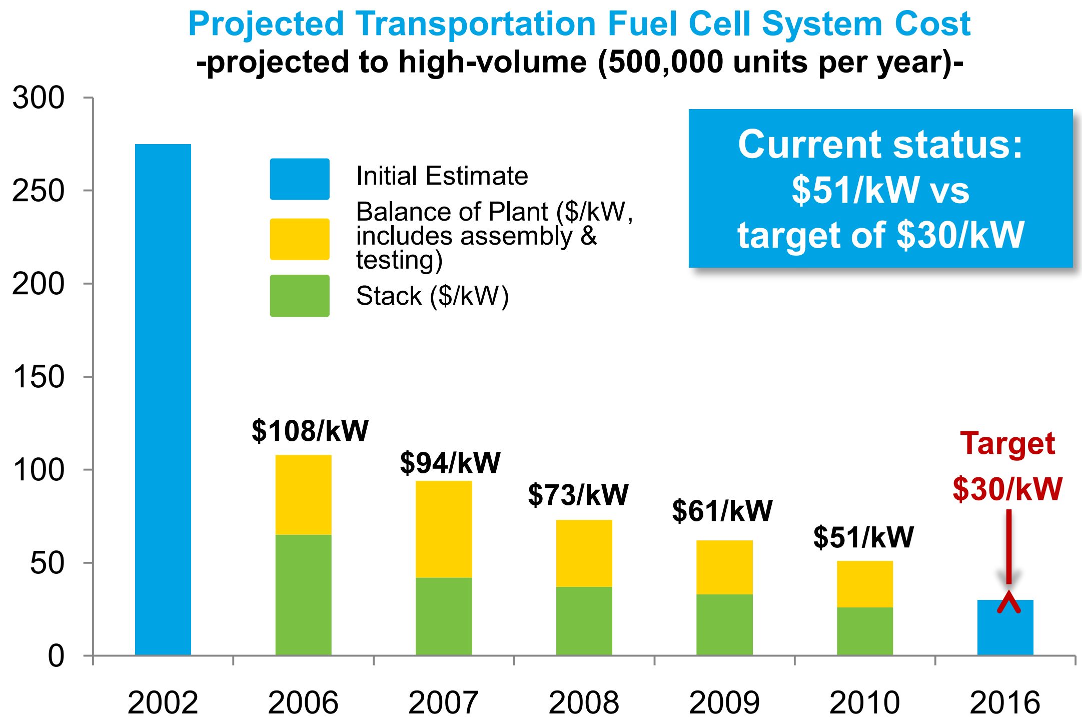
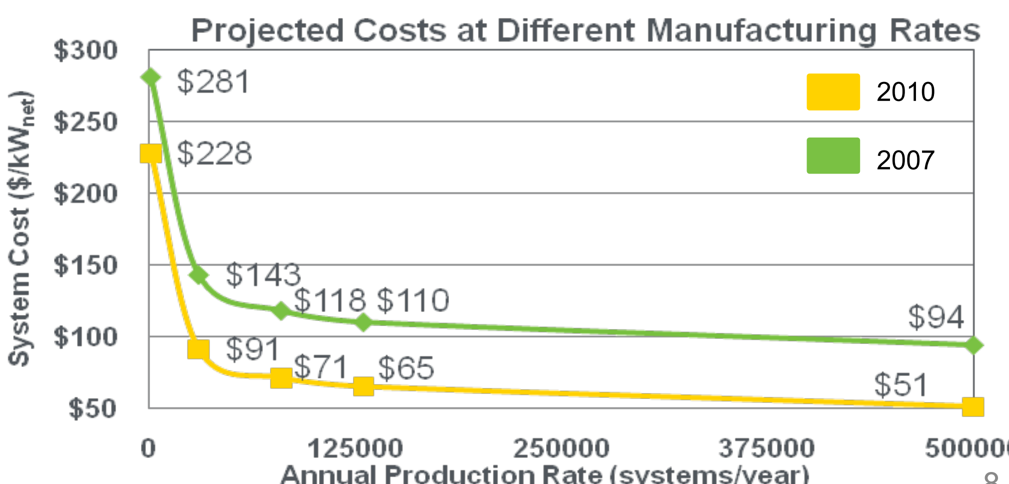
Reduced the projected high-volume cost of fuel cells to $51/kW (2010)*

- ***More than 30% reduction since 2008***
- ***More than 80% reduction since 2002***





**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*

http://www.hydrogen.energy.gov/pdfs/10004_fuel_cell_cost.pdf

Progress: Catalysts

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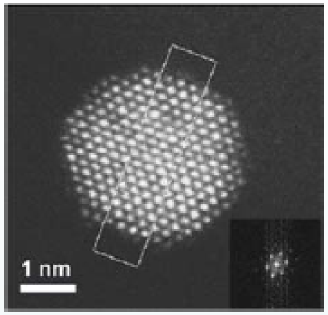
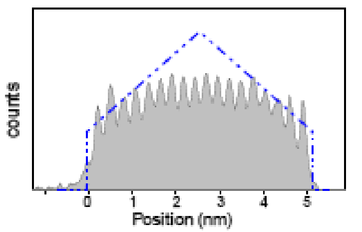
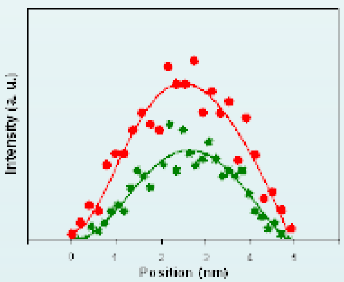
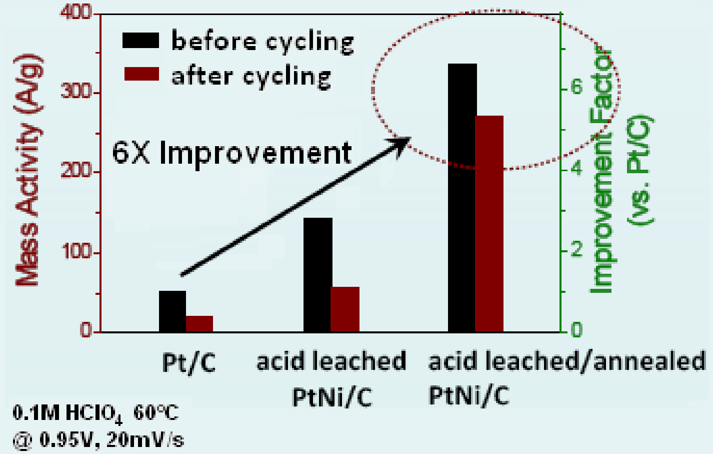
Catalysts: Nano-segregated binary and ternary catalysts demonstrate performance more than 6X that of platinum.

Nanosegregated Binary (PtNi)







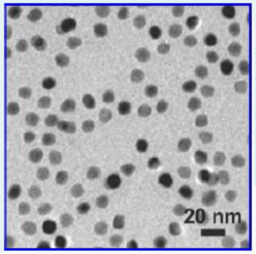


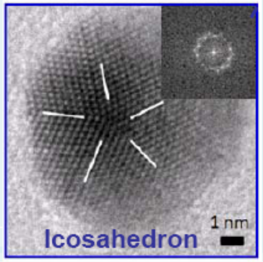
Multilayered Pt-skin surfaces confirmed for PtNi annealed NPs

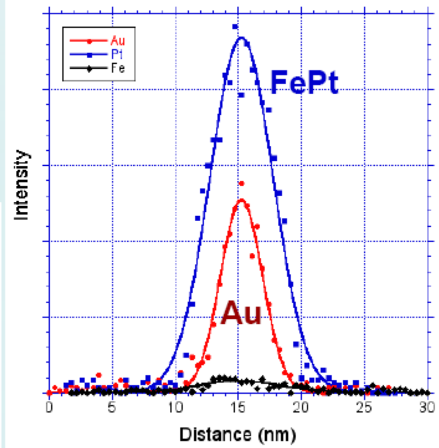
Performance: **Nanosegregated PtNi/C catalysts have ORR mass activity ~0.35 A/mg in MEA testing – *approaching 0.44 A/mg target***

Durability: **3X improved retention of mass activity after 20,000 potential cycles compared to Pt/C**

NanosegregatedTernary (PtFeAu)







Performance:
FePt(shell)/Au(core) demonstrates ORR mass activity more than 3X that of Pt/C

Durability:
Maintains 80% of initial activity after 80,000 potential cycles (cf. less than 20% for Pt/C)

N. Markovic et al., ANL

Progress: Catalysts

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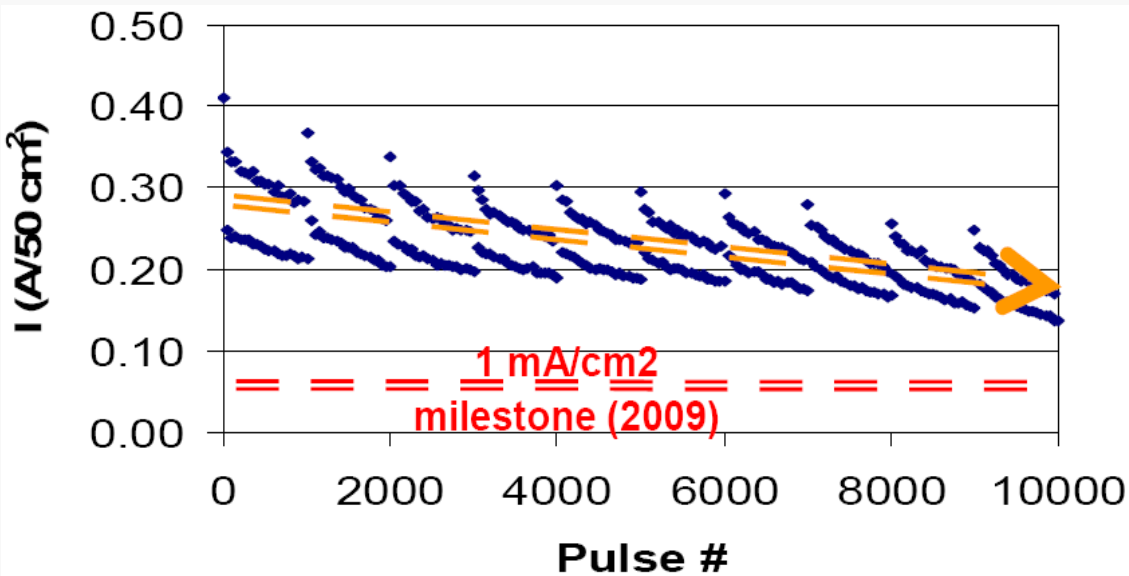
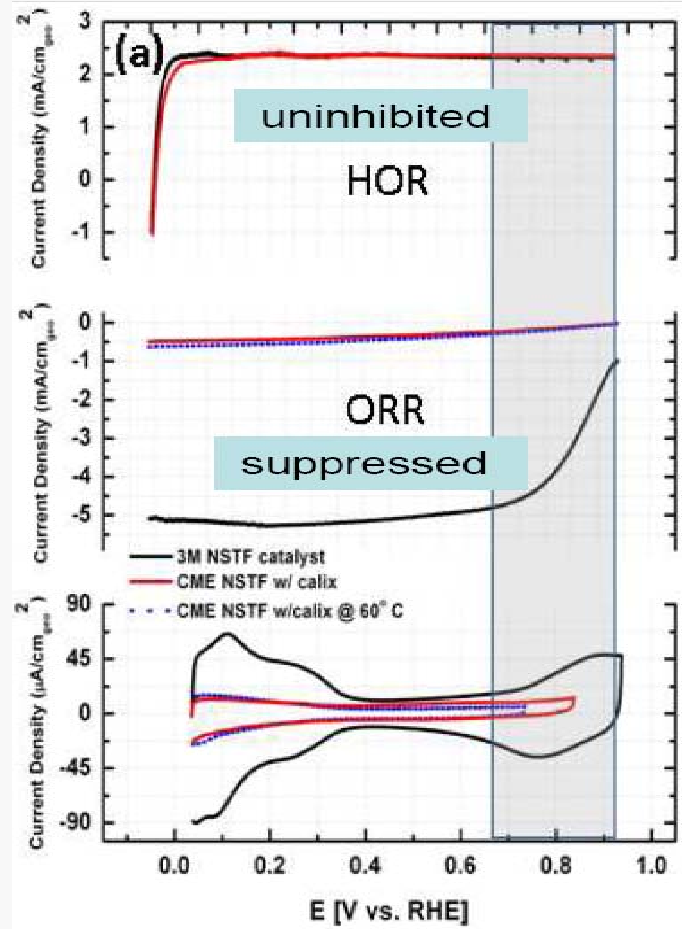
Catalysts: New cathode and anode catalysts demonstrate durability under startup/shutdown.

Cathode side: enhance OER to prevent catalyst/support oxidation, while maintaining ORR performance



OER performance greatly exceeds milestone, and is durable for more than 10,000 cycles

Anode side: suppress ORR to prevent cell reversal, while maintaining HOR performance



New catalyst modifiers allow achievement of 10,000 simulated startup/shutdown cycles with only 2 µg/cm² additional PGM

R. Atanasoski et al., 3M

Progress: Catalysts

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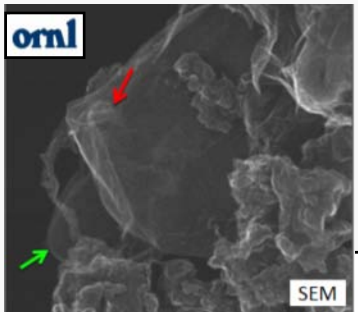
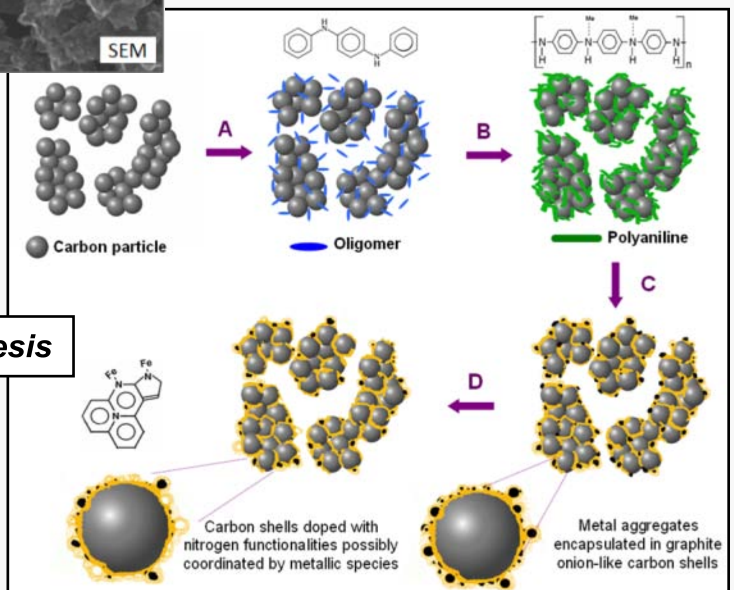
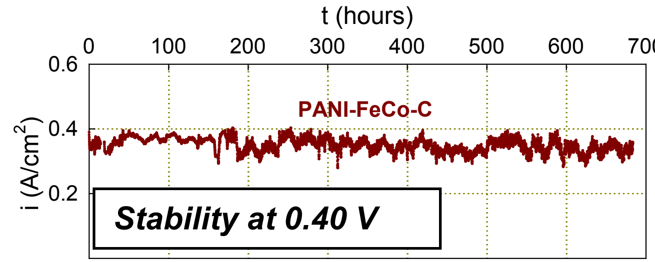
Catalysts: Non-PGM catalysts demonstrate activity approaching that of platinum.

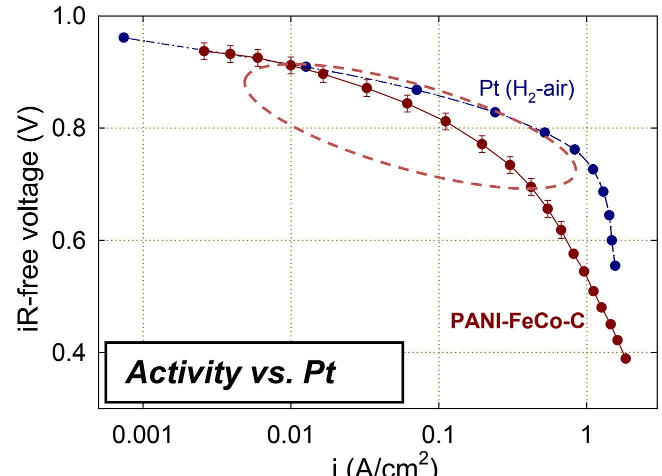


Catalyst SEM: *Layered-graphene sheet marked with green arrow; FeCo-containing nanoparticle shown with red arrow.*

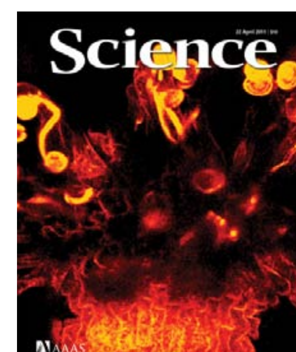
The Synthesis







G. Wu, K. L. More, C. M. Johnston, P. Zelenay, *Science*, **332**, 443-7 (2011)



- **High ORR activity reached with polyaniline-based and cyanamide-based catalysts**
- **Intrinsic catalyst activity is projected to exceed target of 130 A/cm^3 at 0.80 V**

P. Zelenay et al., LANL

Progress: Membranes

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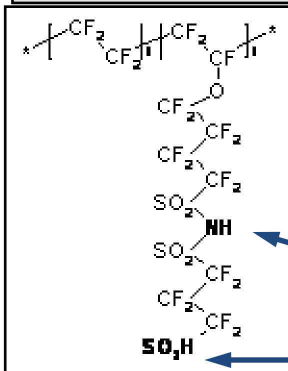
Membranes: Innovative membranes demonstrate high conductivity at low RH.

- **PFIA membranes meet most DOE targets for performance and durability**
- **PFIA maintains high crystallinity at lower equivalent weight than PFSAs → better mechanical properties**
- **High conductivity with PFIA under dry conditions: 0.087 S/cm @ 120 C, 25% RH**



PFIA

Two superacid sites per side chain

Remaining gap

		3M 2011 Status	2015 target
ASR at 120° C (H_2O pp 40-80 kPa)	Ohm cm²	.023 (40 kPa) 0.012 (80kPa)	<0.02
ASR at 80° C (H_2O pp 25-45 kPa)	Ohm cm²	0.013 (25 kPa) 0.006 (44 kPa)	<0.02
ASR at 30° C (H_2O pp 4 kPa)	Ohm cm²	0.02 (3.8 kPa)	<0.03
ASR at -20° C	Ohm cm²	0.10	<0.2
O_2 cross-over	mA/cm²	≤1.0	<2
H_2 cross-over	mA/cm²	≤1.8	<2
Durability Mechanical (%RH Cycle) Chemical (OCV)	Cycles Hours	>20,000 >1100+	>20,000 >500

S. Hamrock et al., 3M

Progress: SOFC

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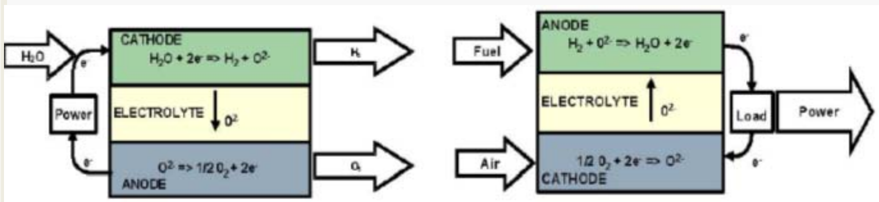
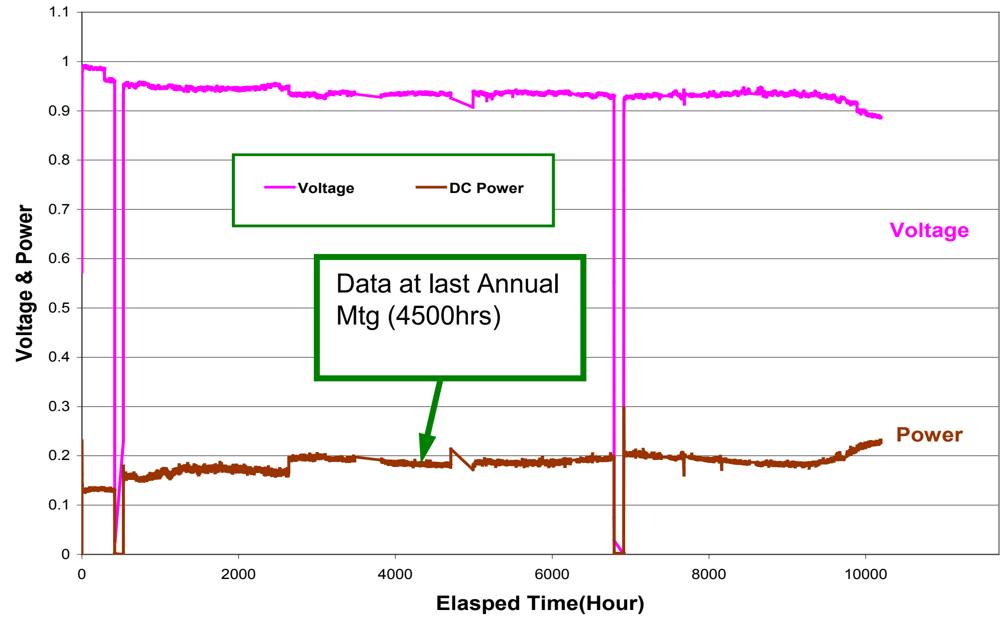
Stationary SOFCs: Improved performance and durability of SOFC systems

Reversible SOFCs under development at Versa Power Systems provide hydrogen generation and energy storage capability



Project Targets Met in 2011:

Metric	Target	Status
☑ **Performance** (Area specific resistance in both SOFC and SOEC operating modes)	**< 0.3 Ω-cm²**	**0.223 Ω-cm² in SOEC** **0.224 Ω-cm² in SOFC**
☑ **Degradation** (Overall decay rate)	**< 4% per 1000 hours**	**~1.5% per 1000 hours**
☑ **Operating Duration**	**> 1000 hours**	**1005 hours** (as of Go/No-Go Decision)
☑ **Operating Current Density**	**> 300 mA/cm²**	**500 mA/cm²**

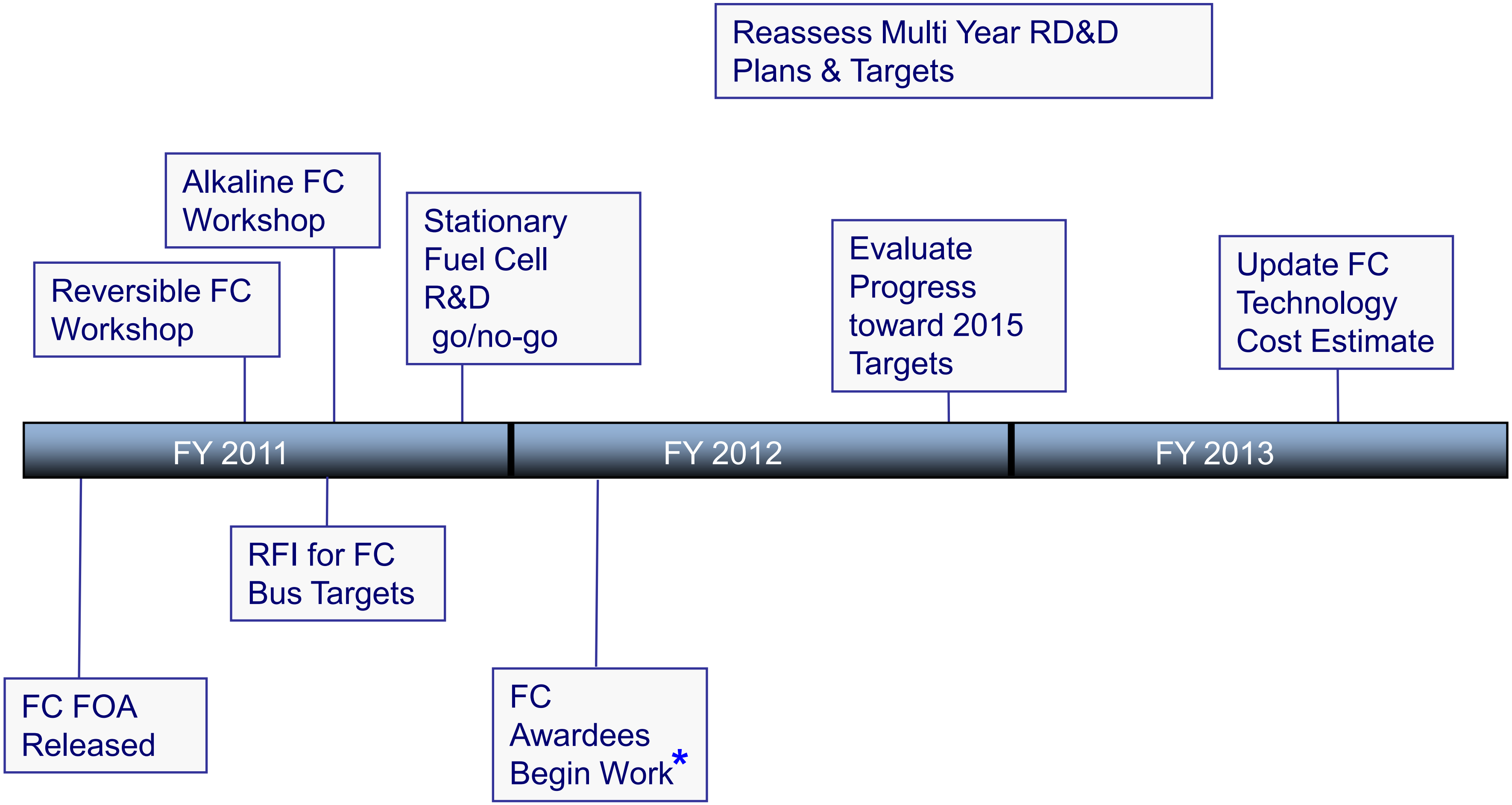


Acumentrics has achieved more than 10,000 hours operation of an SOFC in 2011 – more than double the 2010 durability

R. Petri et al., Versa Power Systems

N. Bessette et al., Acumentrics

Key Milestones and Future Plans



** Subject to appropriations*

Session Instructions

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- This is a review, not a conference.
- Presentations will begin precisely at the scheduled times.
- Talks will be 20 minutes and Q&A 10 minutes.
- Reviewers have priority for questions over the general audience.
- Reviewers should be seated in front of the room for convenient access by the microphone attendants during the Q&A.
- Please mute all cell phones, BlackBerries, etc.
- Photography and audio and video recording are not permitted.

Reviewer Reminders

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- Deadline for final review form submittal is **May 20th at 5:00 PM EDT.**
- ORISE personnel are available on-site for assistance. A reviewer ready room is set-up in room *They Rosslyn Room* (on the lobby level) and will be open Tuesday –Thursday from 7:30 am to 6:00 pm and Friday 7:30 am to 2:00 pm.
- Reviewers are invited to a brief feedback session – at 3:45 pm on Thursday, in this room.

For More Information

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EERE Postdoctoral Fellowship Program

U.S. DEPARTMENT OF ENERGY

- Fuel Cell Technologies Program Opportunities Available
  - Conduct applied research at universities, national laboratories, and other research facilities
  - Up to five positions are available in the areas of hydrogen production, hydrogen delivery, hydrogen storage, and fuel cells
    - ❑ Applications are due June 30, 2011
    - ❑ Winners will be announced mid-August
    - ❑ Fellowships will begin in mid-November 2011

www.eere.energy.gov/education/postdoctoral_fellowships/

Principal Participating Organizations

U.S. DEPARTMENT OF ENERGY

- **Testing and Technical Assessments**
  - LANL
  - Directed Technologies
  - TIAX
  - NREL
  - ANL
  - ORNL
  - NIST
- **Balance of Plant**
  - W. L. Gore & Associates
  - Stark State College
  - Dynalene
- **Bipolar Plates**
  - TreadStone Technologies
  - ORNL
  - ANL
- **Catalysts & Supports**
  - BNL
  - PNNL
  - 3M
  - UTC
  - LBNL
  - ANL
  - LANL
  - General Motors
  - Northeastern University
  - University of South Carolina
  - Illinois Institute of Technology
  - NREL
- **Durability**
  - Ballard
  - LANL
  - Plug Power
  - UTC
  - ANL
  - Nuvera Fuel Cells
  - University of Connecticut
- **Impurities and Fuel Processors**
  - NREL
  - University of Connecticut
  - Clemson University
  - University of Hawaii
  - DuPont
  - Rolls Royce
- **Membranes**
  - Giner Electrochemical Systems
  - Oak Ridge National Laboratory
  - FuelCell Energy
  - University of Central Florida
  - 3M
  - Vanderbilt University
  - Colorado School of Mines
  - Case Western Reserve University
  - LANL
  - Sandia National Laboratory
  - Ion Power
  - University of Southern Mississippi
  - Kettering University
- **Portable Power**
  - Arkema Inc.
  - University of North Florida
  - LANL
  - NREL
- **Stationary Power**
  - Intelligent Energy
  - Acumentrics
  - Versa Power Systems
  - UTC
  - University of Akron
  - Colorado School of Mines
  - Stark State College
- **Transport**
  - SNL
  - LBNL
  - Nuvera Fuel Cells
  - Giner Electrochemical Systems
  - General Motors
  - Rochester IT
  - LANL
  - CFD Research Corporation