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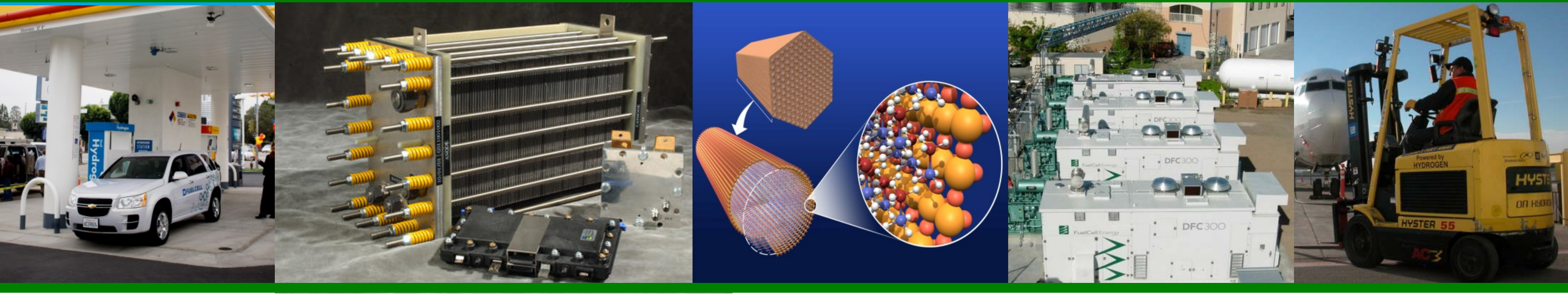

Fuel Cells

-Session Introduction -

Dimitrios Papageorgopoulos

2013 Annual Merit Review and Peer Evaluation Meeting
May 14, 2013

Goals and Objectives

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

Objectives

- 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.
- 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 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 **:**
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

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
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
Fuel processors
Stationary power
Portable power
APUs and Emerging markets

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

High-Impact Areas Addressed – PEMFCs for Automotive Applications

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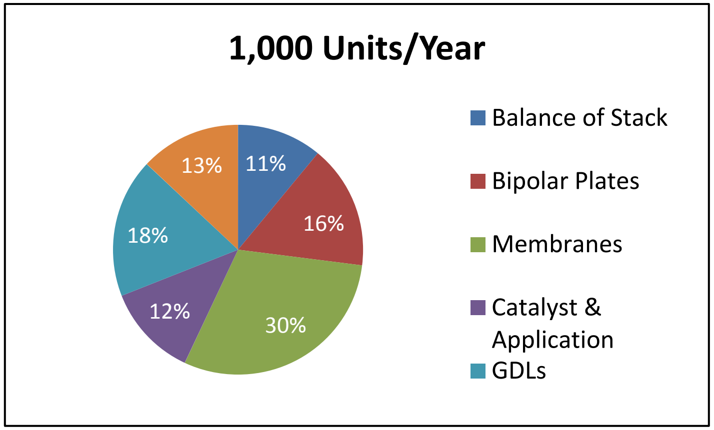
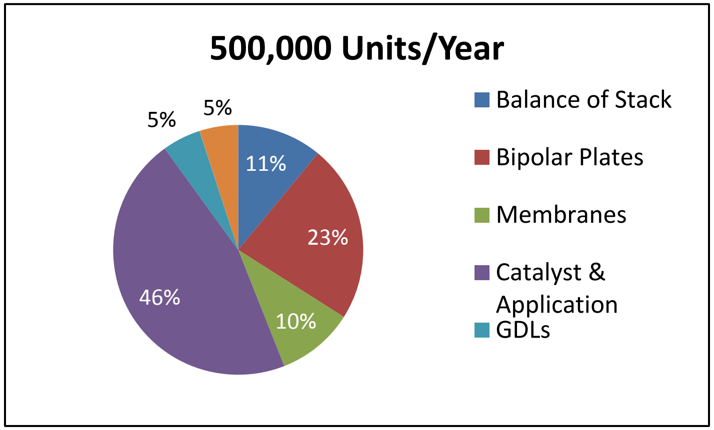
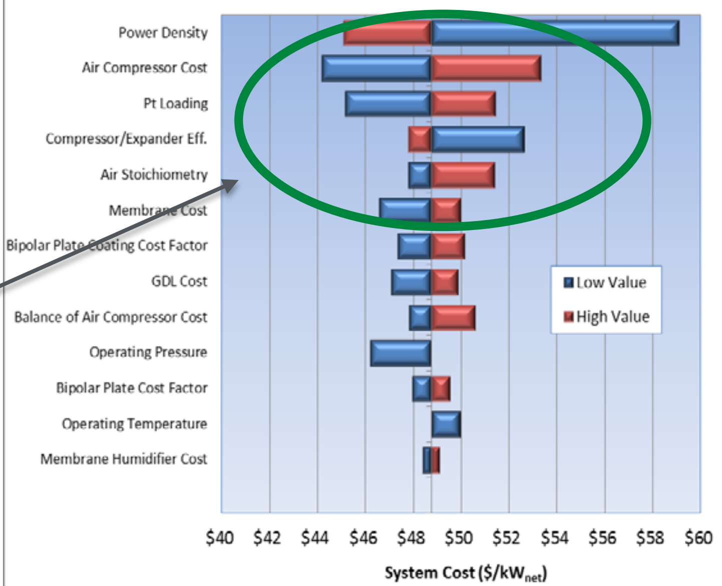
- Strategic technical analysis guides focus areas for R&D and priorities.
- Need to reduce cost to $30/kW and increase durability from 2,500 to 5,000 hours.
- Advances in PEMFC materials and components could benefit a range of applications

PEMFC Stack Cost Breakdown





Key Focus Areas for R&D



Sensitivity Analysis helps guide R&D

Membrane cost is projected to be the largest single component of the cost of a PEMFC manufactured at low volume; the electrocatalyst cost at high volume

Strategies to Address Challenges – Catalyst Examples

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

Fuel Cell R&D - Plans

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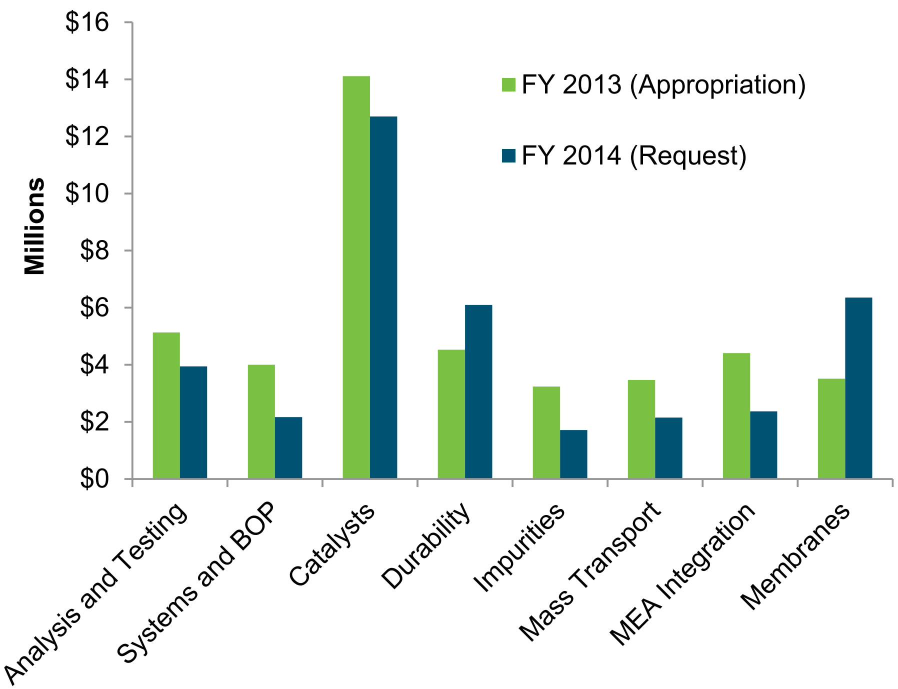
Maintains critical fuel cell R&D to improve the durability, reduce cost, and improve the performance of fuel cell systems for stationary, transportation, and portable power. Key goal: Increase PEM fuel cell power output per gram of PGM catalyst from 2.8 kW/g (in 2008) to 8.0 kW/g by 2017.

FY 2013 Appropriation = $42.4M

FY 2014 Request = $37.5M



*Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

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, sub-systems and systems specifically tailored for stationary and portable power applications (e.g. SOFC).

Progress – Fuel Cell R&D

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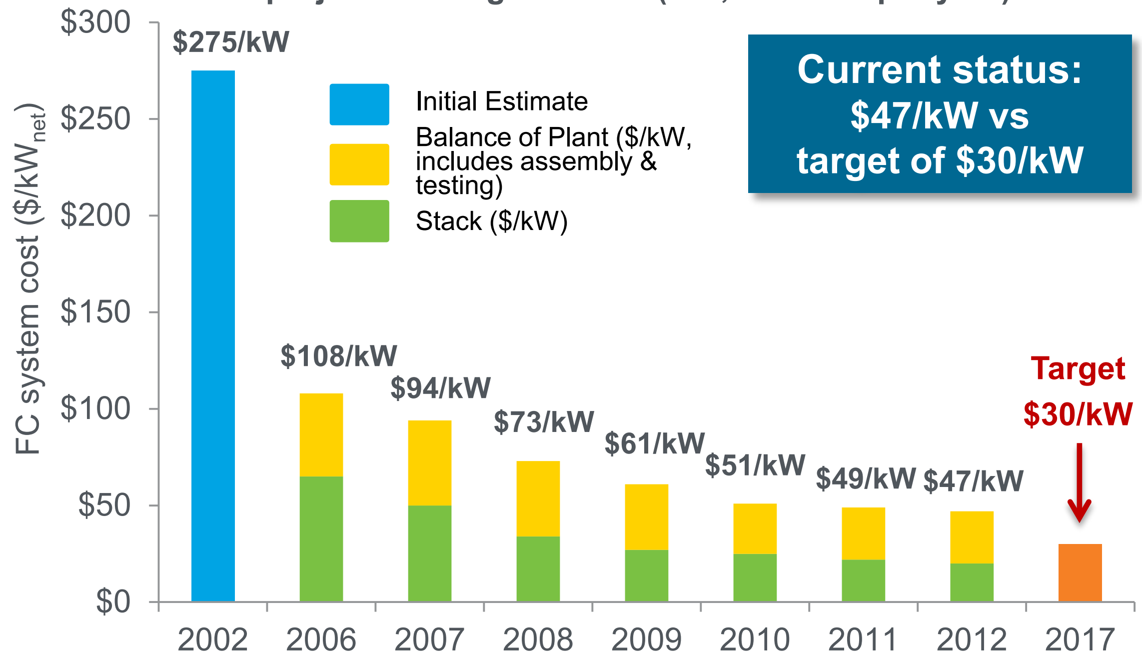
Projected high-volume cost of fuel cells has been reduced to $47/kW (2012)*

- ***More than 35% reduction since 2008***
- ***More than 80% reduction since 2002***

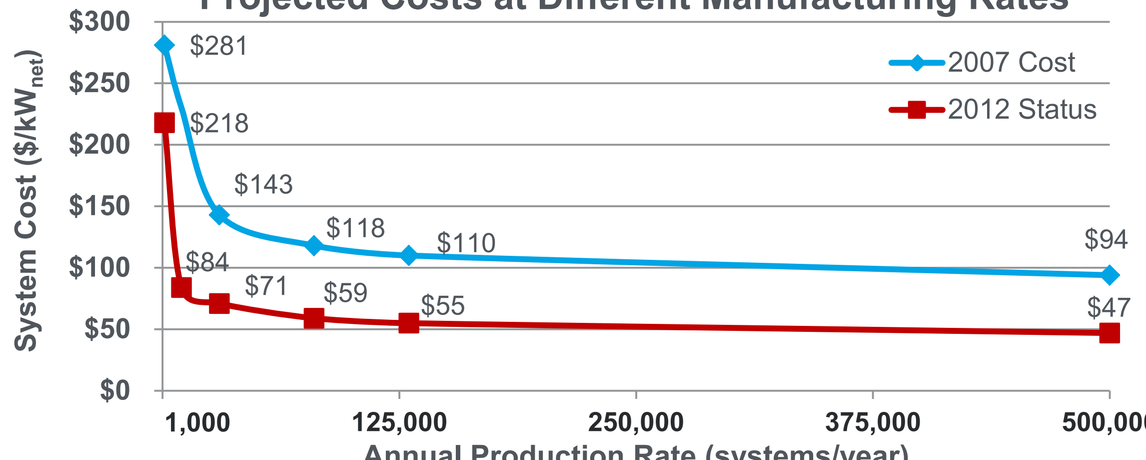
****Based on projection to high-volume manufacturing (500,000 units/year).*** *The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the DOE Program at the laboratory scale. Additional efforts would be needed for integration of components into a complete automotive system that meets durability requirements in real-world conditions.*

Projected Transportation Fuel Cell System Cost

-projected to high-volume (500,000 units per year)-



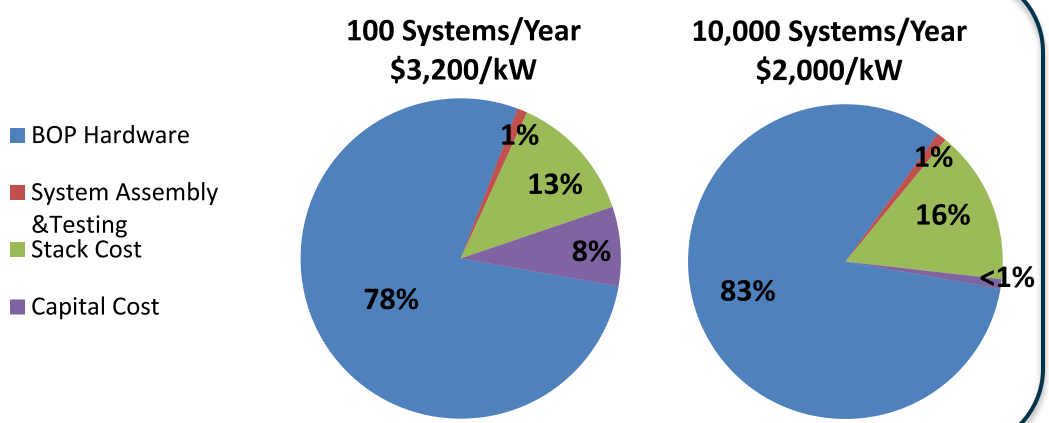
Projected Costs at Different Manufacturing Rates

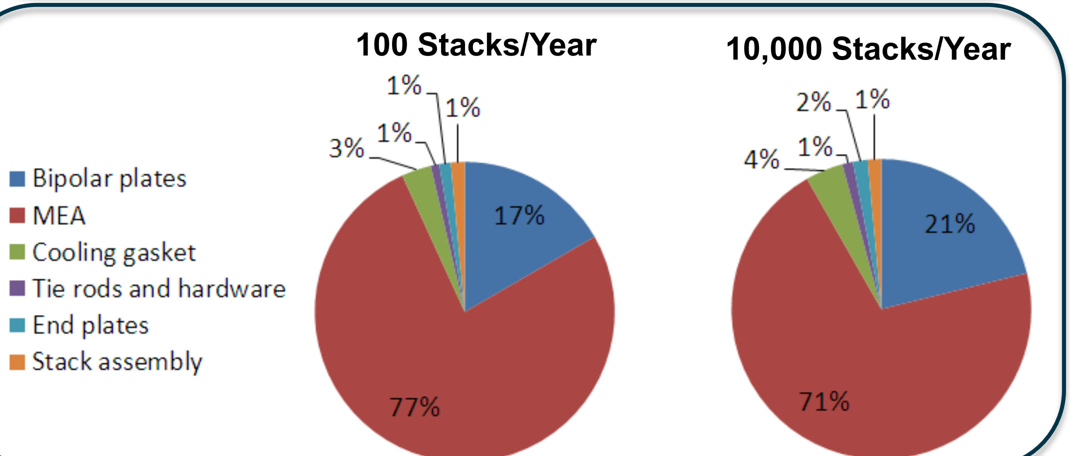


Progress: Emerging Market Cost Analysis

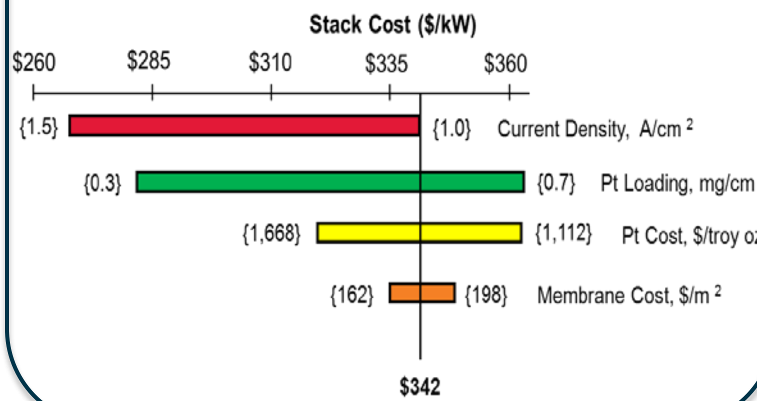
Cost analyses in development for material handling applications

10 kW material handling systems





Sensitivity Analysis: 10 kW Stack Cost ($/kW) (10,000 Production Volume)



- MHE systems @ 10 and 25 kW
- Annual volume of 100; 1,000; and 10,000 systems
- Modeling using DFMA® software based on Battelle internal knowledge and discussion with industry partners
- Future year analysis will examine 1 and 5 kW systems

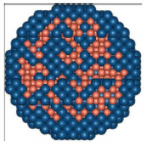
Mahadevan et al., Battelle

Progress: De-alloyed Catalysts

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

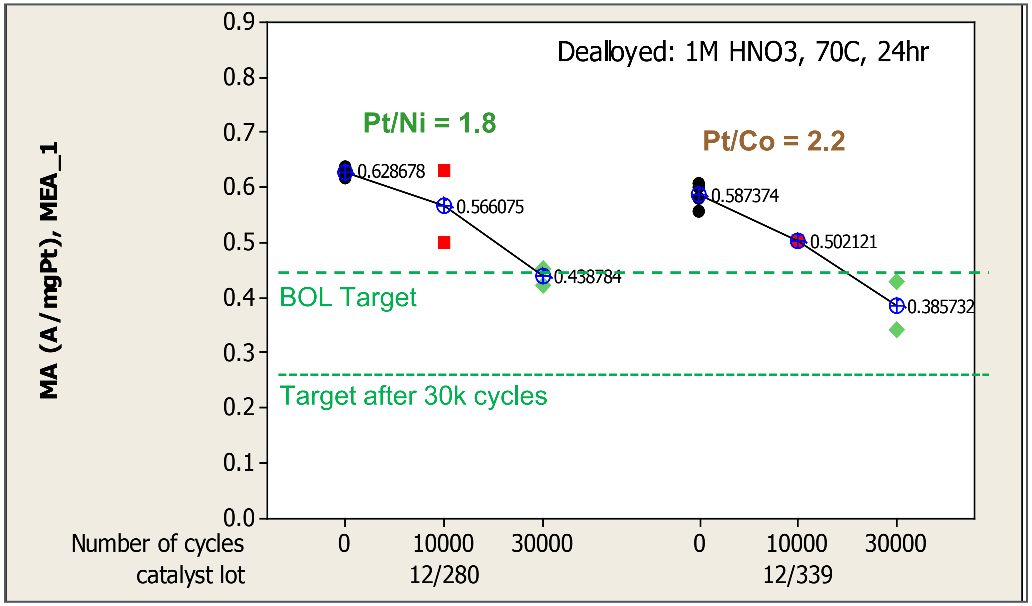
M is one or more non-precious metals

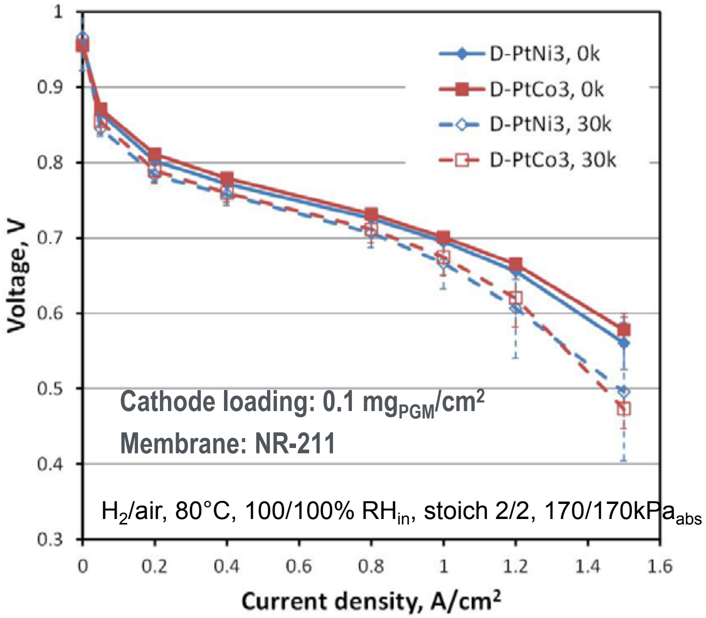
precursor PtM_3/C --- dealloying ---> catalyst $Pt_{1.5\text{-}3}M/C$



Cross section, Pt in blue

Lattice compression of surface Pt layer





- Dealloying of $PtNi_3$ and $PtCo_3$ large-batch precursors yields catalysts that meet initial mass activity and mass activity after voltage cycling targets
- Catalysts based on $PtNi_3$ and $PtCo_3$ have also achieved 0.56 V @ 1.5 A/cm^2 milestone
- Further work needed to maintain performance at 1.5 A/cm^2 after voltage cycling

A. Kongkanand et al., GM

Progress: MEA Integration

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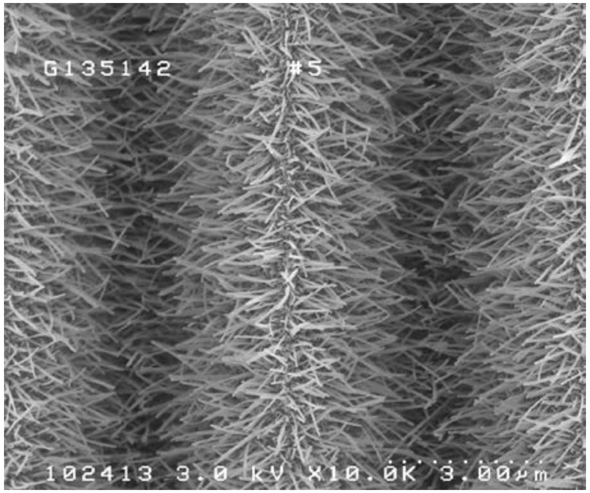
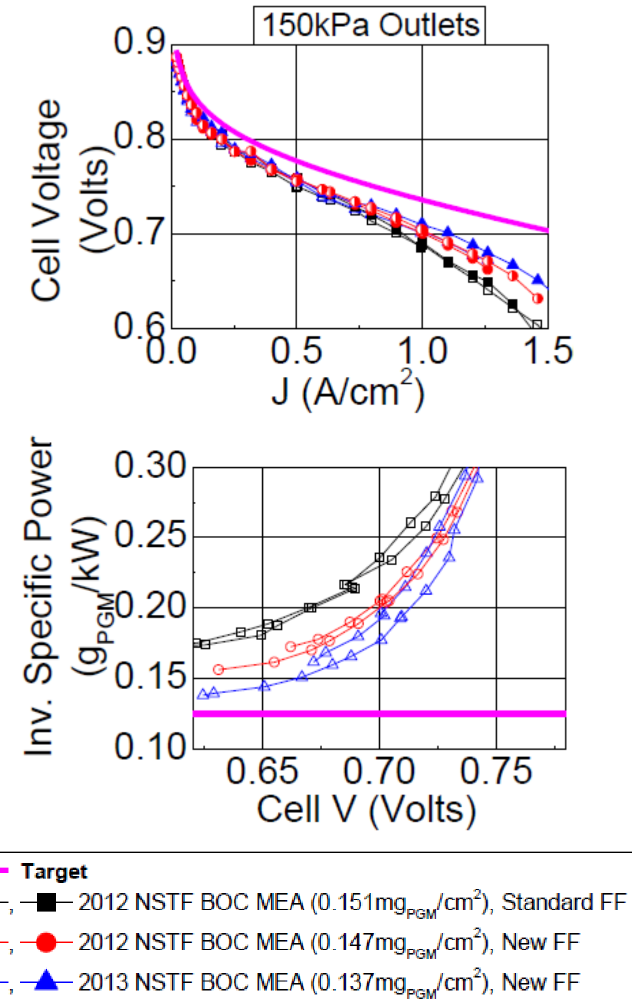
Improved MEA and flowfield led to record low g_{PGM}/kW





Improvements in MEA and flowfield allowed reduction from 0.20 g_{PGM}/kW in 2012 to 0.16 g_{PGM}/kW in 2013

Status vs. targets:

- PGM loading: 0.16 g_{PGM}/kW (target: 0.125 g/kW)
- Mass activity: 0.40-0.48 A/mg (target: 0.44 A/mg)
- Durability w/ cycling: 66% MA loss (target: <40%)

A. Steinbach et al., 3M

Progress: Mesostructured Thin Films

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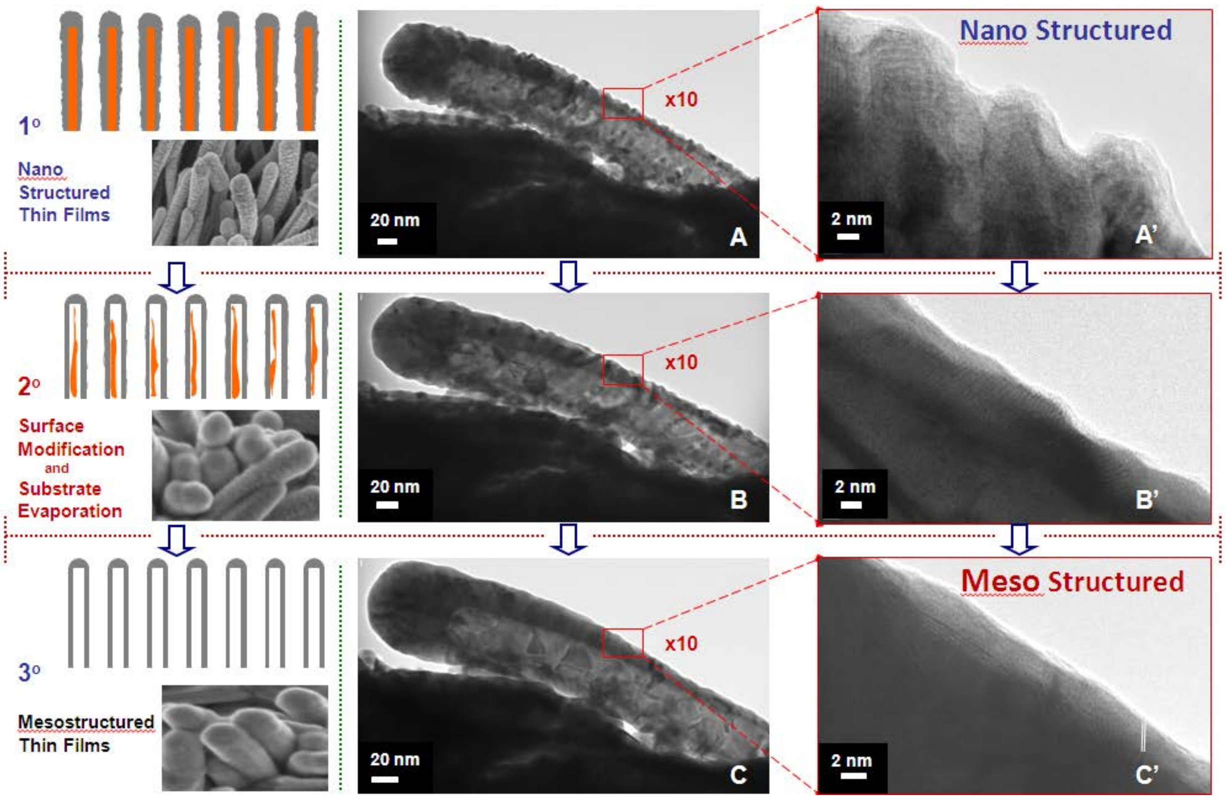
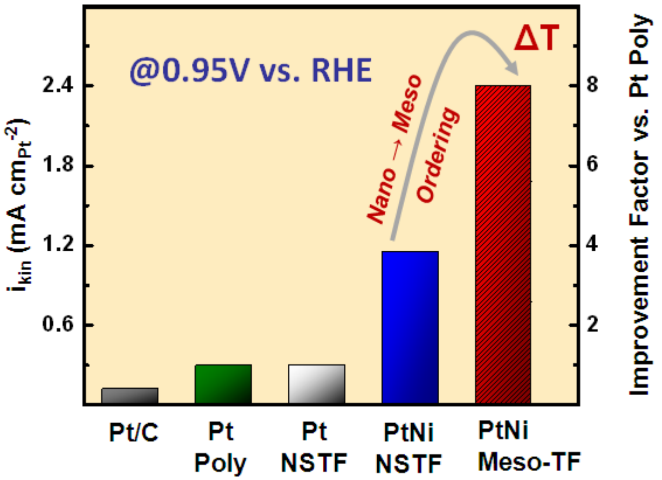
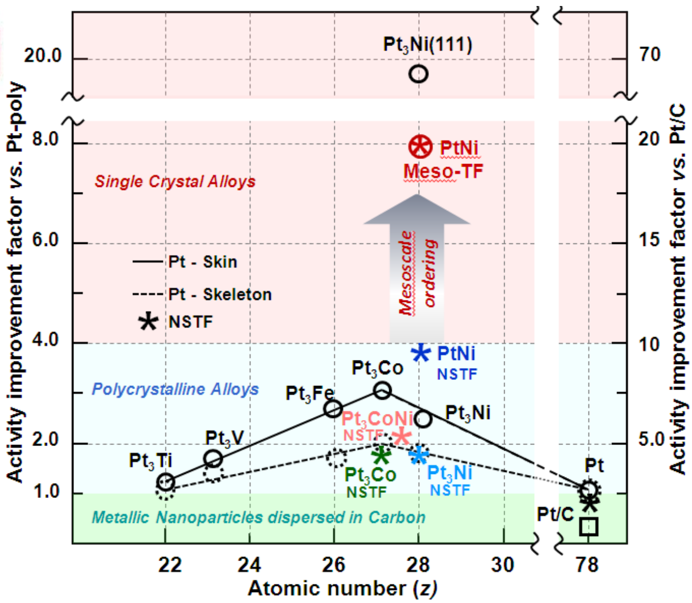
Surface modification and substrate evaporation of NSTF yields mesostructured surface with superior ORR activity







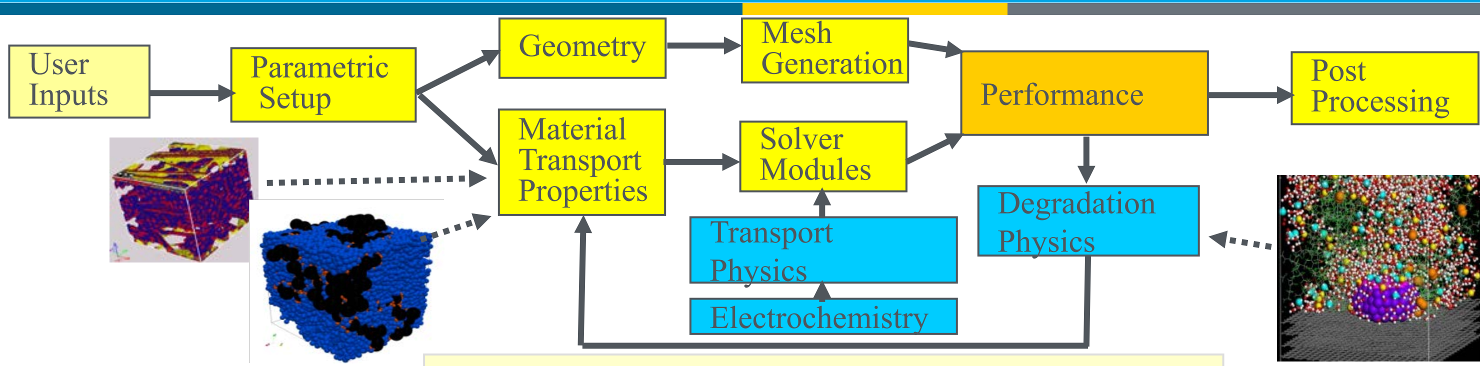
2X increase in specific activity vs. PtNi NSTF and 8x vs. Pt-poly realized through surface modification in which grains coalesce to form surfaces with single crystalline properties

N. Markovic/V. Stamenkovic et al., ANL

Nature Materials 11 (2012) 1051

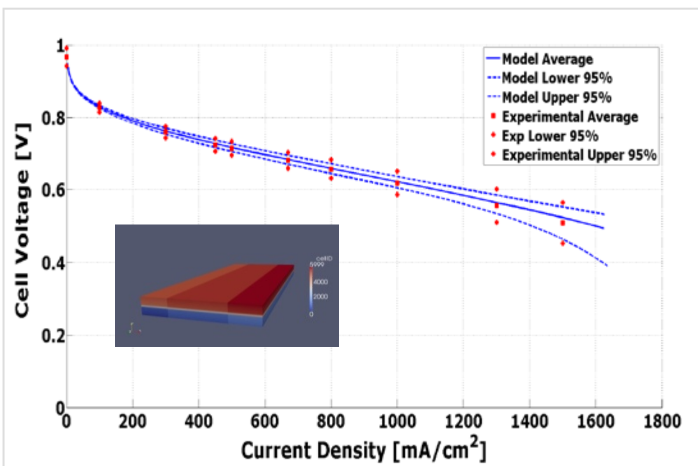
Progress: Performance/Durability Modeling

Open-source FC-PEM performance and durability model developed to address micro-structural mitigation strategies for PEMFCs



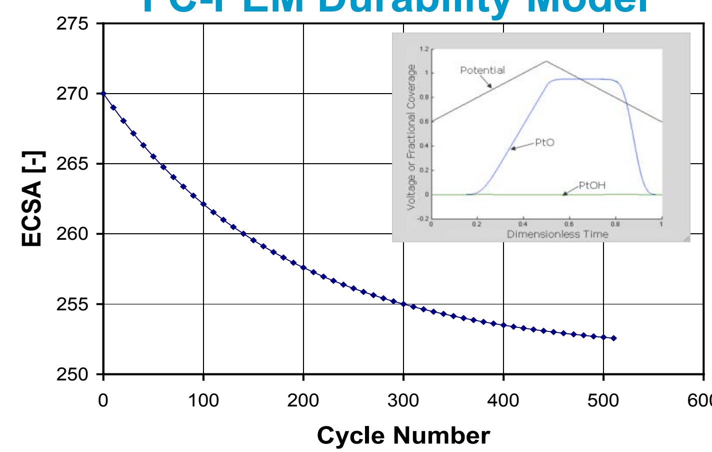
Open-source FC-PEM Package

FC-PEM Performance Model



- Modifiable material properties, geometries, and operational conditions (i.e. loading, ionomer content, thickness, T, RH, etc.)

FC-PEM Durability Model



- Platinum dissolution process coupled to improved Pt oxide model (Air/Nitrogen)
- Carbon oxidation and corrosion using surface oxidation and corrosion steps

S. Wessel et al., Ballard

Summary

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Key milestones and future plans

Stacks and Components

- Projects addressed cost reduction and performance and durability enhancement of stack components including catalysts, membrane electrolytes, and MEAs .

Systems and Balance of Plant

- Maintained R&D on components and sub-systems, including fuel cell air management and humidifiers, and on systems specifically tailored for stationary power applications (e.g. SOFC).

Testing and Technical Assessments

- Analysis projects continued to provide cost annual estimates for transportation, stationary and emerging market applications.

FY 2013	FY 2014	FY 2015

- 3Q 2013: Release RFI on the use of RDE for characterization and screening of the activity and durability of PEMFC electrocatalysts
- 4Q 2013: Release updated cost and technical targets for automotive fuel cell applications.
- 1Q 2014: Develop PEM bipolar plates with a cost less than or equal to \$5/kW
- 3Q 2014: Update fuel cell technology cost estimates for transportation, stationary, and emerging market applications
- 1Q 2015: Develop catalysts with $0.14 g_{PGM}$/kW at rated power
- 2Q 2015: Evaluate membrane technologies for >5,000 hours durability operating at >80^{o}C
- 4Q 2015: Demonstrate medium-scale CHP at 45% electrical efficiency and projected durability of 50,000 hours

Principal Participating Organizations

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- **Analysis and Testing**
  - Battelle
  - LBNL
  - Strategic Analysis
  - LANL
  - NREL
  - ANL
  - ORNL
- **Catalysts & Supports**
  - BNL
  - 3M
  - ANL
  - LANL
  - General Motors
  - Northeastern University
  - University of South Carolina
  - Illinois Institute of Technology
  - NREL
- **Durability**
  - Ballard
  - LANL
  - ANL
  - Nuvera Fuel Cells
- **Impurities and Fuel Processors**
  - NREL
  - University of Hawaii
- **Membranes**
  - Giner Electrochemical Systems
  - FuelCell Energy
  - Ion Power
  - NREL
- **Balance of Plant**
  - Eaton Corporation
  - Dynalene
  - Tetramer
- **MEA Integration**
  - 3M
  - ANL
- **Portable Power**
  - Arkema Inc.
  - LANL
- **Stationary Power**
  - Acumentrics
  - Innovatek
- **Mass Transport**
  - GM
  - Giner
  - LBNL
- **Bipolar Plates**
  - TreadStone Technologies

For More Information

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Tom Benjamin, John Kopasz, and Walt Podolski (ANL); Cassidy Houchins (SRA International)

Session Instructions

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- This is a review, not a conference.
- Presentations will begin precisely at 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 and other portable devices.
- Photography and audio and video recording are not permitted.

Reviewer Reminders

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- Deadline to submit your reviews is Friday, **May 24th at 5:00 pm EDT.**
- ORISE personnel are available on-site for assistance.
  - **Reviewer Lab Hours:**
    - Monday, 5:00 pm – 8:00 pm (Gateway ONLY)
    - Tuesday – Wednesday, 7:00 am – 8:00 pm (Gateway)
    - Thursday, 7:00 am – 6:00 pm (Gateway)
    - Tuesday – Thursday, 7:00 am – 6:00 pm (City)
  - **Reviewer Lab Locations:**
    - Crystal Gateway Hotel—*Rosslyn Room* (downstairs, on Lobby level)
    - Crystal City Hotel—*Roosevelt Boardroom* (next to Salon A)