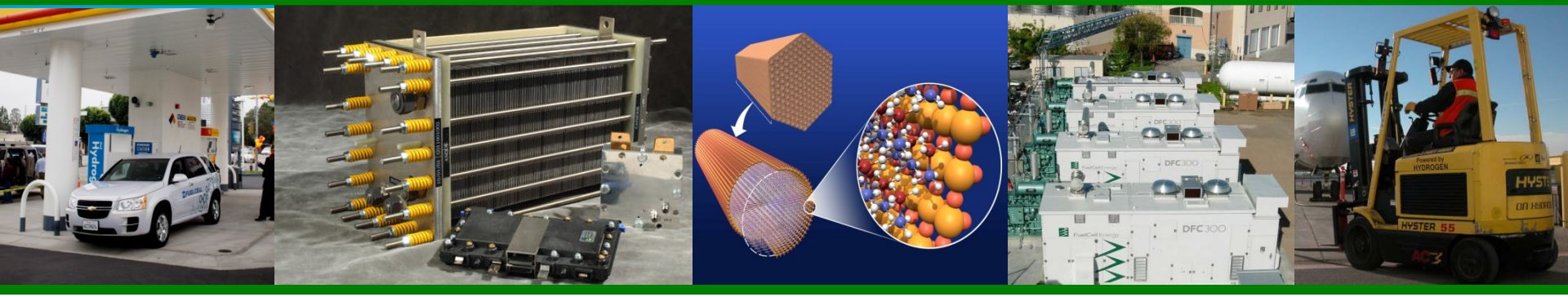
U.S. DEPARTMENT OF ENERGY



Fuel Cells Program Area

- Plenary Presentation-

Dimitrios Papageorgopoulos

Fuel Cell Technologies Office

2016 Annual Merit Review and Peer Evaluation Meeting

June 6 - 10, 2016

Goals and Objectives

Objectives

- By 2020, develop a **transportation fuel cell power system** with 65% peak efficiency, 5,000 hours durability and a mass-produced cost of $40/kW
- By 2020, develop a **DG/CHP fuel cell system** at a cost of $1,000 to $1,500/kW and durability of 60,000 to 80,000 hours, depending on size and application
- Other specific objectives are in the Fuel Cells MYRD&D Plan

GOAL: Advance fuel cell technologies for transportation, stationary and early market applications

Challenges & Strategy

Fuel Cells MYRD&D Plan updated in 2016
http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

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

Performance and Durability

Mass transport
Durability
Impurities

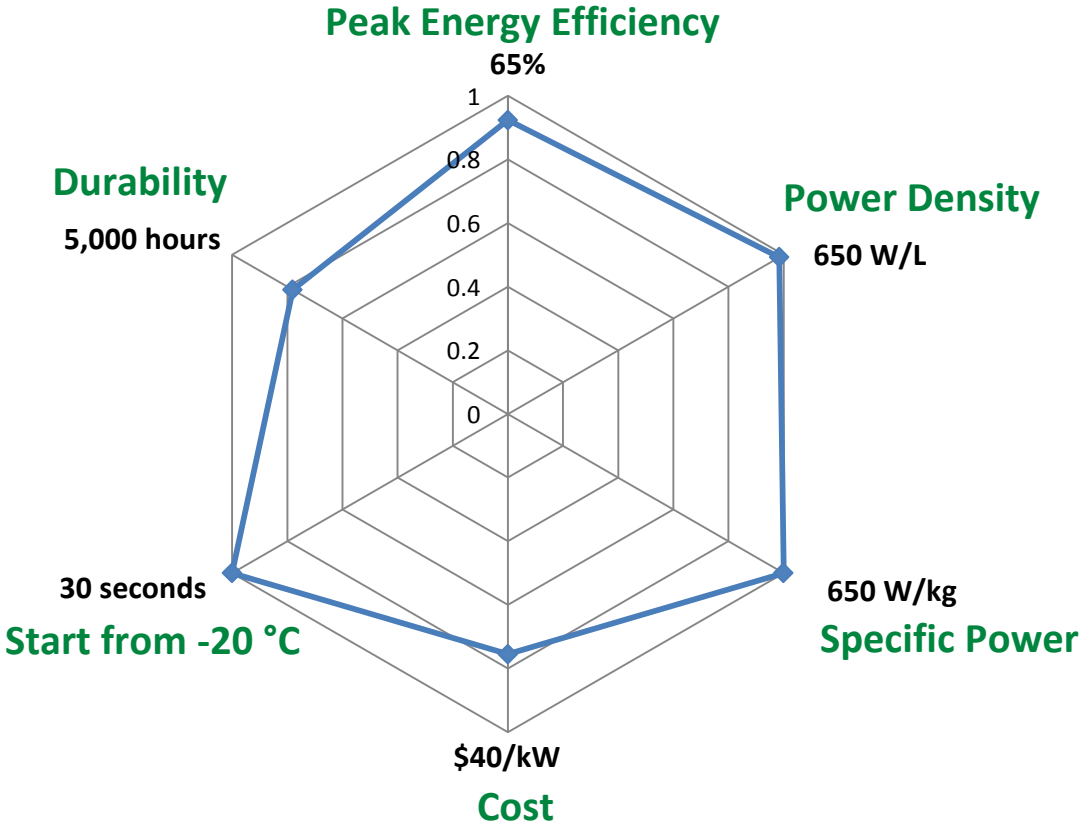
Systems and Balance of Plant (BOP)

BOP components
Fuel processors
Stationary power
APUs
Early markets

The Fuel Cells program supports R&D of fuel cells and fuel cell systems with goals of reducing cost and improving durability

Market-Driven Targets Ensure Competitive Strategy

FC system cost targets allow competition with incumbent technology on a lifecycle cost basis



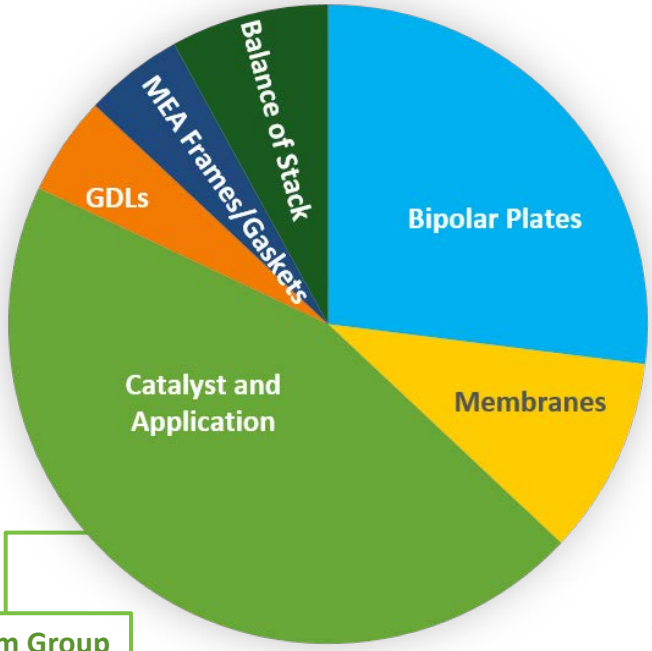
Durability and Cost are the primary challenges to fuel cell commercialization and must be met concurrently

Automotive Fuel Cell Targets
Cost: $40/kW by 2020 and $30/kW ultimate
Durability: 5,000 hours by 2020 and 8,000 hours ultimate

Strategic Technical Analysis Guides Focus Areas for R&D and Priorities

PEMFC Stack Cost Breakdown*

500,000 stacks/year

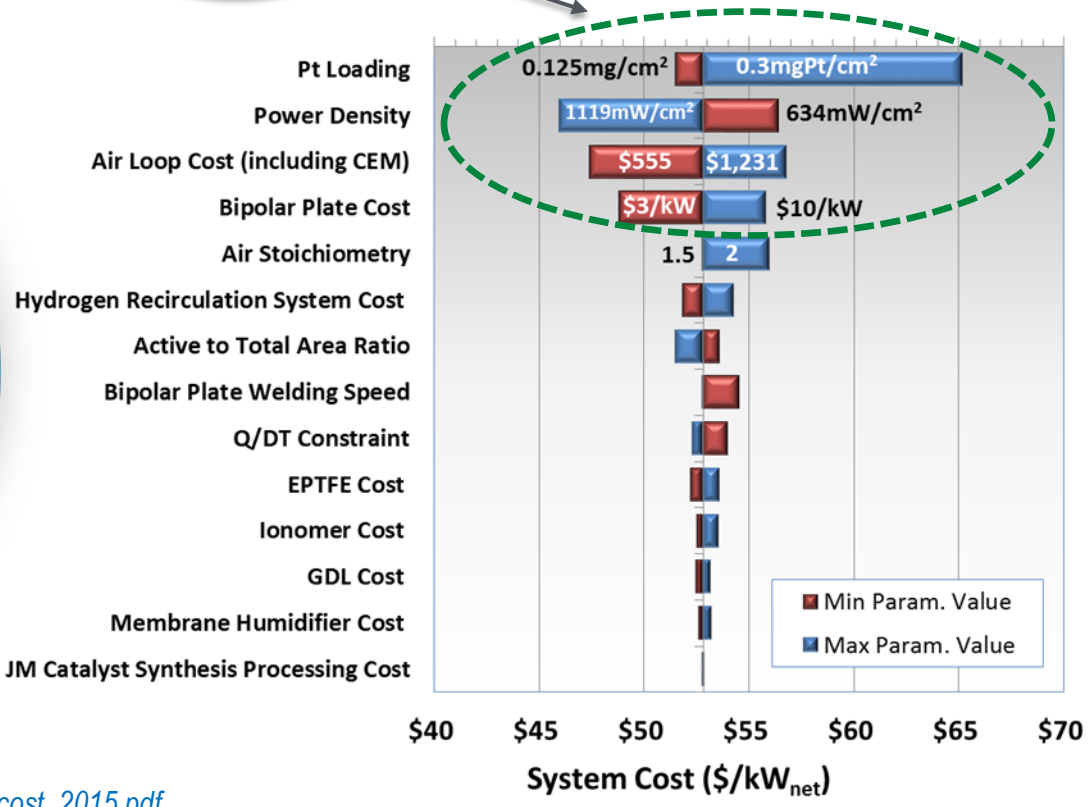


Platinum Group Metals

*https://www.hydrogen.energy.gov/pdfs/15015_fuel_cell_system_cost_2015.pdf

Key Focus Areas for R&D

Sensitivity Analysis helps guide R&D

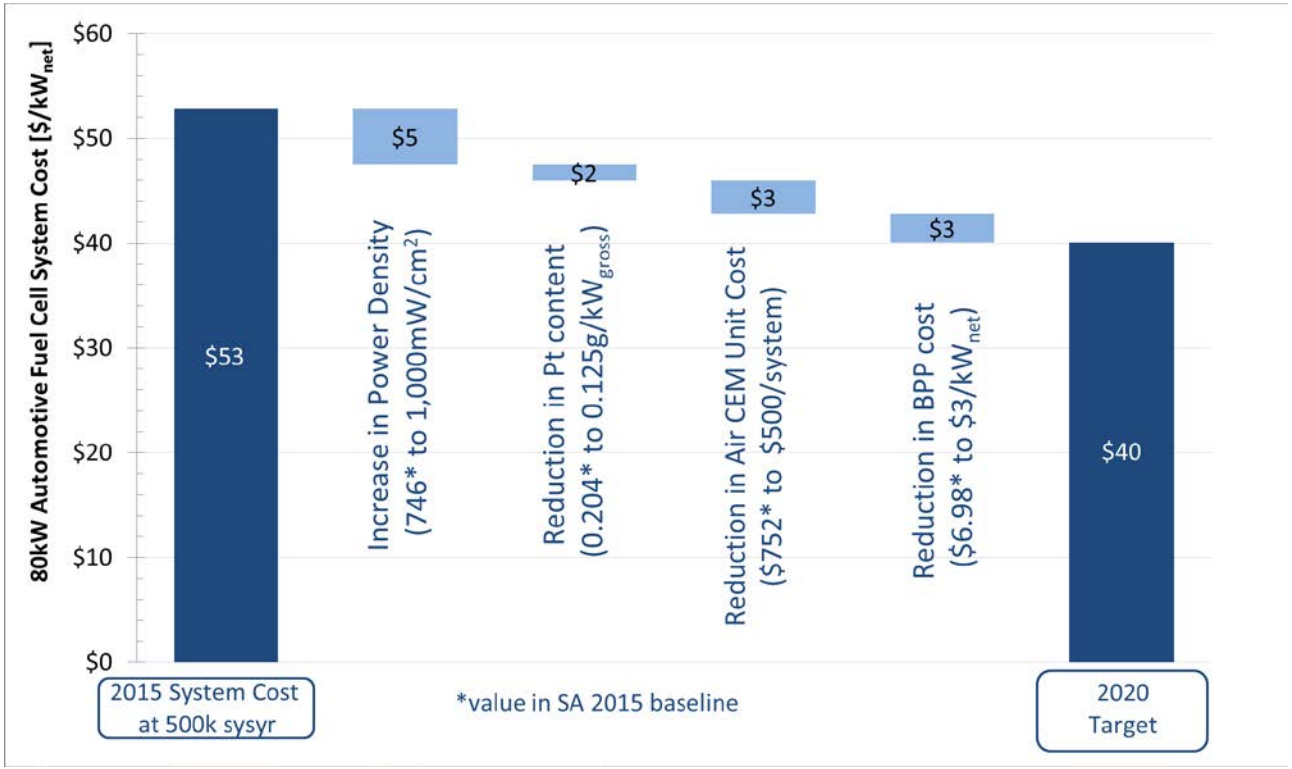


Lowering PGM content and improving activity key to lowering cost

Strategic Technical Analysis Guides Focus Areas for R&D and Priorities

- *Improvements in multiple components are required to meet the 2020 cost target*
- *Advances in PEMFC materials and components could benefit a range of applications*

Potential cost reduction pathway

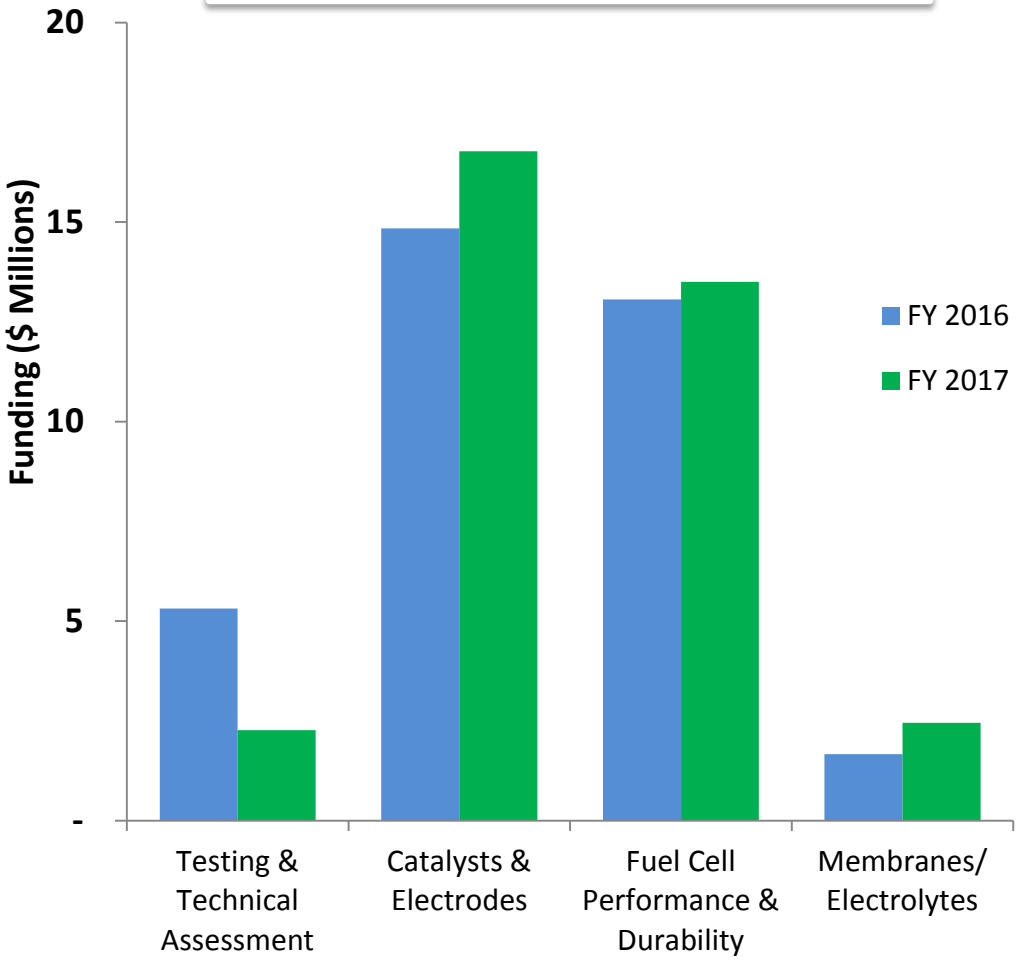


Meeting guideline component level targets could pave path to $40/kW

Fuel Cells Program Budget

FY 2017 Request = $35.0 M

FY 2016 Appropriation = $35.0 M



EMPHASIS

- Increase activity and utilization of low-PGM catalysts and develop PGM-free catalysts for long-term applications
- Develop membranes with enhanced performance and stability at reduced cost
- Advance fuel cell performance and durability by addressing transport and degradation issues
- Improve PEM MEAs through integration of state-of-the-art MEA components

Full-upfront funding for non-lab financial assistance projects selected from FOAs

Fuel Cell Cost

Fuel Cell Cost Reductions

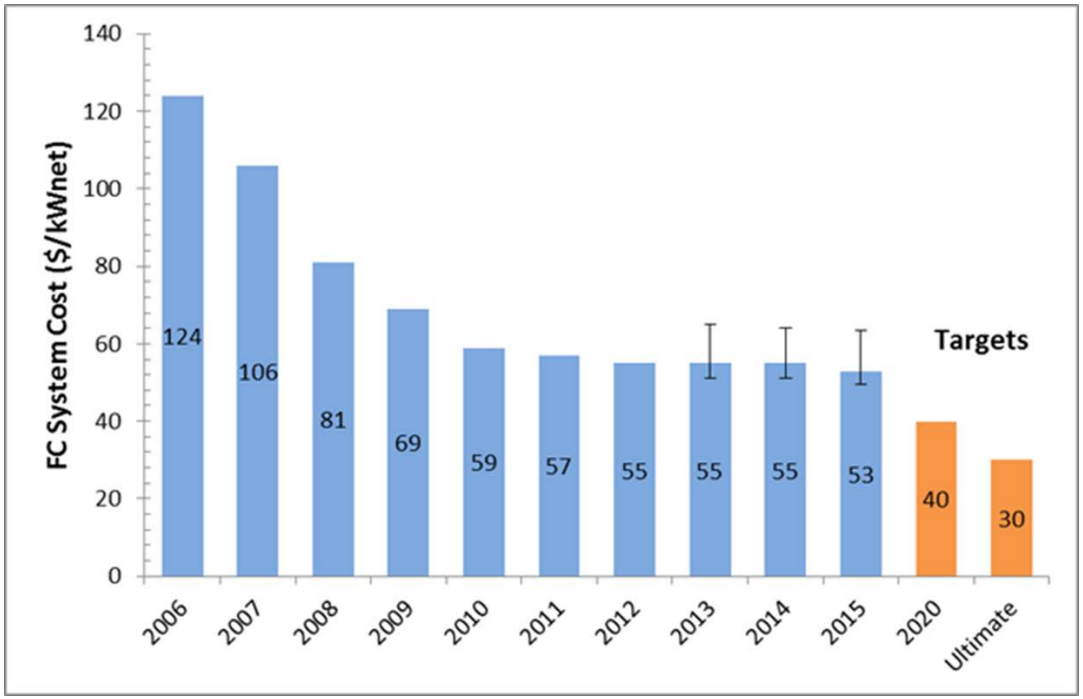
50% from 2006

Fuel Cell

30% from 2008

5X

Platinum Catalyst

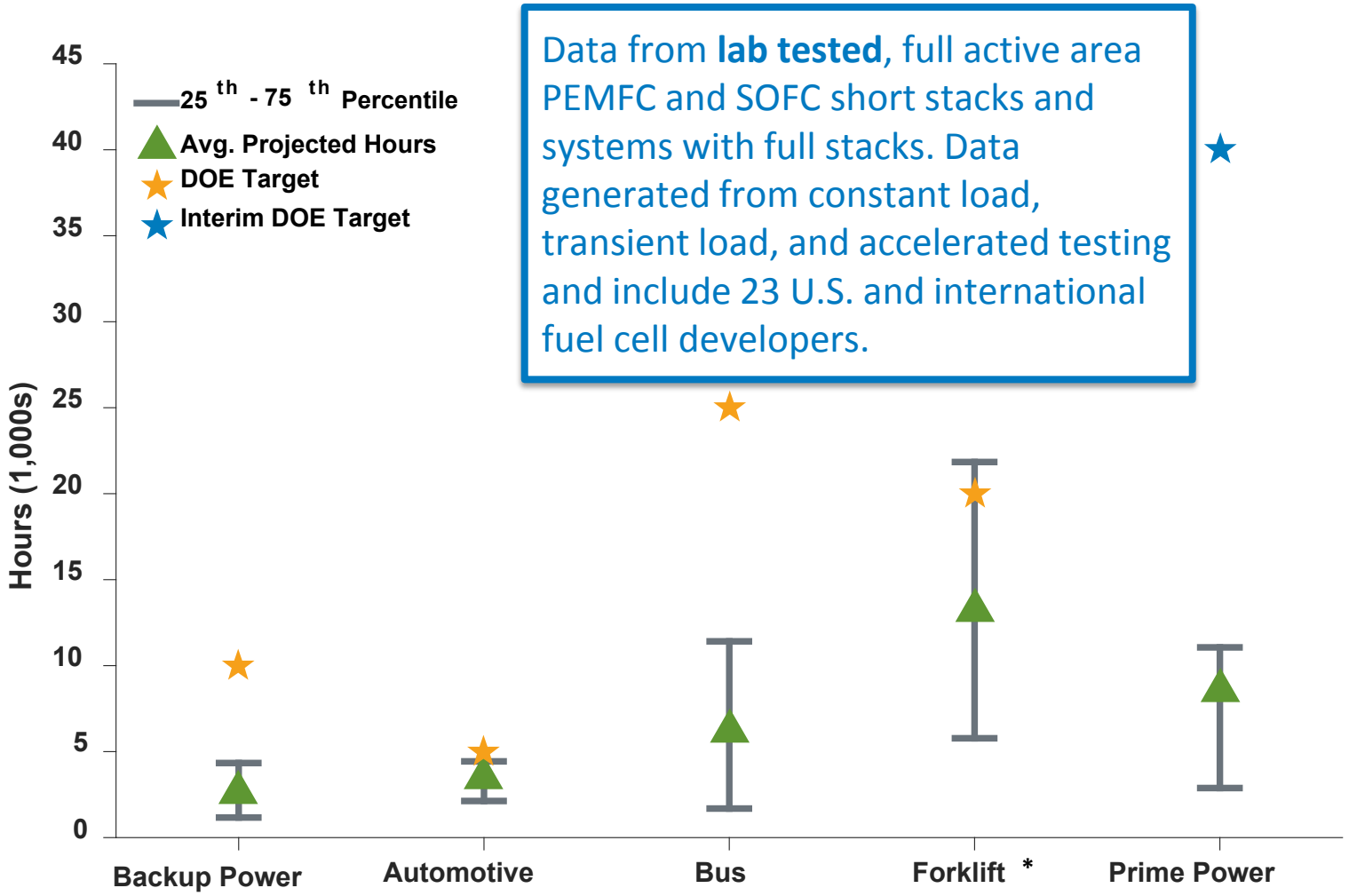


Fuel Cell Cost Status

- **$53/kW*** for 500,000 units/year
- **$60/kW*** for 100,000 units/year
- **$280/kW†** (for current technology at 20,000 units/year) - expected cost for initial FCEV commercialization

** SA, bottom-up analysis of model system manufacturing cost, high volume manufacturing with next-gen lab technology*
† ORNL, top-down analysis based on OEM input

Fuel Cell Durability Assessment:
Voltage Degradation Results by Application

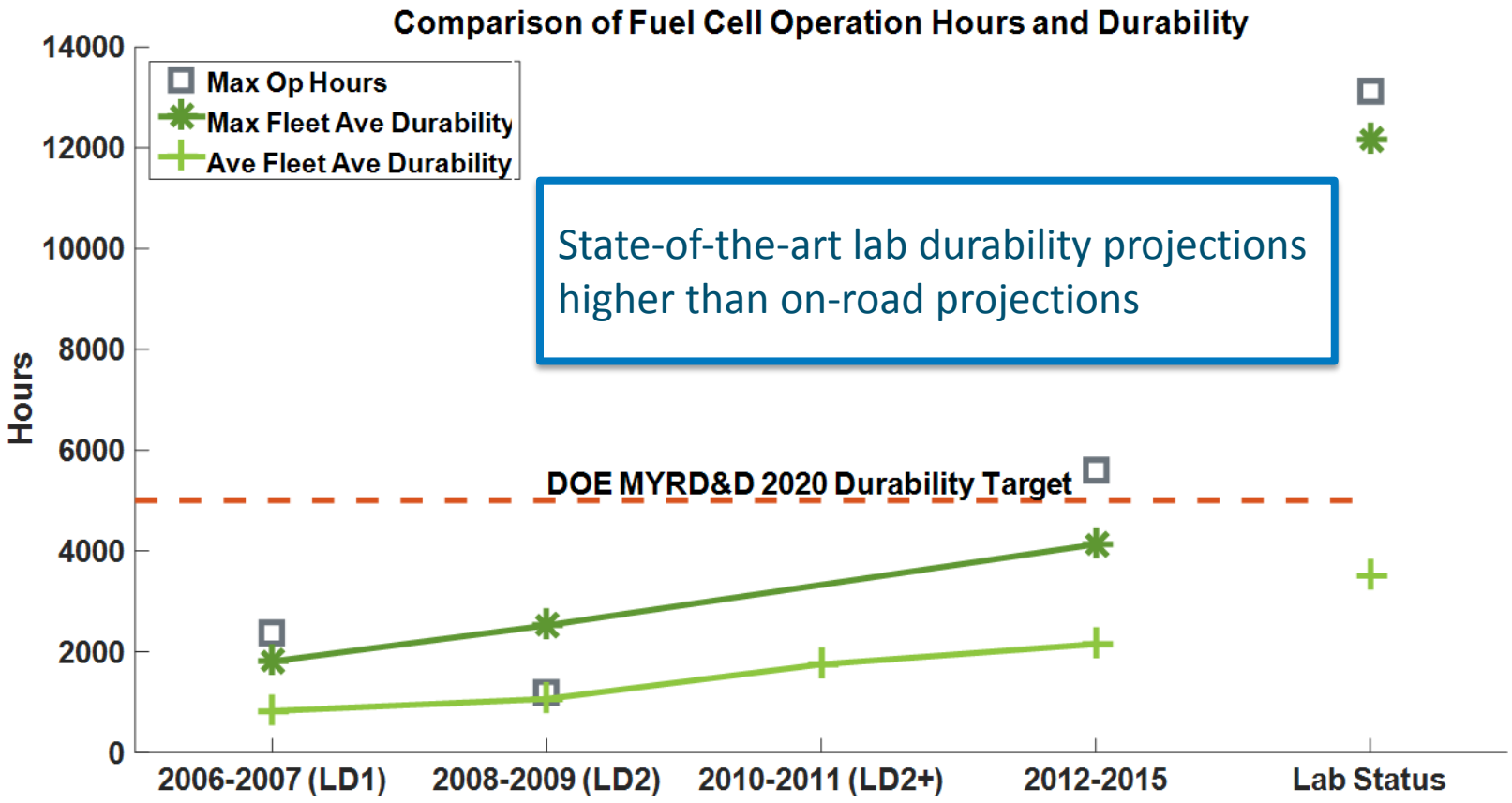


10% voltage degradation metric is used for assessing voltage degradation;
it may not be the same as end-of-life criteria and does not address catastrophic failure modes.

** Preliminary DOE Target*

J. Kurtz et al., NREL

Fuel Cell Durability Assessment:
Comparison with On-Road FCEV voltage durability



J. Kurtz et al., NREL

Continued durability improvements for fuel cell technology yet to be deployed

FC-PAD:
Consortium for Fuel Cell Performance And Durability

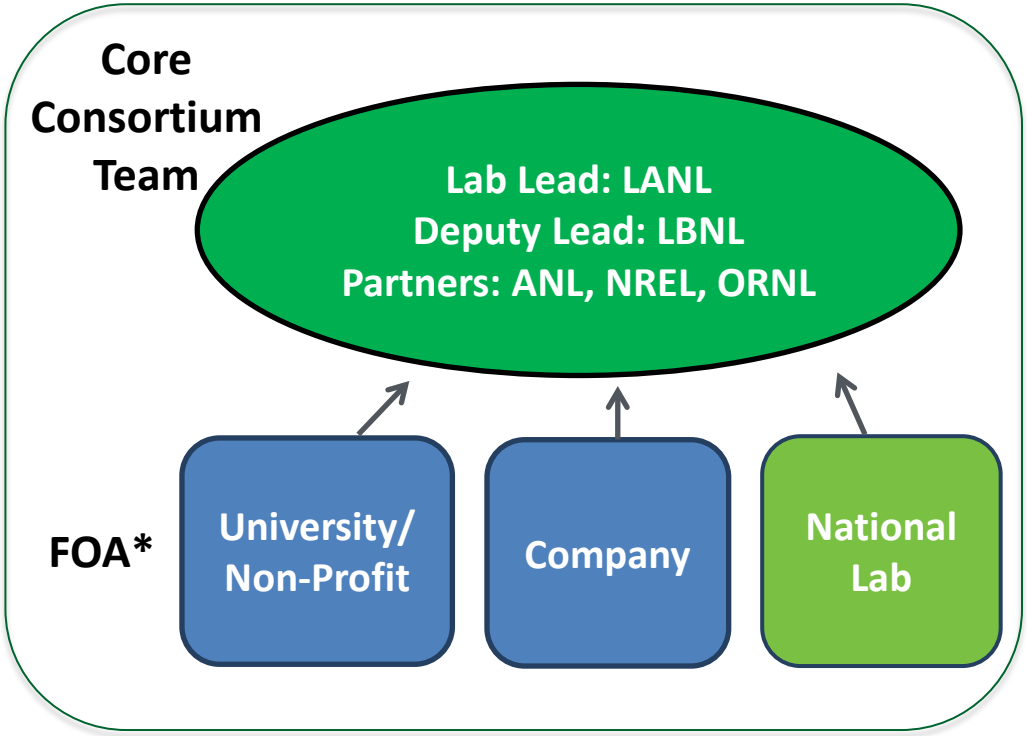
FUEL CELL PERFORMANCE AND DURABILITY

Approach:

- Couple national lab capabilities with funding opportunity announcements (FOAs) for an influx of innovative ideas and research

Objectives:

- Improve component stability and durability
- Improve cell performance with optimized transport
- Develop new diagnostics, characterization tools, and models



Consortium will foster sustained capabilities and collaborations

**Partners to be added by DOE DE-FOA-0001412*

Established Consortium to advance fuel cell performance and durability

FC-PAD: Structural Approach

FUEL CELL PERFORMANCE AND DURABILITY

1. Electrocatalysts and Supports
2. Electrode Layer
3. Ionomers, GDL, Bipolar Plates
4. Modeling and Validation
5. Operando Evaluation
6. Component Characterization

FC-PAD

Fuel Cell Consortium for Performance and Durability

Foundational Science

Industry + Academia

Research Organizations

Lead: Rod Borup (LANL)
Deputy Lead: Adam Z. Weber (LBNL)

Los Alamos NATIONAL LABORATORY | BERKELEY LAB | Argonne | OAK RIDGE National Laboratory | NREL | U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FC-PAD structured across six component and cross-cutting thrusts

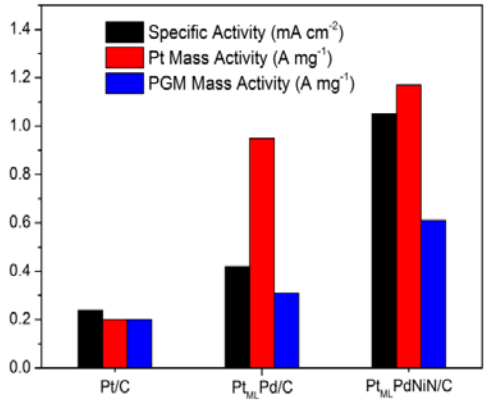
www.fcpad.org

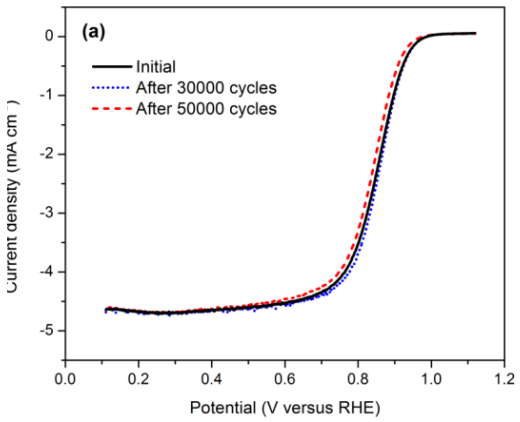
The FC-PAD website is now online!

Accomplishments: Platinum Monolayer Catalysts

Nitriding core components can facilitate the development of high-performance Pt-ML catalysts with low- or no-noble metal cores

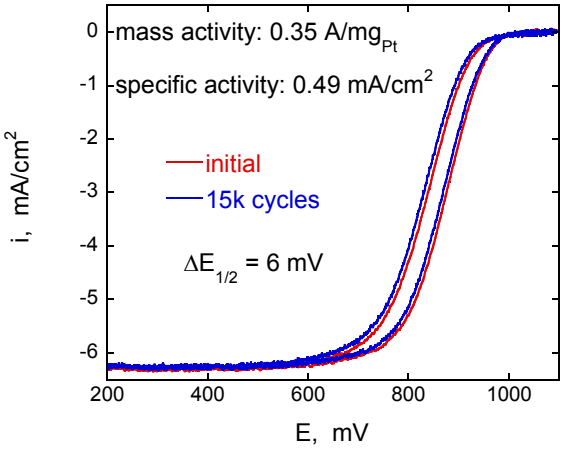
NiPd calcined at 250 °C in N_2 and 510 °C in NH_3

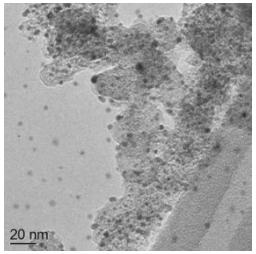




- Pd content is reduced by 50% in comparison with Pt/Pd/C.
- Ni nitride formation stabilizes Ni.

Niobium nitride as a core





- Non-optimized Pt/NbN/C shows promising activity.
- Future studies will focus on improving synthesis and durability.

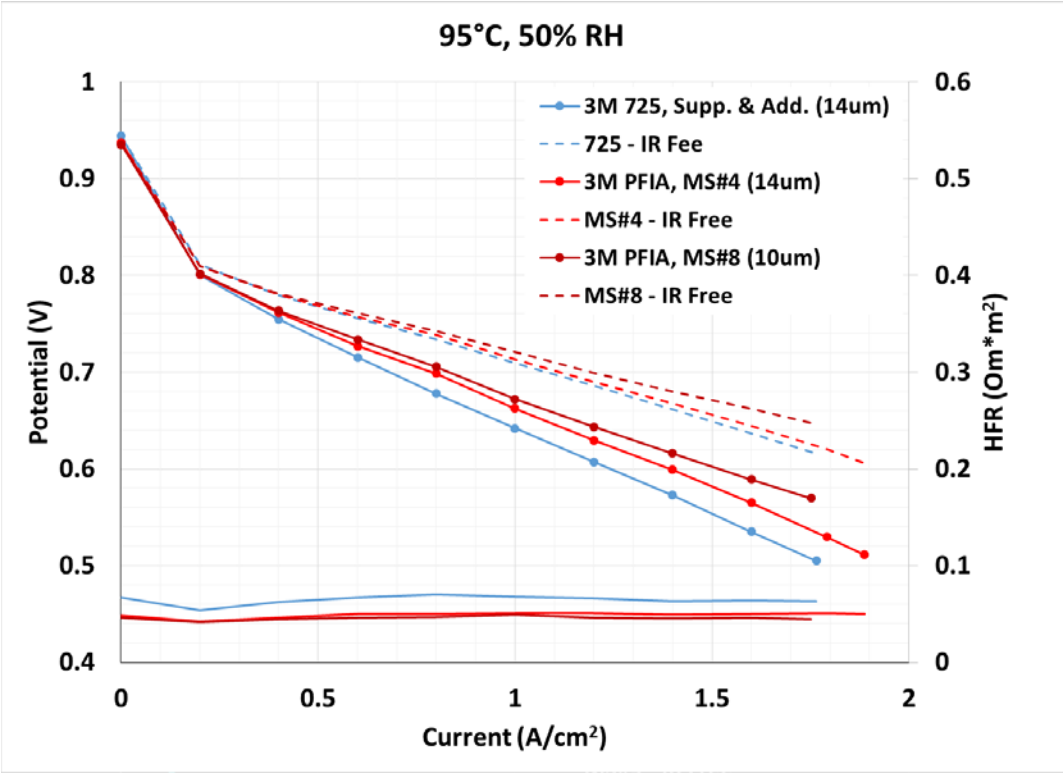
R. Adzic et al., BNL

BNL demonstrated potential to develop low-cost Pt monolayer catalysts with noble metal free cores

Accomplishments: New Membranes

3M developed 10 μm supported Perfluoro Imide Acid membrane with chemical additive:

- meets the resistance target at 80 °C for all humidities and at 120 °C only for the highest humidity; and
- meets mechanical and chemical durability targets

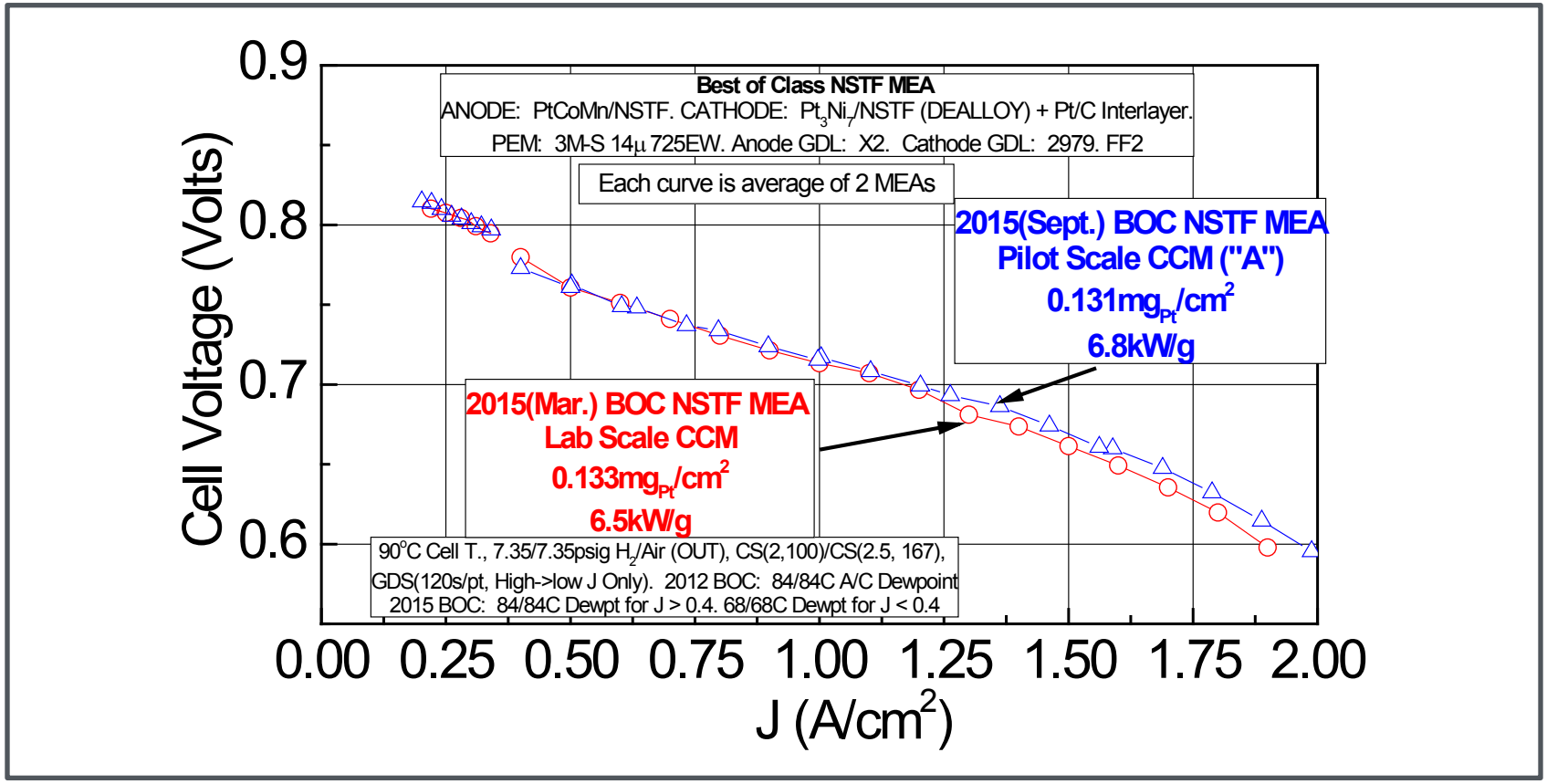


Characteristic	Units	2020 Targets	MS#8 PFIA-S (10 μm)
Area specific proton resistance at:			
120°C, P_{H2O} 40 kPa (20% RH)	Ohm cm²	0.02	0.054
120°C P_{H2O} 80 kPa (40% RH)	Ohm cm²	0.02	0.019
80°C P_{H2O} 25 kPa (50% RH)	Ohm cm²	0.02	0.020
80°C P_{H2O} 45 kPa (100% RH)	Ohm cm²	0.02	0.008
Durability:			
Mechanical	Cycles	20,000	>24,000
Chemical	hrs	>500	614

M. Yandrasits et al., 3M

3M PFIA membranes meet most 2020 DOE targets

Accomplishments: MEA Integration



Improved MEAs produce **6.8 kW/g$_{PGM}$** under conditions that satisfy Q/ΔT target **(2008 baseline 2.8 kW/g$_{PGM}$; 2014 status 6.2 kW/g$_{PGM}$; 2015 status 6.5 kW/g$_{PGM}$)**

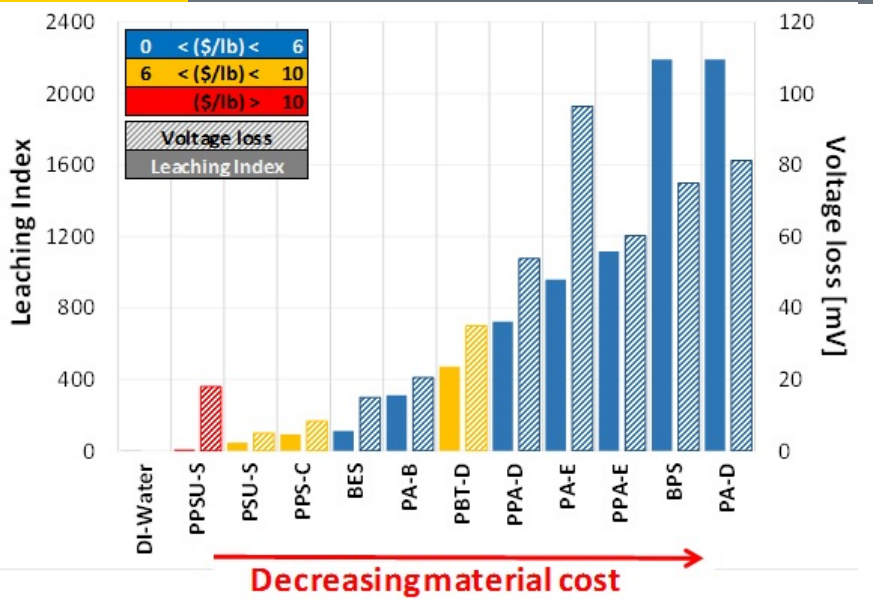
- Further work required to meet performance, durability, and robustness targets simultaneously.

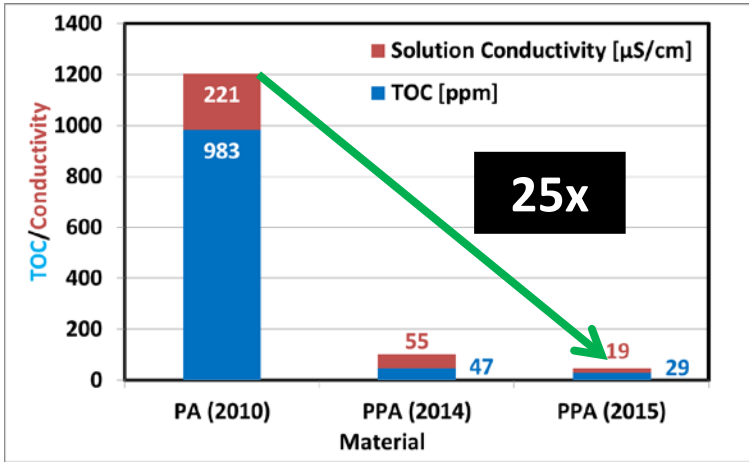
A. Steinbach et al., 3M

3M MEA integration R&D leads to improved performance and decreased PGM content

Accomplishments: Contamination Detection Study

- NREL and GM investigated system material-driven contamination of the fuel cell stack.
- Included structural plastics, hoses, lubricants, adhesives, seals.
- Correlated a "leaching index" to MEA degradation and cost.
- The project identified a cleaner PPA structural material with no significant increase in material cost and higher performance.
- Developed a publicly available material screening data tool and extensive database.*





*www.nrel.gov/hydrogen/system_contaminants_data/

- *~1400 site visits since May 2013*

H. Dinh et al., NREL

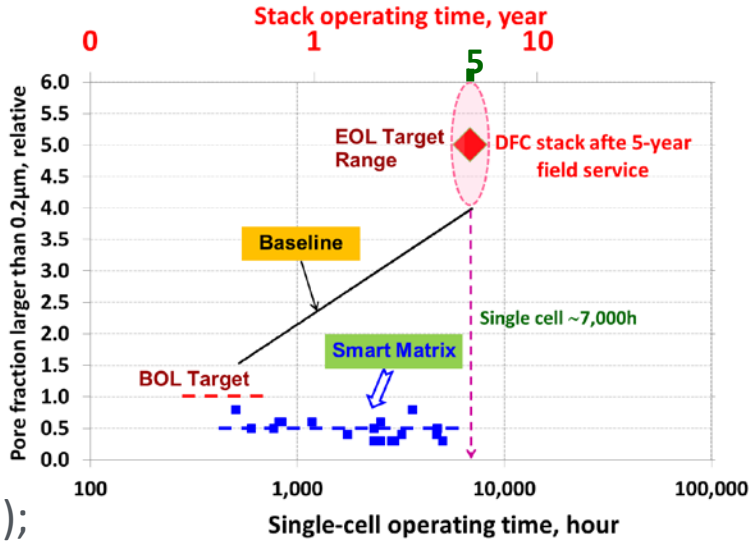
Study of system contaminants led to public dataset of materials, with leaching index, identity and quantity of contaminants, and recommended common test procedures

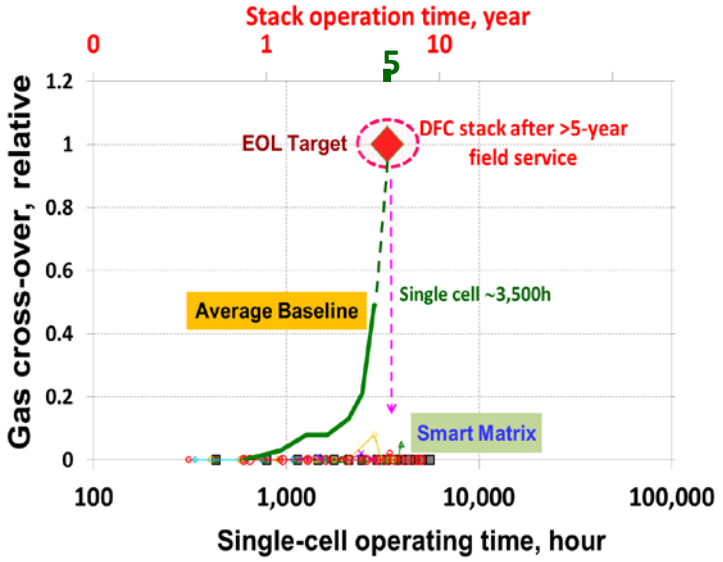
Accomplishments: Molten Carbonate Fuel Cells

"Smart Matrix" project targets technology advancement toward meeting stationary fuel cell durability of 80,000 hours

Improved porous ceramic matrix formulation resulted in:

- stable pore size during AST;
- high phase stability (<3% phase transformation);
- low particle growth (3.5x reduction in coarsening);
- >80% reduction in gas crossover;
- >40% increase in mechanical strength;
- ***5,000 h AST durability demonstrating projected 80,000 h stack durability.***



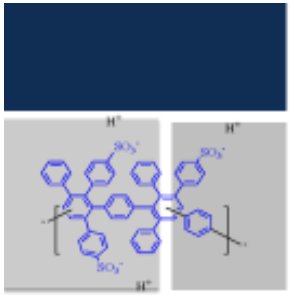


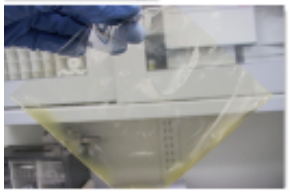
C. Yuh et al., FuelCell Energy

Novel MCFC electrolyte matrix projected to hit 80,000 hours target for stationary applications

Lab T2M: SNL Membranes for Energy/H_2O Electrochemical Systems

SNL Team in Lab-Corps Program





Sandia National Laboratories

Exceptional service in the national interest

Polymer Membrane Team

Cy Fujimoto	Principal Investigator
Jeff Nelson	Entrepreneurial LEAD
Tom Brennan	Industry Mentor

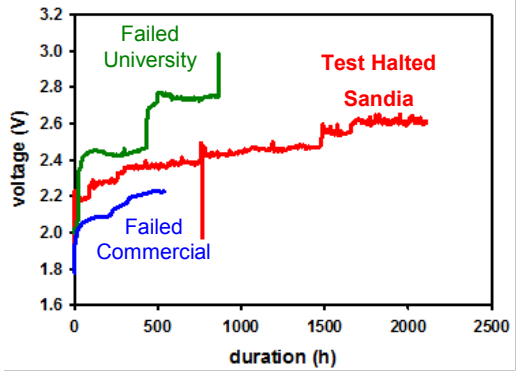
Interviews to date total:33

ENERGY NNSA

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

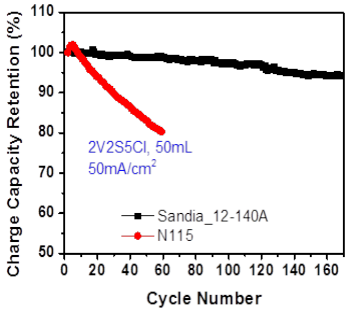
SNL membrane technologies demonstrate commercial potential for employment in a range of applications

Demonstrated durability in AEM electrolyzers



Higher performance and lower maintenance in flow batteries

	Power (mW/cm^2)
Sandia	1159 (+23%)
Nafion	946



SNL developed AEM/PEM technologies with a focus on commercialization

FY15 FOA & Lab Call Awards

Recipient	Location	Project Title
Catalysts & Supports topic of Funding Opportunity Announcement DE-FOA-0001224		
3M Company	St. Paul, MN	Highly Active, Durable, and Ultra-low PGM NSTF Thin Film ORR Catalysts and Supports
General Motors	Pontiac, MI	Highly-Accessible Catalysts for Durable High-Power Performance
National Renewable Energy Laboratory	Golden, CO	Extended Surface Electrocatalyst Development
Illinois Institute of Technology	Chicago, IL	Corrosion-resistant non-carbon electrocatalyst supports for PEFCs
AEMFC and Catalyst R&D Lab Call		
LANL (RPI, SNL, ANL)	Los Alamos, NM	Advanced Materials for Fully-Integrated MEAs in AEMFCs
NREL (CSM, LBNL, ORNL)	Golden, CO	Advanced Ionomers and MEAs for AEMFCs
ANL (LANL, LBNL, ORNL)	Argonne, IL	Tailored High Performance Low-PGM Cathode Catalysts
BNL (LANL)	Upton, NY	Platinum Monolayer Electrocatalysts

New awards fill gaps in Fuel Cell R&D portfolio

ElectroCat (Electrocatalysis Consortium) Established

Goal

Accelerate the deployment of fuel cell systems by **eliminating the use of PGM catalysts**

Leads

Argonne NATIONAL LABORATORY

High-throughput materials discovery, characterization, and testing

Los Alamos NATIONAL LABORATORY

Design and synthesis of PGM-free catalysts and electrodes

Mission

Develop and implement PGM-free catalysts by:

- **streamlining access** to unique synthesis and characterization tools across national labs
- **developing missing strategic capabilities**
- **curating a public database** of information

The Bigger Picture

ElectroCat
Electrocatalysis Consortium

Part of

Energy Materials Network
U.S. Department of Energy

Save The Date: ElectroCat Workshop

ElectroCat
Electrocatalysis Consortium

WORKSHOP: July 26, 2016

@ Argonne National Laboratory

An Outreach Event on

PGM-free Catalyst Development, Characterization, Modeling, and High Throughput Approaches

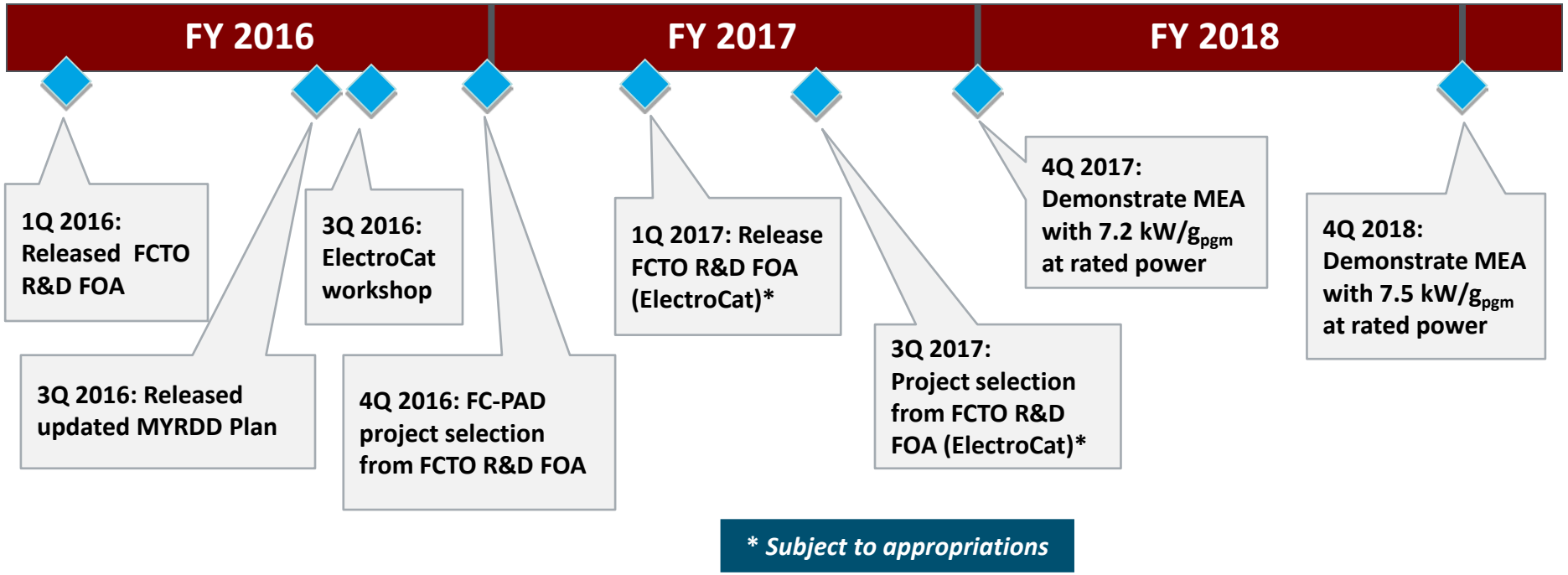
Outlining capabilities

Assessing stakeholder needs

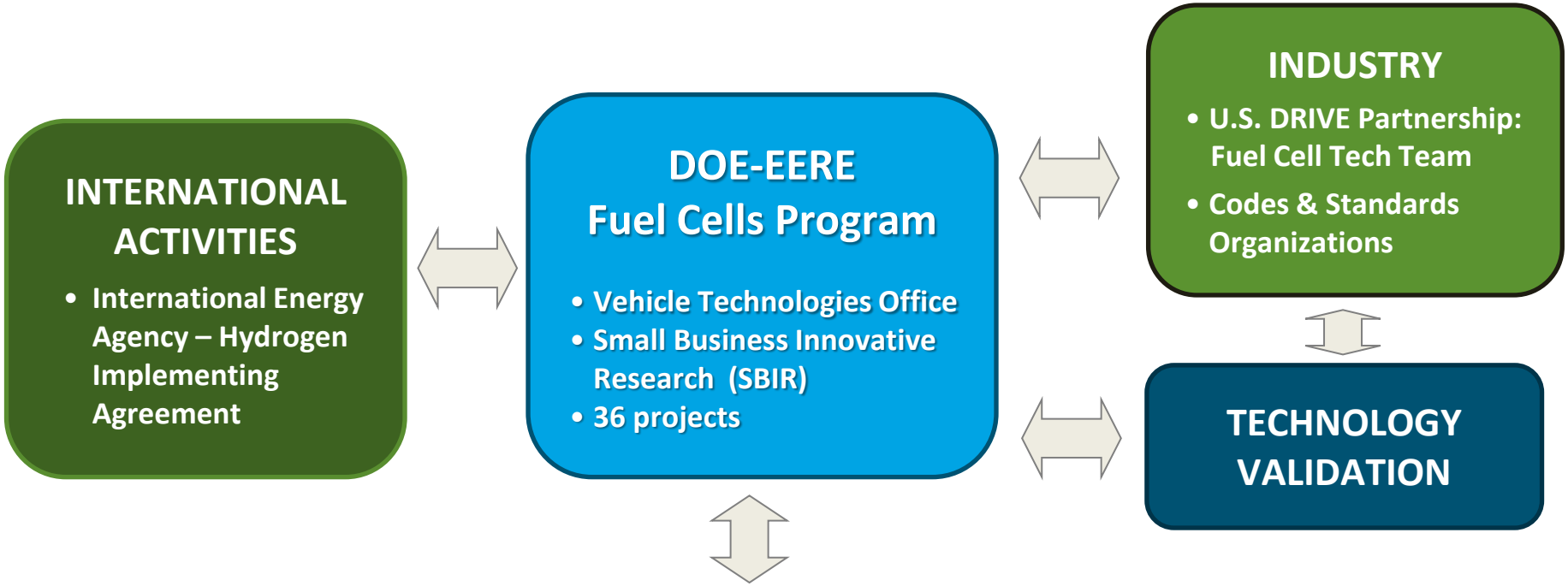
More info to follow

Summary of Activities and Upcoming Milestones

- Projects address cost reduction, performance and durability enhancement of stack components including catalysts, membranes and MEAs
- FC-PAD Consortium established to advance fuel cell performance and durability
- ElectroCat launched to coordinate PGM-free catalyst development and gather state-of-the-art tools at the national labs under one umbrella for easy access by stakeholders and the research community.



Collaborations



National Collaborations (inter- and intra-agency efforts)

DOE - FE	DOE - BES	DOE – ARPA-E	DOT/FTA	DOD	DOC/NIST
SOFC Program	Catalysts and Membranes	REBELS and IONICS Programs	Fuel Cell Buses	DOD/DOE MOU	Neutron Imaging

Applied R&D is coordinated among national and international organizations

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John Kopasz and Tom Benjamin
(Argonne National Laboratory)
Shaun Onorato, Chris Werth and Jonathan Jin
(Allegheny Science & Technology)
Bahman Habibzadeh (on detail from BTO)

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