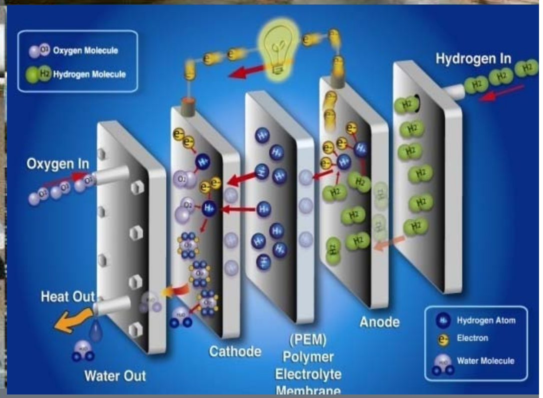
PEMFC MEA Component R&D at the DOE Fuel Cell Technologies Program

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









CARISMA 2012

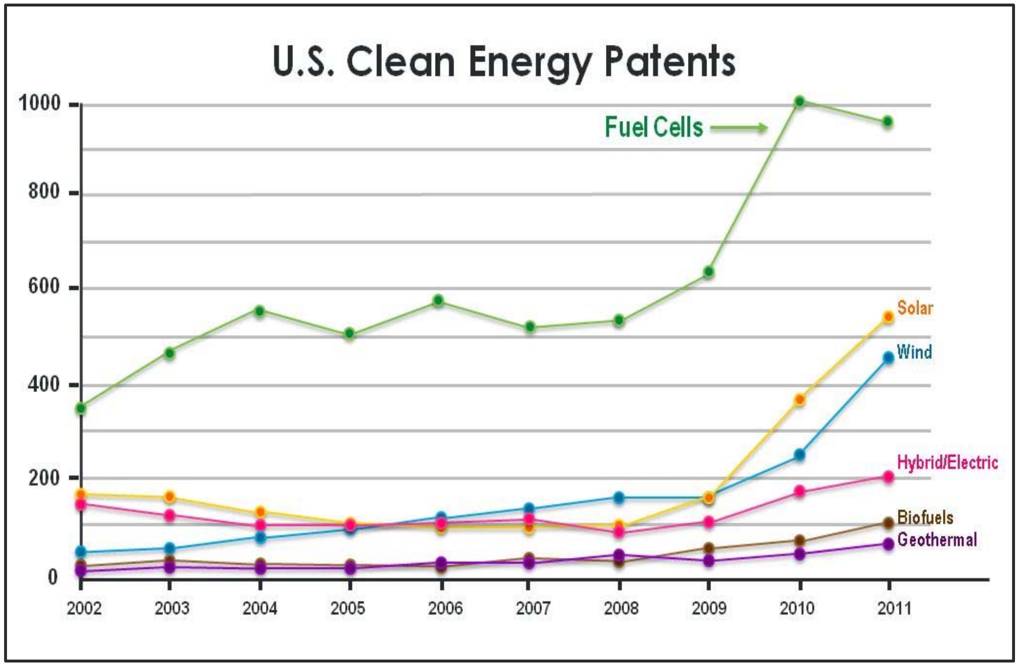
Copenhagen, Denmark

September 3, 2012

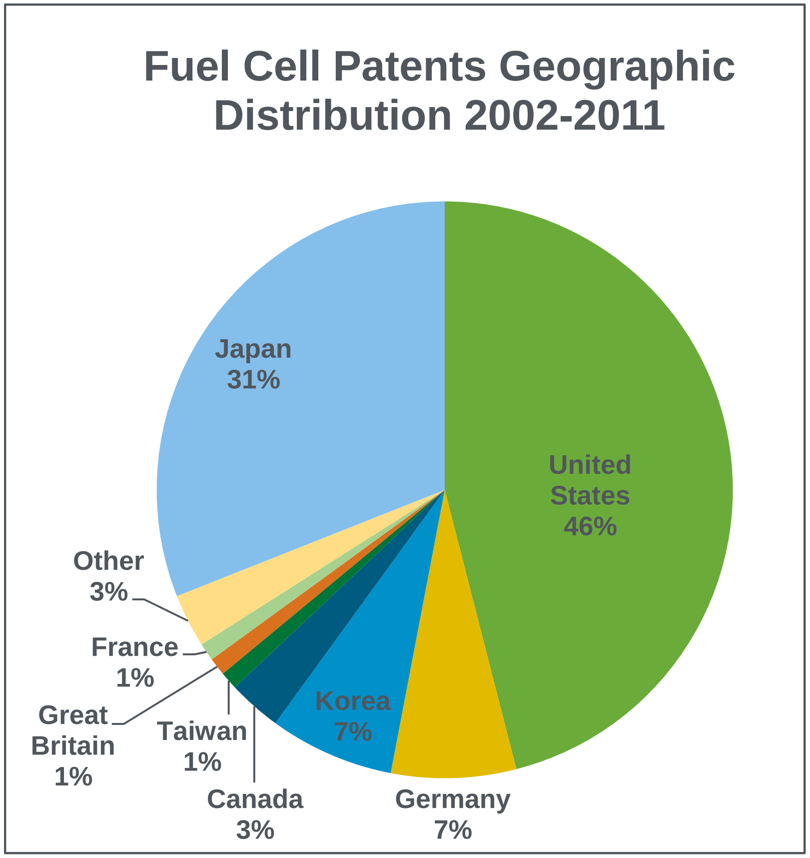
Dr. Dimitrios Papageorgopoulos

Fuel Cells Team Leader
Fuel Cell Technologies Program
U.S. Department of Energy

Fuel Cells – An Emerging Industry



Top 10 companies: GM, Honda, Samsung, Toyota, UTC Power, Nissan, Ballard, Plug Power, Panasonic, Delphi Technologies



Clean Energy Patent Growth Index[1] shows that fuel cell patents lead in the clean energy field with over 950 fuel cell patents issued in 2011.

- Nearly double the second place holder, solar, which has ~540 patents.

[1] http://cepgi.typepad.com/heslin_rothenberg_farley_/

Fuel Cell Market Overview

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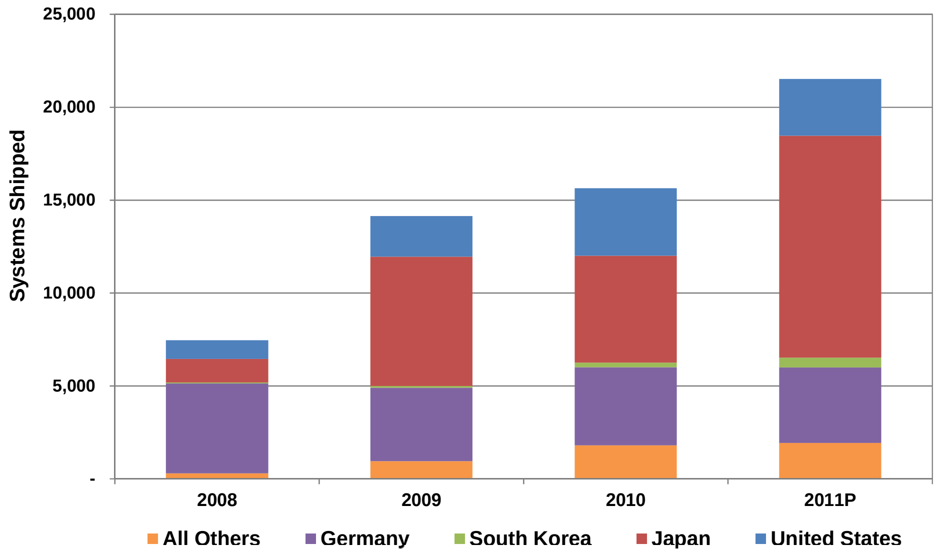
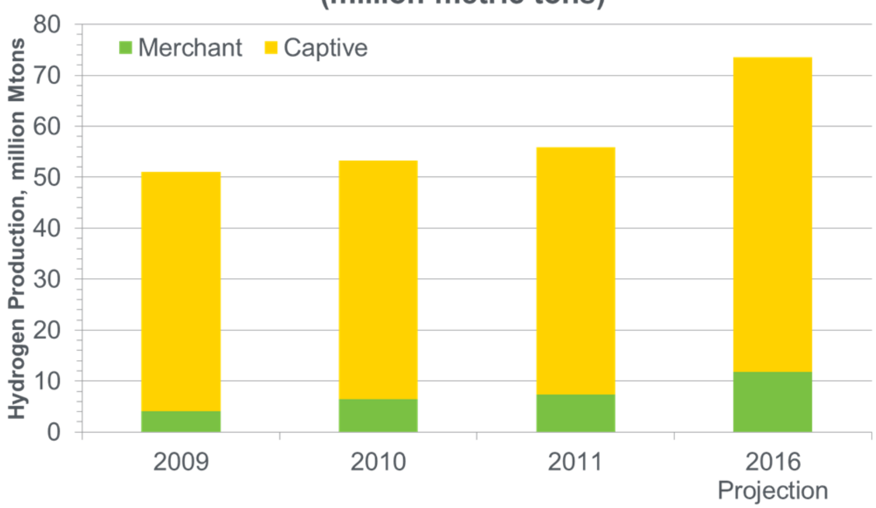
System Shipments by Key Countries: 2008-2011



Global Hydrogen Production Market 2009 - 2016 (million metric tons)



Fuel cell market continues to grow
>20,000 units shipped in 2011
>35% increase over 2010

Various analyses project that the global fuel cell/hydrogen market could reach maturity over the next 10 to 20 years, producing revenues of:

- **$14 – $31 billion/year for stationary power**
- **$11 billion/year for portable power**
- **$18 – $97 billion/year for transportation**

Widespread market penetration of fuel cells could lead to:
180,000 new jobs in the US by 2020
675,000 jobs by 2035

The global hydrogen market is also robust with over 55 Mtons produced in 2011 and over 70 Mtons projected in 2016, a > 30% increase.

FuelCells2000, Pike Research, Fuel Cell Today, ANL, See DOE FCT 2011 Market Report

Current Program Structure

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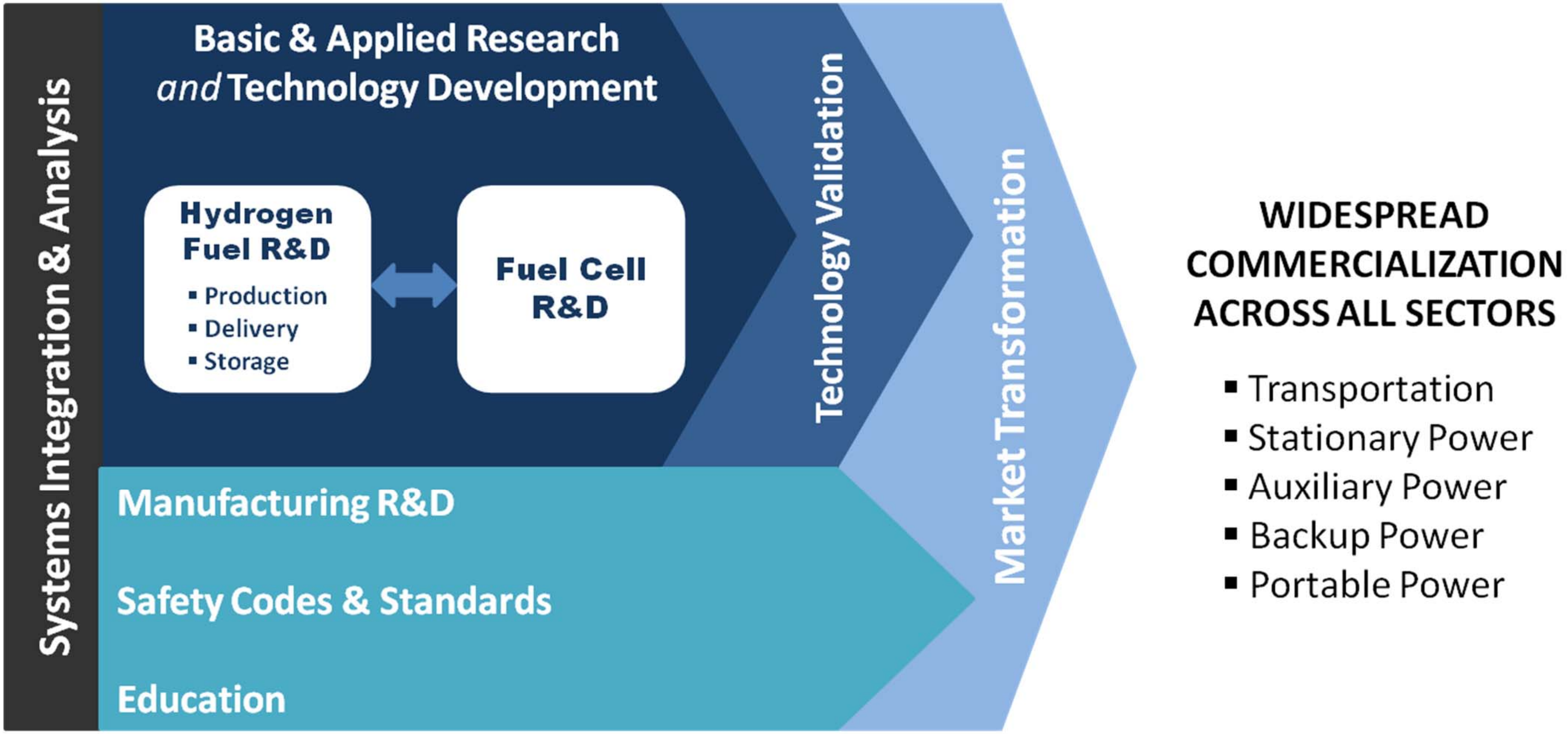
The Program is an integrated effort, structured to address all the key challenges and obstacles facing widespread commercialization.



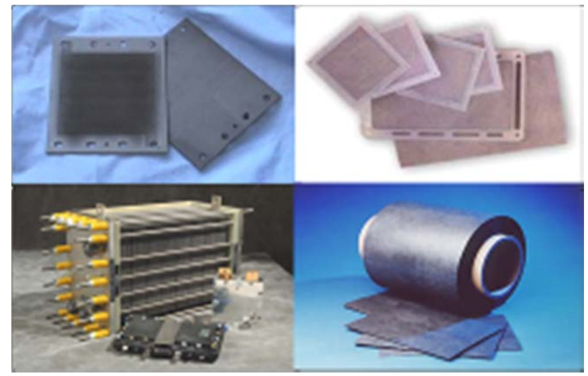
The Program includes activities within the Offices of Energy Efficiency & Renewable Energy, Fossil Energy, Nuclear Energy, and Science.

Fuel Cells: Goals and Objectives

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

Objectives

- By 2015, a fuel cell system for portable power (<250 W) with an energy density of 900 Wh/L.
- 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.



Fuel Cells: 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.

Fuel Cell MYRD&D Plan recently updated:
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
- Stationary power
- Fuel processor subsystems
- Portable power
- APUs and emerging markets

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

Targets: Membranes

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Membranes for Transportation Applications				
Characteristic	**Units**	**2011 Status**	**2017 Targets**	**2020 Targets**
Maximum oxygen cross-over	mA / cm^2	<1	2	2
Maximum hydrogen cross-over	mA / cm^2	<1.8	2	2
Area specific proton resistance at:				
Max. temp., 40-80 kPa water vapor	Ohm cm^2	0.023 (40kPa) 0.012 (80kPa)	0.02	0.02
80°C, 25-45 kPa water vapor	Ohm cm^2	0.017 (25kPa) 0.006 (44kPa)	0.02	0.02
30°C, up to 4 kPa water vapor	Ohm cm^2	0.02 (3.8 kPa)	0.03	0.03
-20°C	Ohm cm^2	0.1	0.2	0.2
Operating temperature	°C	<120	≤120	≤120
Minimum electrical resistance	Ohm cm^2	–	1,000	1,000
Cost	$ / m^2	–	20	20
Durability				
Mechanical	Cycles with <10 sccm crossover	>20,000	20,000	20,000
Chemical	hours	>2,300	>500	>500

Revised targets in recently released MYRDD Plan
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

Targets: Catalysts and MEAs

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Electrocatalysts for Transportation Applications				
Characteristic	Units	2011 Status	Targets	
			2017	2020
PGM total content (both electrodes)	g / kW (rated)	0.19	0.125	0.125
PGM total loading (both electrodes)	mg_{PGM} / cm^2	0.15	0.125	0.125
Loss in initial catalytic activity	% mass activity loss	48	<40	<40
Electro catalyst support stability	% mass activity loss	<10	<10	<10
Mass activity	A / mg Pt @ 900 $mV_{iR\text{-}free}$	0.24	0.44	0.44
Non-Pt catalyst activity per volume of supported catalyst	A / cm^3 @ 800 $mV_{IR\text{-}free}$	60 (measured at 0.8 V) 165 (extrapolated from >0.85 V)	300	300

Membrane Electrode Assemblies				
Characteristic	Units	2011 Status	2017 Targets	2020 Targets
$Q/\Delta T_i$	kW/°C	–	1.45	1.45
Cost	$ / kW	13 (without frame and gasket) 16 (with frame and gasket)	9	7
Durability with cycling	hours	9,000	5,000	5,000
Performance @ 0.8 V	mA / cm^2	160	300	300
Performance @ rated power	mW / cm^2	845	1,000	1,000

Revised targets in recently released MYRDD Plan
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

Challenges and Strategy: Automotive Applications

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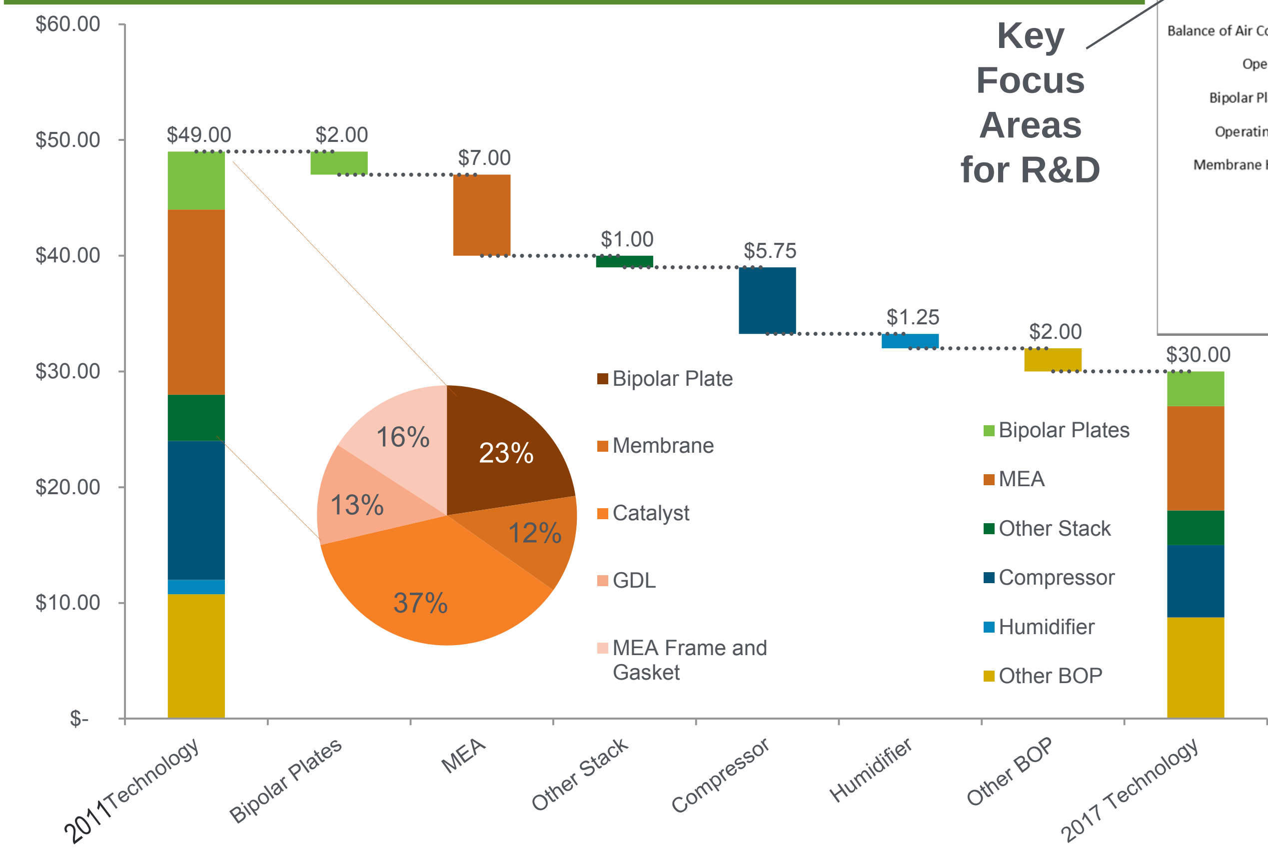
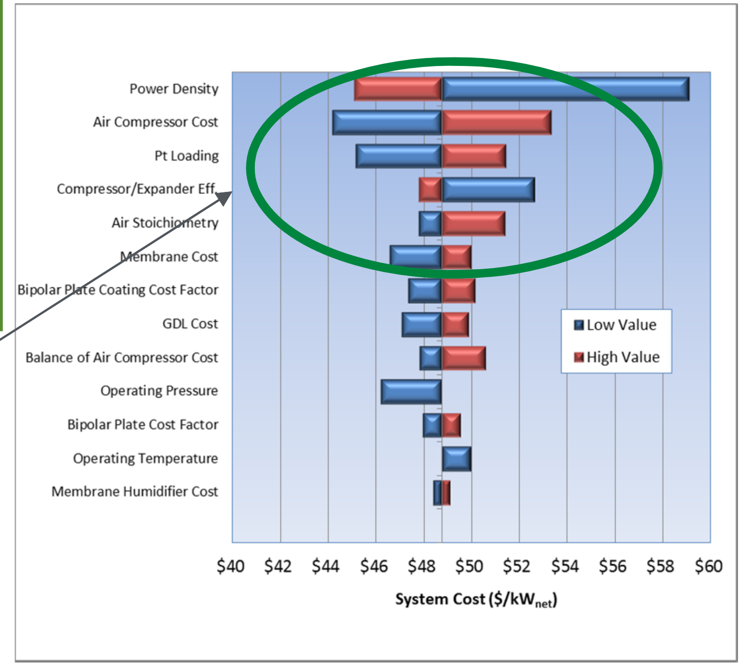
- **Strategic technical analysis guides focus areas for R&D and priorities.**
- **Need to reduce cost from $49/kW to $30/kW and increase durability from 2,500 to 5,000 hours.**
- **Advances in PEMFC materials and components could benefit a range of applications**



Key Focus Areas for R&D



Sensitivity Analysis helps guide R&D

Targeted 80 kW PEM fuel cell system cost: $30/kW at 500,000 units/yr

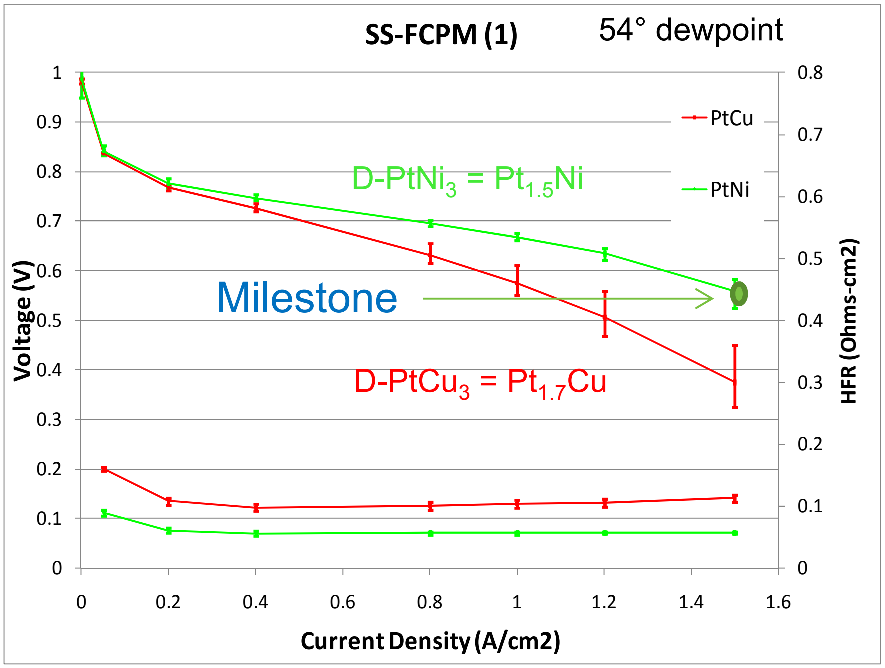
Strategies to Address Challenges – Catalyst Examples

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

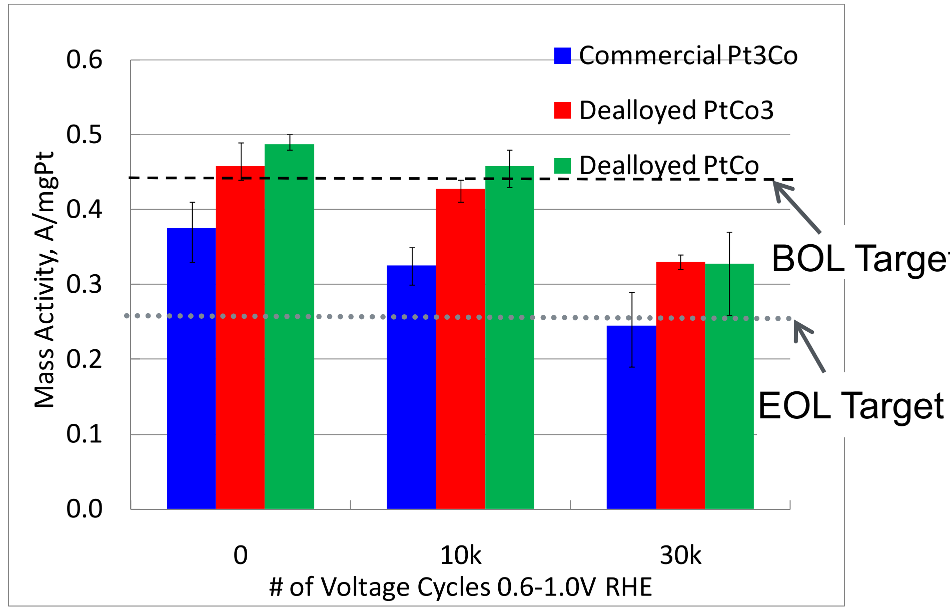
De-alloyed Catalysts

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

GM 50 cm^2 MEAs, at 0.1 mg_{Pt}/cm^2
H_2/air, 80° C, 170 kPa_{abs}, stoichs 2/2



GM 50 cm^2 MEAs, 0.2 mg_{Pt}/cm^2

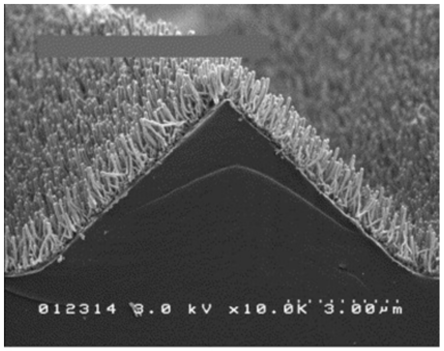


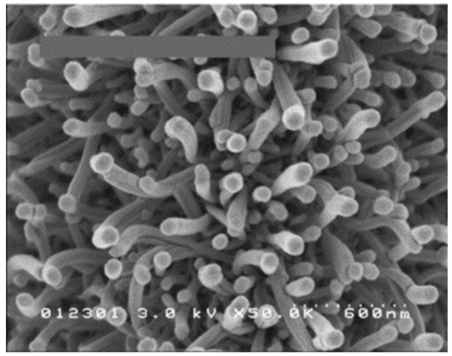
- $PtCo_3$ and $PtNi_3$ meet 0.44 A/mg_{PGM} mass activity target
- $PtCo_3$ meets 30,000 cycle durability target
- $PtNi_3$ meets 0.56 V @ 1.5 A/cm^2 milestone

0.46 A/mg_{PGM} for $PtCo_3$,
0.52 A/mg_{PGM} for $PtNi_3$ in 50 cm^2 MEA testing

F. Wagner et al., GM

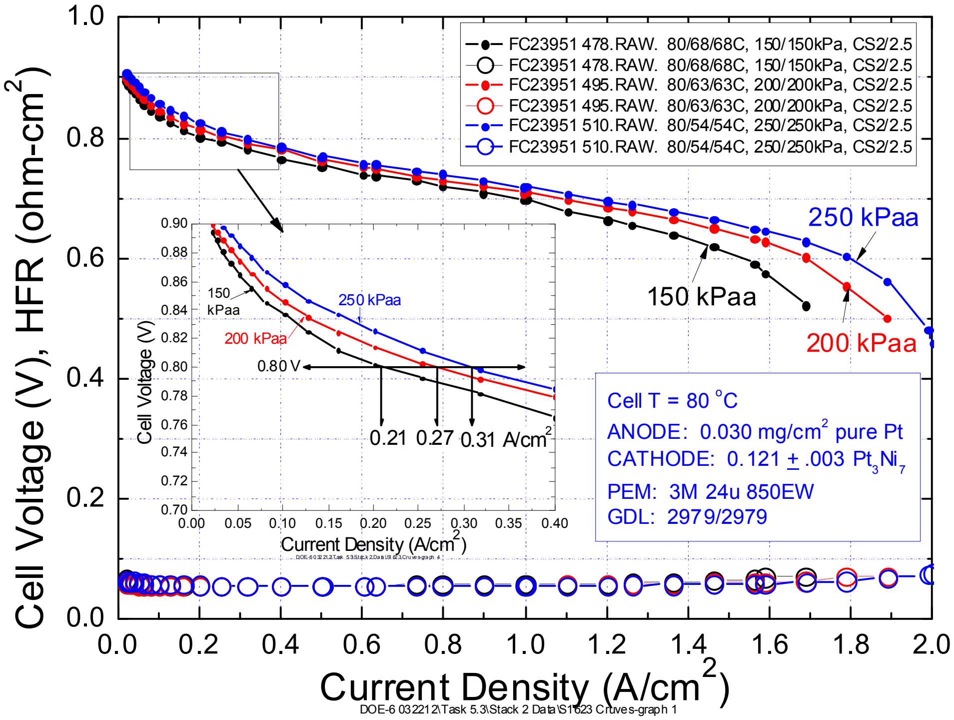
NSTF catalysts achieve 0.44 A/mg$_{PGM}$ target in MEAs





- ~ 5 billion whiskers/cm^2
- Whiskers are ~ 25 X 50 X 1000 nm

- **Achieved 0.44 A/mg$_{PGM}$ target** on roll-to-roll produced MEAs through improvements in Pt_3Ni_7 catalyst processing techniques
- Progress in improving high-current performance of Pt_3Ni_7; still opportunity for further improvement



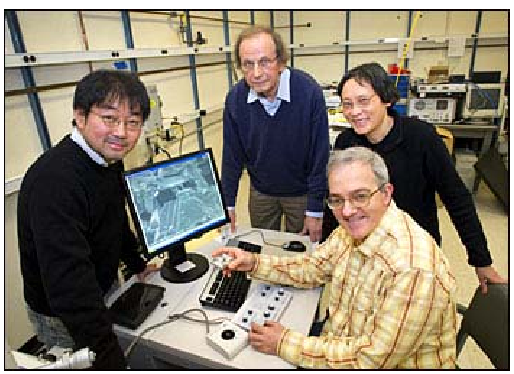
New 3M project will improve MEA components and optimize component integration to simultaneously achieve catalyst, membrane, and MEA targets

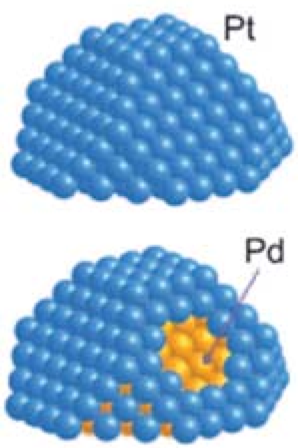
M. Debe et al., 3M

Catalyst Scale-up

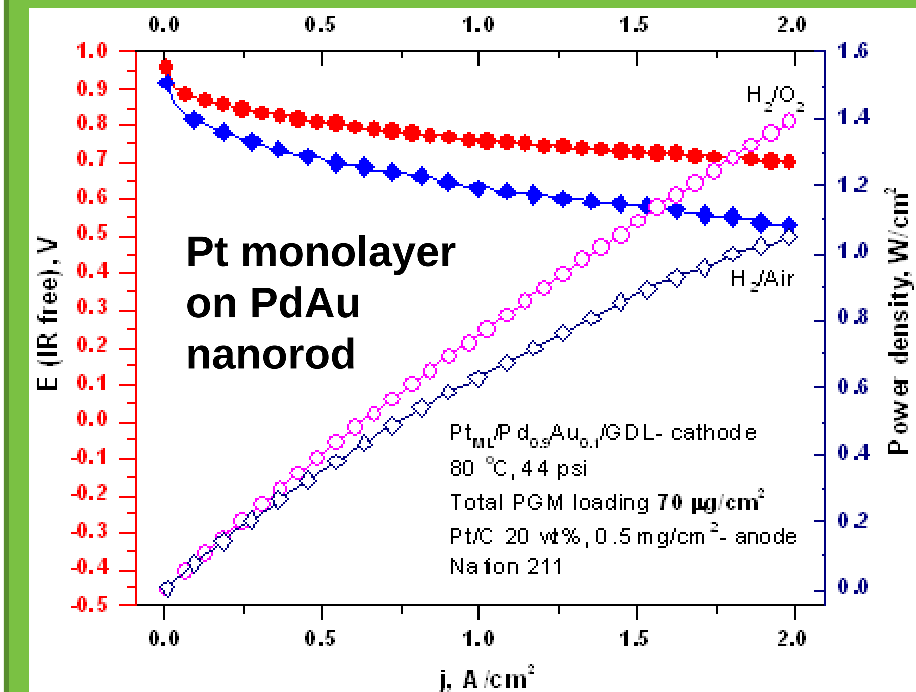
Brookhaven core-shell catalyst technology licensed by leading catalyst manufacturer

- Jan. 3, 2012 – N.E. Chemcat Corporation, a leading catalyst and precious metal compound manufacturer, licensed core-shell electrocatalysts developed by BNL under previous EERE project
- Includes catalysts with Pd or Pd-alloy cores, Pt shells
- N.E. Chemcat also licensed innovative methods for making the catalysts and an apparatus design used in manufacturing them





Current BNL project is developing new core-shell structures and improving performance and durability



R. Adzic, et al., BNL

Nanosegregated PtNi Catalysts

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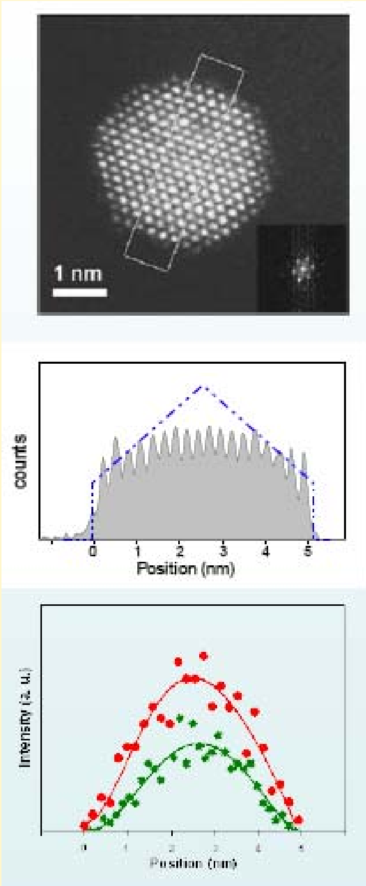
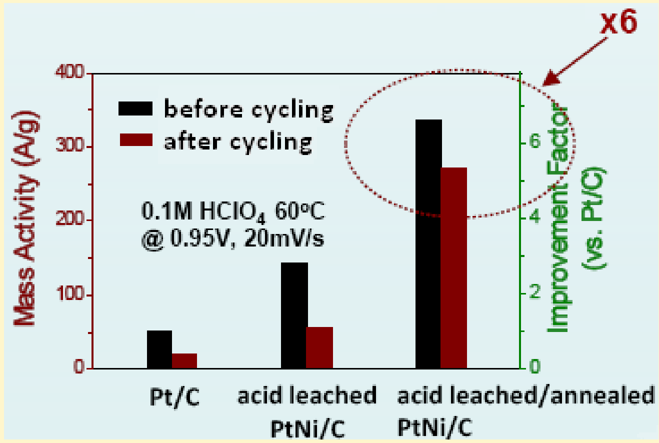
Nano-segregated PtNi catalysts demonstrate performance more than 6X that of platinum in RDE testing

Nanosegregated PtNi - RDE



Multilayered Pt-skin surfaces confirmed for PtNi annealed NPs



Performance:
Nanosegregated PtNi/C catalysts have ORR mass activity 6X that of Pt/C in RDE testing.

Durability: **Loss in mass activity after 20,000 potential cycles is ~1/3 that of Pt/C.**

N. Markovic et al., ANL

Nanosegregated PtNi - MEA

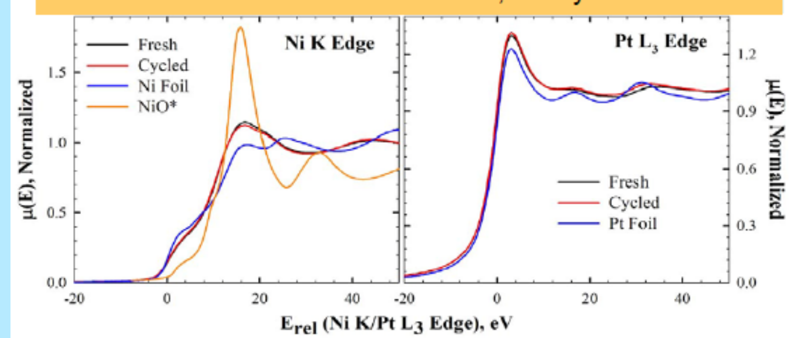
Sample	ECSA (m^2/g_{Pt})	M.A. (A/mg_{Pt})	S.A. ($\mu A/mg_{Pt}$)	% loss in M.A.
PtNi/C (1)	41	0.327	794	12%
PtNi/C (2)	39	0.287	700	

12% degradation during 20,000 cycles, 0.6 – 0.95 V

Performance: **Approaching 0.44 A/mg_{PGM} target, but further work needed to transfer high RDE activity to MEAs.**

Durability: **Initial testing indicates likelihood of meeting <40% mass activity degradation target during 30,000 cycles from 0.6 – 1.0 V; further testing needed. EXAFS indicates catalyst structure maintained during cycling.**

Ex-Situ EXAFS: Before and after 20,000 cycles in MEA



Catalyst Degradation

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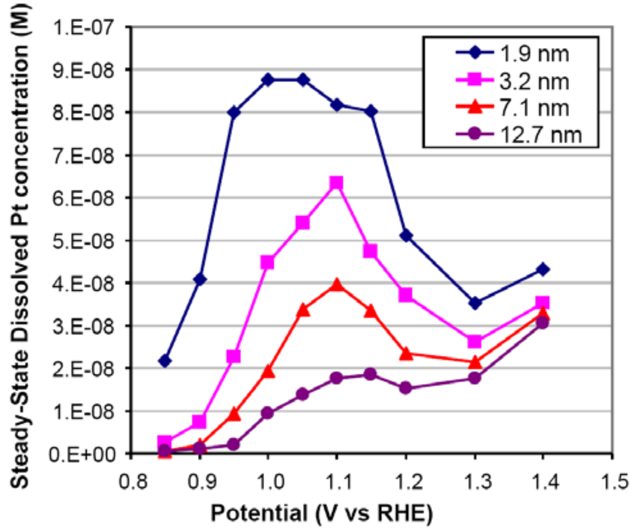
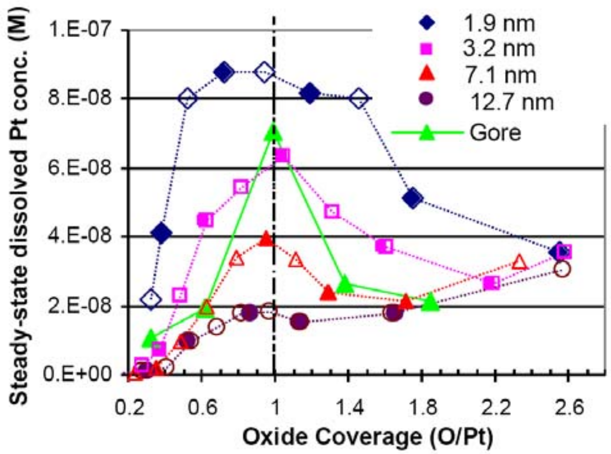
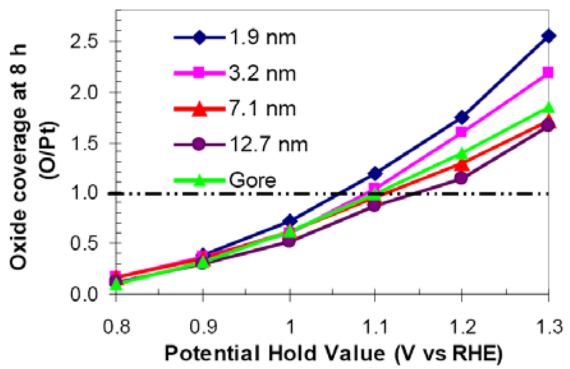
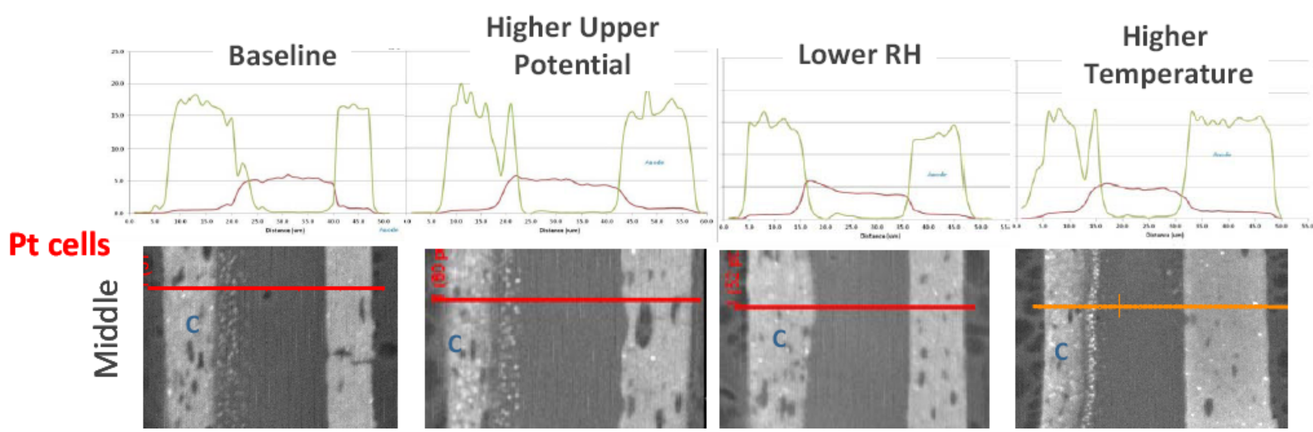
Quantitative characterization of effects of Pt particle size and cell operating conditions on durability







Smaller Pt particles have increased Pt oxidation and Pt dissolution



- **Higher potentials and higher temperatures → higher Pt content in membrane (faster degradation)**
- **Lower RH → lower Pt content in membrane (improved durability)**

D. Myers et al., ANL

Durable Catalysts

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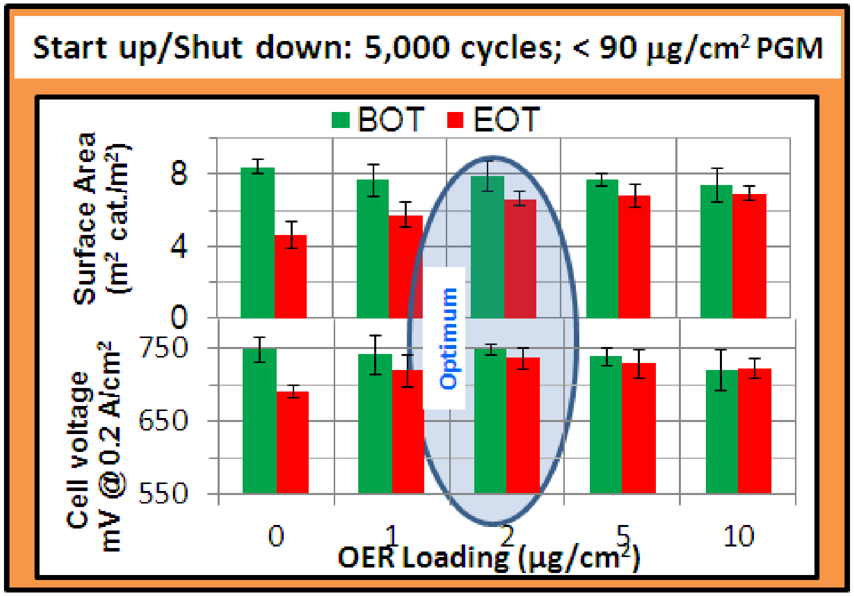
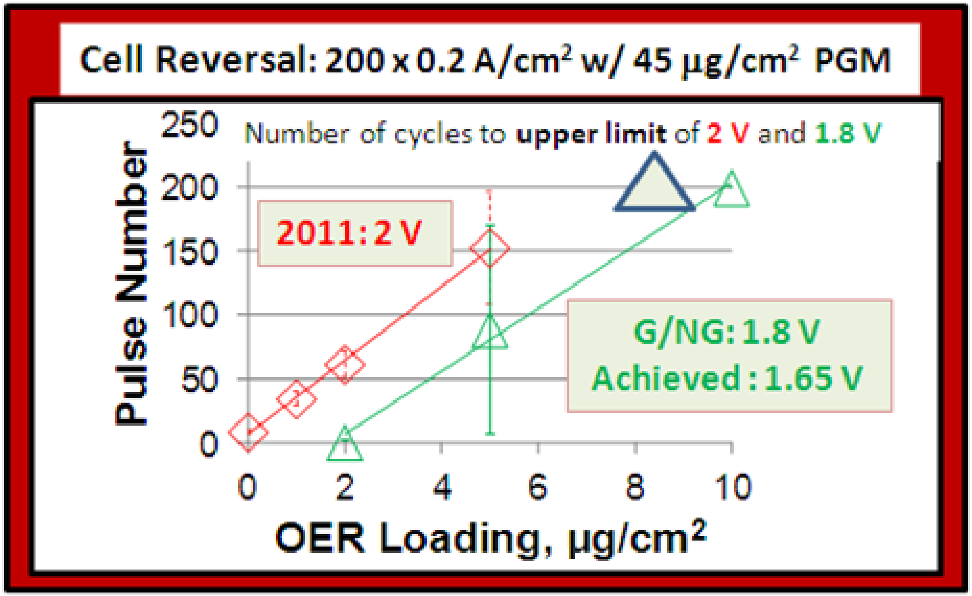
3M catalysts demonstrate durability under startup, shutdown, and cell reversal



IrRu-modified cathodes have achieved the SU/SD Go/No Go requirement: 5,000 cycles with end voltage < 1.60 V, ECSA loss <10% with < 0.09 mg/cm² PGM



IrRu-modified anodes have achieved the cell reversal Go/No Go requirement: 200 cycles with end voltage < 1.80 V, with < 0.045 mg/cm² PGM

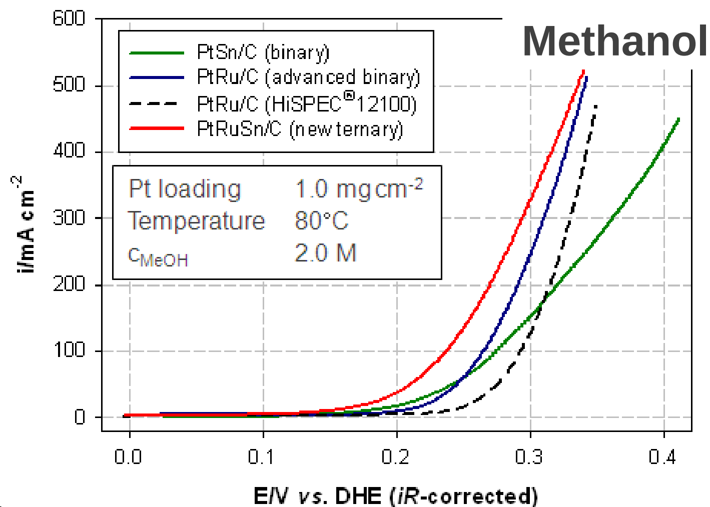
All Go/No go milestones surpassed at:
- **PGM loading < 0.135 mg/cm² total**
- **Voltages meet the set goals**

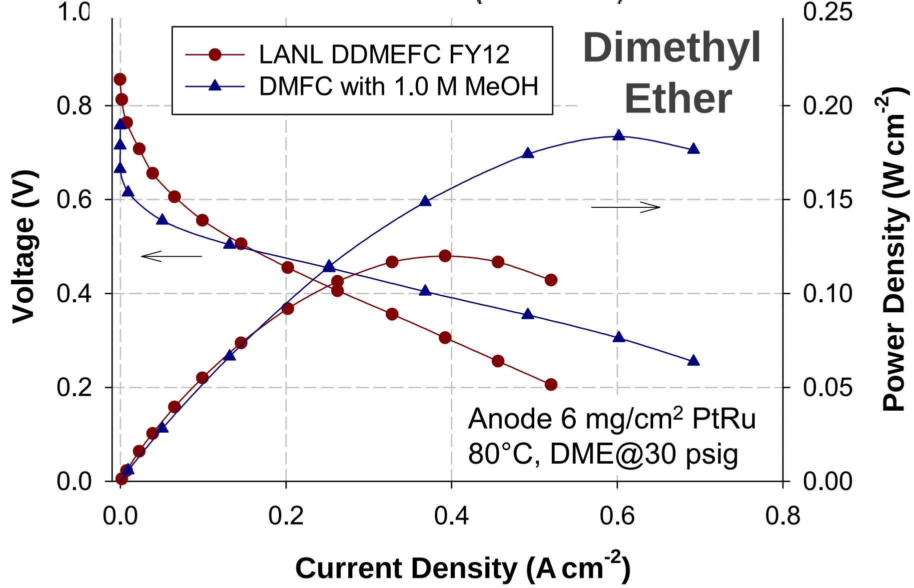
R. Atanasoski et al., 3M

Catalysts for Liquid Fuels

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

High-activity catalysts developed for methanol and dimethyl ether





- JMFC's ternary PtRuSn/C DMFC catalyst combines advantages of PtSn at low overpotentials and PtRu at high overpotentials
- PtRuSn/C outperforms the best thrifted PtRu/C catalyst

PtRuSn/C methanol mass activity exceeds **500 mA/mg$_{Pt}$** at 0.35 V, **150% higher than FY12 milestone**

- DME fuel cell outperforms DMFC at low current due to **low DME crossover**

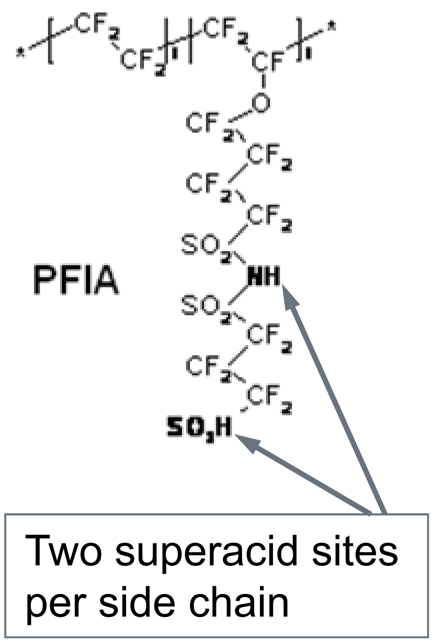
DME fuel cell achieves **150 mA/cm^2** at 0.5 V – **60% higher than FY11**, **130% higher than best published data**

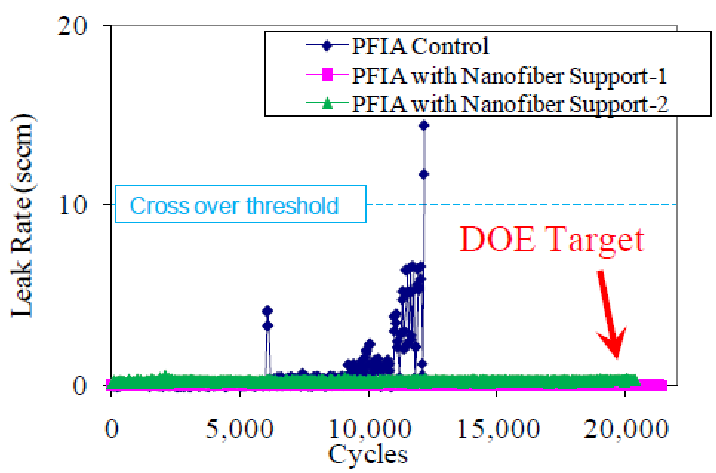
P. Zelenay et. al., LANL

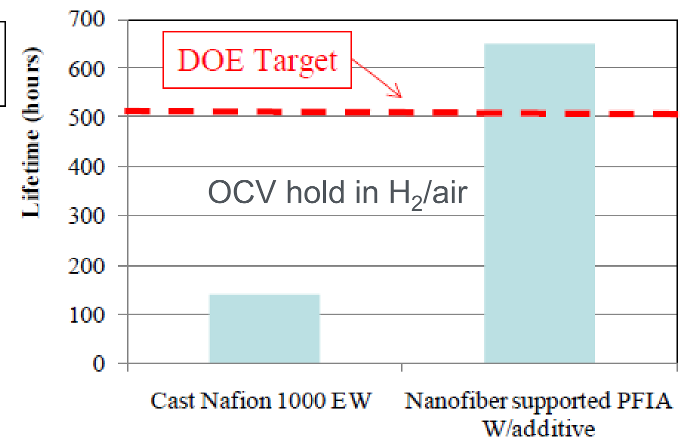
Innovative membranes demonstrate high conductivity at low RH

- **3M PFIA membranes meet most DOE targets for performance and durability**
- **PFIA maintains high crystallinity at lower equivalent weight than PFSAs → better mechanical properties**

		PFIA Status	2017 Target
ASR at 120 C (p_{H2O} 40-80 kPa)	Ohm cm^2	0.023 (40 kPa) 0.012 (80 kPa)	≤0.02
ASR at 80 C (p_{H2O} 25-45 kPa)	Ohm cm^2	0.013 (25 kPa) 0.006 (44 kPa)	≤ 0.02
ASR at 30 C (p_{H2O} 4 kPa)	Ohm cm^2	0.02 (3.8 kPa)	≤ 0.03
ASR at -20 C	Ohm cm^2	0.1	≤ 0.2
O_2 Crossover	mA/cm^2	<1.0	≤ 2
H_2 crossover	mA/cm^2	<1.8	≤ 2
Mechanical Durability Chemical Durability (OCV)	RH Cycles Hours	>20,000 2,025	≥20,000 ≥ 500





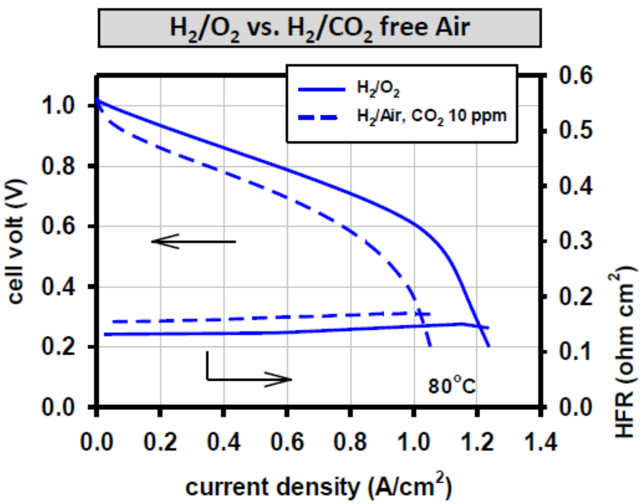


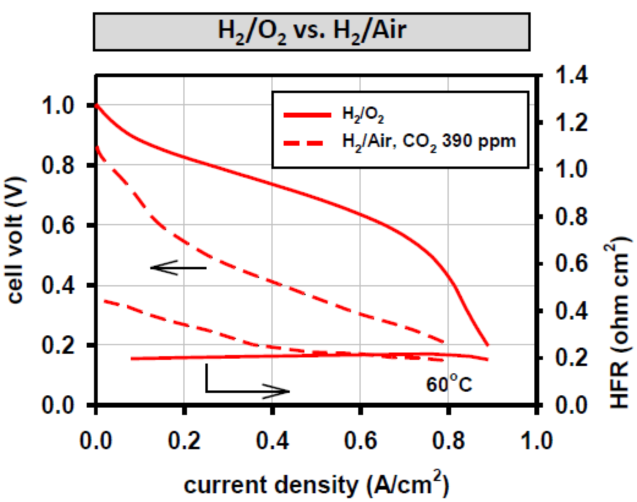
S. Hamrock et al., 3M

Alkaline Membrane Fuel Cells

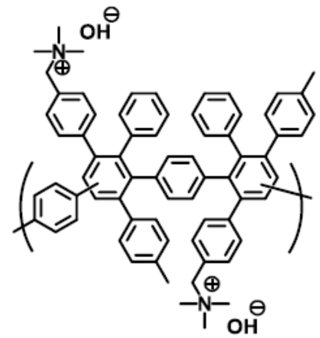
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

High power density (450 mW/cm²) demonstrated on H_2/air

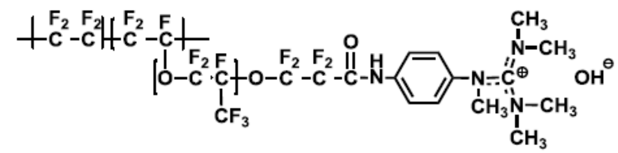




AEM & hydrocarbon ionomer: ATM-PP 3



PF ionomer: M-Nafion®-FA-TMG



- Hydrocarbon-based membrane and fluorocarbon-based electrode ionomer both have stable polymer backbones, but cation stability in MEAs is an issue
- Fluorocarbon-based electrode ionomer has high O_2 permeability, providing good triple-phase boundary
- **450 mW/cm² achieved on H_2/air** (low-CO_2 air)
- CO_2 poisoning issue needs to be addressed

Y. Kim et al., LANL

System/Stack Durability Assessment

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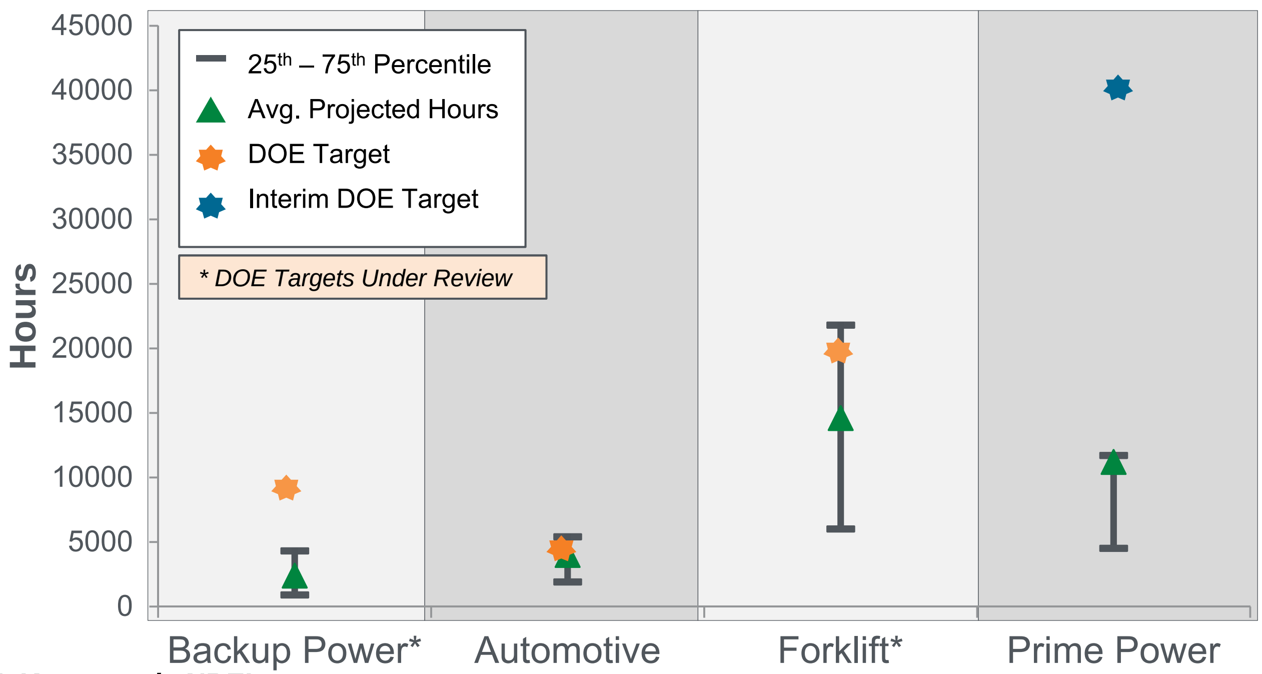
Aggregated results provide a benchmark in time of state-of-the-art fuel cell durability

NREL is analyzing and aggregating durability results by application, providing a benchmark of state-of-the-art fuel cell durability (time to 10% voltage degradation). Results include 82 data sets from 10 fuel cell developers.

Application	Avg Projected Time to 10% Voltage Drop	Avg Operation Hours
Backup power	2,400	1,100
Automotive	4,000	2,700
Forklift	14,600	4,400
Prime	11,200	7,000



J. Kurtz, et al., NREL

PEM & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing.

Please send inquires to Fuelcelldatacenter@ee.doe.gov

Thank you

Dimitrios.Papageorgopoulos@ee.doe.gov

www.hydrogenandfuelcells.energy.gov